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The relationship between PM_{10} and SO_2 exposure and Covid-19 infection rates in Turkey using nomenclature of territorial units for statistics level 1 regions

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A R T I C L E I N F O

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A B S T R A C T

The Covid-19 pandemic, which has been affecting the world since December 2019, has become one of the biggest problems of the 21st century. There are studies stating that the contagiousness of the Covid-19 pandemic, which is transmitted from person to person, increases more with environmental factors such as air pollution, and accordingly, there is an increase in the number of cases. In this study, a panel regression model to investigate the effect of air pollution concentrations such as PM_{10} and SO_2 as environmental factors and population density on the monthly mean number of Covid-19 cases for 12 regions at the nomenclature of territorial units for statistics (NUTS) level 1 in Turkey between June 2020 and November 2020, and a linear regression model to investigate the effect at the regional level. we used. Based on the model results, we concluded that a small increase in air pollution indicators led to an increase in the number of Covid-19 cases in Turkey and its regions. It is very important to identify preventable environmental factors in order to prevent and minimize the effects of respiratory tract diseases and rapidly spreading pandemic diseases such as Covid-19. Accordingly, we can conclude that countries should take some measures, especially on air pollution, in order to develop public health and pandemic/disease management strategies and to reduce the risk of respiratory diseases.

1. Introduction

The Covid-19 pandemic, which originated in Wuhan, China at the end of 2019 and became one of the biggest problems of the 21st century, was seen for the first time in Turkey on March 11, 2020. The Covid-19 virus, which has a very high spread rate, was defined as a pandemic by the World Health Organization (WHO) and caused some negative impacts economically and socially around the world. In the literature, it has been tried to determine the risk factors affecting the disease in order to reduce the negative effects that have arisen since the declaration of the pandemic and to control the spread of the disease. General risk factors obtained as a result of research can be expressed as social (education, occupation, number of individuals in the household etc.), demographic (age, gender, ethnicity etc.), health (hereditary diseases such as cancer, diabetes) and environmental factors (climate, air particles etc.) [1].

One of the main causes of air pollution is man-made activities that release highly concentrated pollutants harmful to human health [2,3]. Air pollution consists of small particulate matter (PM) and gases pollutants (ground-level ozone (O_3), sulfur dioxide (SO_2) etc.) [4]. PM, which is one of the most important indicators of air pollution, consists of organic dust, airborne bacteria, construction dust

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and coal particles and it can be classified according to its size as coarse particles (PM_{10}), fine particles ($PM_{2.5}$) and very fine particles [4–6]. Different types such as particulate matter with aerodynamic diameter of less than 2.5 μm ($PM_{2.5}$) and less than 10 μm (PM_{10}) affect respiratory infections, lung disorders and immune systems [7]. Gaseous pollutants such as nitrogen oxides, including nitrogen dioxide (NO2) and nitric oxide (NO), ozone, sulfur dioxide (SO_2), volatile organic compounds, and carbon monoxide (CO), have detrimental effects on heart health and the respiratory tract [4]. It has been shown in various studies that PM_{10}, SO_2, NO_2O_3, CO and CO_2 concentrations, which are known as the biggest elements of air pollution, cause serious health problems such as respiratory and cardiovascular diseases, blood pressure and lung cancer [8–10]. In addition, it is estimated that around 7 million people worldwide die every year from exposure to air pollution [11]. For all these reasons, it is thought that air pollution may worsen the prognosis of Covid-19 disease by triggering chronic diseases and negatively affecting the immune system [12,13].

In the literature, there are many studies showing a relationship between exposure to air pollutants, which is one of the environmental risk factors, and the number of Covid-19 cases and deaths [14]. Wu et al. [15] used a negative binomial mixed model to examine the relationship between $PM_{2.5}$ air pollution indicator and Covid-19 death rate in 20 states of America. They found a positive association between exposure to $PM_{2.5}$ air pollutants and the Covid-19 mortality rate. Czwojdzińska et al. [16] examined the effect of $PM_{2.5}$ and PM_{10} air pollution indicators on the number of Covid-19 cases and deaths in Poland and its provinces in a one-year observation period. They have observed that, except for some months, air pollutant indicators affect the number of Covid-19 cases and deaths. Travaglio et al. [17] used the binomial regression model to investigate the relationship between air pollutant indicators (NO_2, NO and O_3) and Covid-19 incidence/mortality in the UK, and as a result, they found that a one-unit increase in air pollutant indicators increased Covid-19 incidence and mortality. Renard et al. [18] applied correlation analysis to examine the relationship between the $PM_{2.5}$ and Covid 19 mortality rates for the years 2020–2022 in 6 Western European Countries (France, Germany, Italy, Netherlands, Spain, United Kingdom) and they have found a linear slope between pollution and mortality rate. Bhatti et al. [19] examined the air pollution concentrations of 13 cities in China's Jiangsu province before, during and after the Covid-19 period, and examined the effect of quarantine on air quality during the Covid-19 period. As a result, due to the government's implementation of quarantine policies, they detected the change in air pollution from pre-Covid-19 to active Covid-19 period more than in previous years. They also stated that air pollution concentrations increased after the Covid-19 period. Wu et al. [20] investigated the change of six different air pollution concentrations (NO_2, O_3, SO_2, CO, PM_{10} and $PM_{2.5}$) by constructing models for different periods in the last five years in Jiangsu province of China. Emphasizing that the measures taken during the Covid-19 period had a positive impact on the environment, they made some suggestions that would enable living things to be less affected by the air pollution concentrations. Perone [21] benefited negative binomial regression, ordinary least squares model, and spatial autoregressive models to investigate the relationship between exposure to air pollutants and mortality/infectiousness of Covid-19 for 107 Italian provinces between 2014 and 2019, and found a positive correlation between the two variables. Bhatti et al. [22] applied a deep learning bi-directional long-term short-term method to investigate the effect of the quarantine applied in the Covid-19 outbreak on more than one city. In their study, changes in air quality during Covid-19 in 18 cities of Henan from 2019 to 2021 were investigated temporally and spatially over 3 periods. As a result, they found that with the quarantine measures implemented during the Covid-19 period, Henan's air quality has reached grade 1 air quality standards, and this has benefited some health advantages in the short term.

Turkey is one of the countries with the highest air pollution among the countries in Europe. It ranks 7th in the $PM_{2.5}$ air quality ranking of European countries in 2021 year [23]. Guzel and Ozer [23], in their study on air pollution and health expenditures in Turkey, stated that approximately 45 thousand preventable deaths occur every year in Turkey due to air pollution. Therefore, our aim in the current study is to examine whether there is a relationship between exposure to air pollution, population density and the number of Covid-19 cases in Turkey. Although there is no study that directly examines the relationship between the number of Covid-19 cases and air pollutants in Turkey, there are some studies on air pollution and Covid-19 pandemics for different provinces and regions of Turkey. Sahin [24] used correlation analysis to examine the difference between the number of Covid-19 cases and some air pollutant parameters for 9 big cities in Turkey and found a positive significant relationship between the SO_2 indicator and the number of Covid-19 cases. Dursun et al. [25] investigated the effects of the measures taken during the Covid-19 pandemic (travel restriction, curfew, online education etc.) on air quality for 29 major cities and Zonguldak in Turkey. As a result, they determined that these measures taken during the pandemic period had positive effects on air quality. Ulutas et al. [26] used principal components analysis and regression model to investigate the effects of air pollution indicators and metrology parameters on the number of Covid-19 cases in Western Anatolia and Western Black Sea region of Turkey. As a result of analysis, they found that wind speed, SO_2, CO, NOX and O_3 concentrations did not affect the number of new Covid-19 cases in the Western Black Sea Region, while wind speed, SO_2, CO, NOX, and O_3 concentrations were effective on the number of new cases in Western Anatolia.

In this study, we first investigated the potential relationships between some air pollution indicators, population density and the number of Covid-19 cases in Turkey and regionally. Since the data set obtained from Covid-19 case numbers and air pollution indicators for 12 regions at NUTS level 1 in Turkey includes both time dimension and cross-sectional data, we used a panel regression model in the analysis of the data. As a result, we determined that there is a positive relationship between the PM_{10}, population density and the number of Covid-19 cases in Turkey, while there is no relationship between the SO_2 indicator and the number of Covid-19 cases. Accordingly, we can say that the increase in PM_{10} concentrations and population density causes an increase in the number of Covid-19 cases. It is very important to identify preventable environmental factors such as air pollution in order to prevent and minimize the effects of rapidly spreading pandemic diseases such as respiratory diseases and Covid-19. In addition, increasing knowledge with studies examining the relationship between these environmental factors and respiratory diseases will contribute to the development of public health and pandemic/disease management strategies.

2. Materials and methods

2.1. Data sources of Covid-19 cases

In this study, we used countrywide and subregional information to estimate the relationship between air pollution and Covid-19 in Turkey. Cases determined as positive by polymerase chain reaction (PCR) tests in Turkey are published by the Turkish Ministry of Health. We have obtained the number of Covid-19 cases officially shared between June 29, 2020 and November 23, 2020 monthly and cumulatively. The data obtained were analyzed at the level of 12 sub-regions included in the Turkish Statistical Regional Units Classification level 1 described in Table 1, which is used in the statistical region classification determined by the European Union and used to determine the economic and social differences at the regional level of the candidate countries [27]. In addition, the daily number of Covid-19 deaths in Turkey during the specified date range was not reported by the ministry, so it could not be included in the analysis.

2.2. Demographic data

Population density data per m^2 of 12 regions in Turkey at the NUTS-1 level were obtained from the annual population data of the Turkish Statistical Institute (https://data.tuik.gov.tr/Kategori/GetKategori?p=nufus-ve-demografi-109&dil) = 1). According to the 2020 census results, the population of Turkey is 83.6 million and the population densities for 12 regions are obtained by dividing the total population of the cities in the regions by the total surface area and are shown in Table 2.

2.3. Air pollution data sources

To investigate the effect of air pollution indicators on the number of Covid-19 cases, we used the website of the Ministry of Environment and Urbanization (https://sim.csb.gov.tr/STN/STN_Report/DataBank) to obtain PM_{10} and SO_2 concentrations. All data obtained from 152 stations measuring daily PM_{10} concentrations and 169 stations measuring SO_2 concentrations between June 29, 2020 and November 23, 2020 for all provinces at the NUTS-2 level of Turkey were used. Since some provinces do not have stations measuring air pollutant indicators, provinces representing regions at NUTS-1 level were included in the analysis and their monthly means were calculated. The national legislative limit for PM_{10} and SO_2 indicators is 40 $\mu g/m^3$ and the legislative limit set by the World Health Organization is 20 $\mu g/m^3$ for both indicators.

2.4. Statistical analyses

The relationships between the number of Covid-19 cases per 1000 people per month and PM_{10}, SO_2, population density of each region were examined by panel regression model and multiple linear regression analysis. PM_{10} and SO_2 concentrations are included in

Table 1
Turkey NUTS classified levels and regions.

Code	Level 1 (12 Regions)	Code	Level 2 (26 Sub-regions)	Level 3 (81 Cities)
TR1	Istanbul (I)	TR10	İstanbul sub-region	İstanbul
TR2	West Marmara (WM)	TR21	Tekirdağ sub-region	Tekirdağ, Edirne, Kırklareli
		TR22	Balıkesir sub-region	Balıkesir, Çanakkale
TR3	Aegean (A)	TR31	İzmir sub-region	İzmir
		TR32	Aydın sub-region	Aydın, Denizli, Muğla
		TR33	Manisa sub-region	Manisa, Afyonkarahisar, Kütahya, Uşak
TR4	East Marmara (EM)	TR41	Bursa sub-region	Bursa, Eskişehir, Bilecik
		TR42	Kocaeli sub-region	Kocaeli, Sakarya, Düzce, Bolu, Yalova
TR5	West Anatolia (WA)	TR51	Ankara sub-region	Ankara
		TR52	Konya sub-region	Konya, Karaman
TR6	Mediterranean (M)	TR61	Antalya sub-region	Antalya, Isparta, Burdur
		TR62	Adana sub-region	Adana, Mersin
		TR63	Hatay sub-region	Hatay, Kahramanmaraş, Osmaniye
TR7	Middle Anatolia (MA)	TR71	Kırıkkale sub-region	Kırıkkale, Aksaray, Niğde, Nevşehir, Kırşehir
		TR72	Kayseri sub-region	Kayseri, Sivas, Yozgat
TR8	West Black Sea (WBS)	TR81	Kayseri sub-region	Zonguldak, Karabük, Bartın
		TR82	Zonguldak sub-region	Kastamonu, Çankırı, Sinop
		TR83	Kastamonu sub-region	Samsun, Tokat, Çorum, Amasya
TR9	East Black Sea (EBS)	TR90	Samsun sub-region	Trabzon, Ordu, Giresun, Rize, Artvin, Gümüşhane
TRA	Northeast Anatolia (NA)	TRA1	Trabzon sub-region	Erzurum, Erzincan, Bayburt
		TRA2	Erzurum sub-region	Ağrı, Kars, Iğdır, Ardahan
TRB	Middle East Anatolia (MEA)	TRB1	Ağrı sub-region	Malatya, Elâzığ, Bingöl, Tunceli
		TRB2	Malatya sub-region	Van, Muş, Bitlis, Hakkâri
TRC	Southeastern Anatolia (SA)	TRC1	Van sub-region	Gaziantep, Adıyaman, Kilis
		TRC2	Gaziantep sub-region	Şanlıurfa, Diyarbakır
		TRC3	Şanlıurfa sub-region	Mardin, Batman, Şırnak, Siirt

Table 2
Characteristics of study population.

	Population Number (N)	Density (N/km^2)	Monthly mean number of Covid-19 cases	Monthly mean of PM_{10} [$\mu g/m^3$]	Monthly mean of SO_2 [$\mu g/m^3$]
Istanbul	15,519,267	25,091	9521,167	37,600	2,003
West Marmara	3,601,928	8,064	769,667	47,067	9,638
Aegean	1,0618,433	23,806	3913,000	45,683	12,234
East Marmara	8,124,975	15,969	4301,167	42,136	7,753
West Anatolia	8,124,729	15,581	6077,667	42,924	7,047
Mediterrenian	10,627,530	16,804	3428,333	39,756	7,751
Middle Anatolia	4,075,758	5,567	2861,833	43,656	7,682
West Black Sea Region	4,666,150	10,329	2223,333	37,967	9,423
East Black Sea Region	2,690,180	15,829	991,500	40,285	7,872
Northeast Anatolia	2,200,022	3,292	1264,167	47,017	5,775
Middle East Anatolia	3,930,407	7,827	2772,500	49,737	14,983
Southeastern Anatolia	8,975,618	14,512	6123,500	57,416	13,870

the models as monthly mean concentrations for each region. In addition, the population density of each region was calculated by dividing the total population of the provinces covering the regions by the total area. In the models, we considered PM_{10}, SO_2 concentrations and population density values as explanatory variables and the number of Covid-19 cases as dependent variables, and expressed all data in logarithmic form for easier interpretation of the variables.

2.4.1. Panel regression model

Panel data includes observations obtained at different time points for the same units, individuals, or entities. They are cross-sectional datasets that contain both time and horizontal dimensions [28]. In general, the panel regression model can be expressed as,

$$y_{it} = \beta_0 + \sum_{k=1}^{k} x_{itk}\beta_k + u_{it}. \tag{1}$$

where β_0 is intercept, i represents the number of subject ($i = 1, 2, \ldots, N$) and t shows the point of observation of each unit. k shows the number of independent variables and u_{it} is random errors [28]. The error term u_{it} is assumed to be identical and independent normally (IIN) distributed for all units over time with zero mean and fixed variance ($u_{it} \sim IIN(0, \sigma_u^2)$) [29].

Panel regression models are classified according to the assumptions made on whether the both fixed and slope parameters are fixed with respect to units and/or time. In panel data analysis, the classical model given in Eq. (1), where both constant and slope parameters are constant for all units and time points, the fixed effects model is used in cases where the fixed parameter changes according to the cross-sectional units and the slope parameters are constant among all cross-section units, and the random effects model is used in cases where unobservable unit effects in each unit are thought to cause differences between units [30].

In order to investigate the effects of air pollution concentrations and population densities of 12 regions in Turkey on the number of Covid-19 cases, we examined the development of Covid-19 case numbers both in terms of region and time, using a panel regression model. For this, we established three different panel regression models consisting of classical, fixed effects and random effects models for 12 regions of Turkey at NUTS1 level for the period of June 2020 and November 2020, respectively Eqs. (2)–(4), and we checked the assumptions to determine which model was appropriate.

$$log\ (Covid_{it}) = \beta_0 + \beta_1 log(PM_{10it}) + \beta_2 log(SO_{2it}) + \beta_3 log(P\_density_{it}) + u_{it,} \tag{2}$$

$$\log\ (Covid_{it}) = \beta_{0i} + \beta_1 \log(PM_{10it}) + \beta_2 log(SO_{2it}) + \beta_3 log(P\_density_{it}) + u_{it,} \tag{3}$$

$$\log\ (Covid_{it}) = \beta_{0i} + \beta_1 \log(PM_{10it}) + \beta_2 log(SO_{2it}) + \beta_3 log(P\_density_{it}) + \left(u_{it} + \mu_i\right) \tag{4}$$

Here $Covid_{it}$, PM_{10it}, SO_{2it} and $P\_density_{it}$, shown respectively the number of new Covid-19 patients per 1000 people in i. region ($i = 1, 2, \ldots, 12$) and t. month ($t = 1, 2, \ldots, 6$), PM_{10}, SO_2 and population density data. $Covid_{it}$ dependent variable; PM_{10it}, SO_{2it} and $P\_density_{it}$ independent variables; β_0 fixed term; β_1, β_2 and β_3 show the effect of independent variables on the dependent variable; u_{it} residual term and μ_i represents the unit error that shows the individual difference of the region i.

2.4.2. Multiple linear regression model

The linear regression model is used to investigate the effect of the independent variable on the dependent variable and to fit the y data estimates for the explanatory variables in a straight line. The linear regression model is expressed as in Eq. (5) and X and Y are explanatory and dependent variable, β_0 is the intercept and β_1 is the regression parameter as slope and the ϵ is random error, respectively [31].

$$Y = \beta_0 + \beta_1 X + \epsilon. \quad (5)$$

In linear regression, since a single explanatory variable tries to explain the change on the dependent variable, the relationship between the variables may not be clearly explained. For this reason, the effects of different explanatory variables on dependent variables can be investigated with multiple linear regression analysis. The regression equation containing more than one explanatory variable can be expressed as in Eq. (6),

$$Y = \beta_0 + \sum_{k=1}^{k} \beta_k X_k + \epsilon. \quad (6)$$

where Y and X dependent variable and explanatory variables, respectively. β_k is regression coefficients, β_0 is y-intercept and ϵ error term [31].

We performed multiple linear regression analyzes to test whether daily exposure to PM_{10} or SO_2 is associated with daily incidence of Covid-19 across regions. In all models, we considered the dependent variable as the number of daily Covid-19 cases and the explanatory variables as PM_{10} and SO_2 concentrations. According to the model result, if the coefficients are positive, it means that a one-unit increase in the explanatory variable will cause an increase in the dependent variable. The negative coefficient indicates that a one-unit increase in the explanatory variable will cause a decrease in the dependent variable. We considered the significance level as $p - value < 0.05$ in all statistical tests and the data were analyzed using Stata 17 program.

3. Results

According to Fig. 1 and Table 2, the highest six-month mean PM_{10} concentration were observed in Southeastern Anatolia, Middle East Anatolia and West Marmara regions, with mean air pollution levels of 57.42, 49.74 and 47.10$\mu g/m^3$, respectively, among the 12 regions. In addition, it is seen that the PM_{10} concentrations of all regions are above the WHO standards (20 $\mu g/m^3$) and the concentrations of only Istanbul, West Black Sea Region and Mediterranean regions are below the nationally determined limits (40 $\mu g/m^3$). A similar situation is observed in the six-month mean SO_2 concentrations; It is seen that it is 13.87$\mu g/m^3$ for Southeastern Anatolia region, 14.98$\mu g/m^3$ for Middle East Anatolia region and 12.23$\mu g/m^3$ for Aegean region. It is seen that the SO_2 and PM_{10} concentrations of all regions are below the WHO and national standards. When the number of Covid-19 cases seen in the regions is examined, it is observed that the highest number of Covid-19 cases in six months was reported in the region of Istanbul, which has the highest

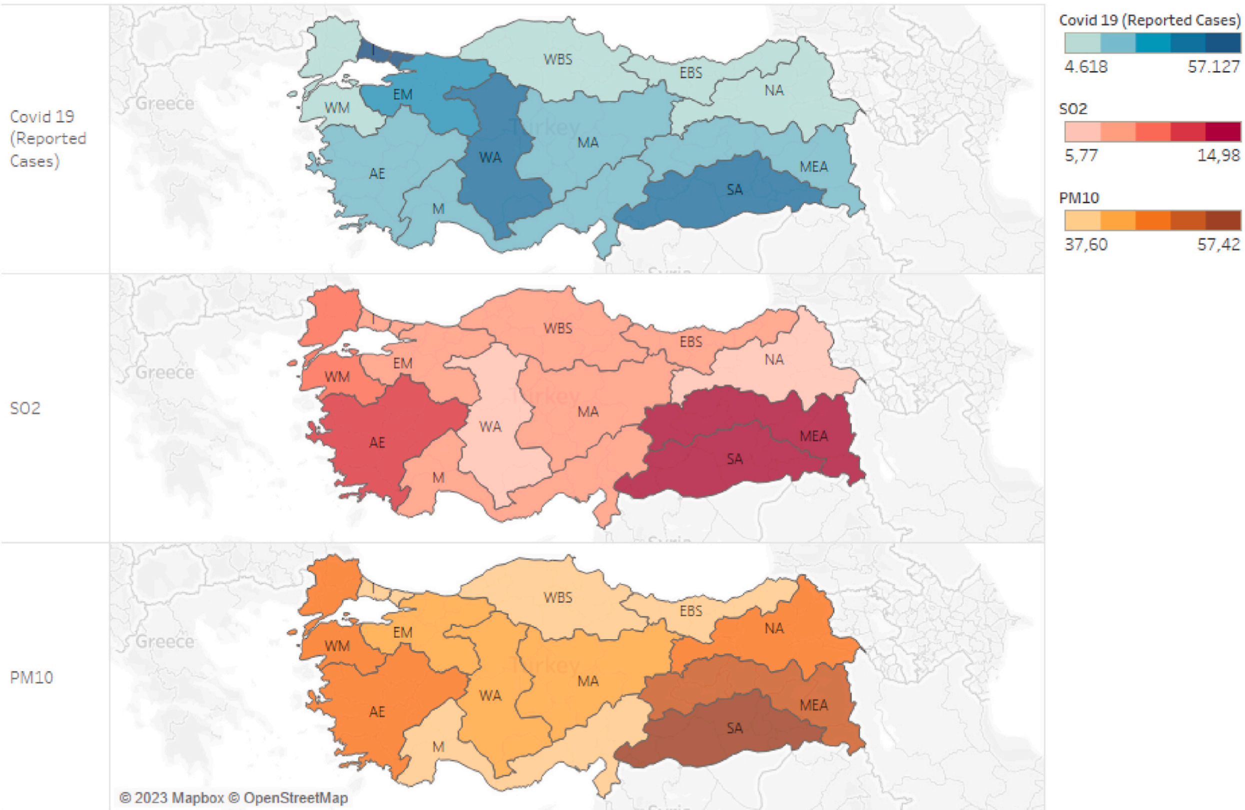

Fig. 1. Summary of the mean concentration of air pollution and Covid-19 cases.

population density. This situation is followed by Southeastern Anatolia region and West Anatolia regions, respectively.

The monthly changes of PM_{10} and SO_2 indicators within the months included in the analysis are given in Fig. 2 a) and b), respectively. Accordingly, lower PM_{10} levels were observed in August compared to other months, while the highest PM_{10} levels were observed in October. When the SO_2 levels of the regions are analyzed by months, it is observed that there is an increase in SO_2 levels in October and November compared to other months. In this context, we can say that there is a seasonal difference between air pollution indicators, although it is not clear.

In Fig. 3 a) and b), the number of Covid-19 cases per 1000 people and the changes in air pollution indicators over time are given at the level of 12 regions at the NUTS1 level of Turkey. Accordingly, it is seen that the number of Covid-19 cases has increased over time in all regions. When the change of air pollution indicator levels over time is examined, it is seen that there are partial decreases or no serious changes in the air pollution concentrations of other regions except the Middle East Anatolia region. These differences may be due to the measures taken by the Turkish government against the increasing number of Covid-19 cases.

We first examined some assumptions to decide on the panel model to be used to investigate the impact of air pollution indicators and population density on the number of Covid-19 cases. First, we performed some assumption tests such as cross-section dependence, unit root test, autocorrelation in order to obtain unbiased and consistent parameter estimations, and as a result, according to Pesaran CD test $p > 0.05$ for all variables and unit root (according to all variables) in the series. to Levin, Lin and Chu, and ADF – Fisher Chi-Square test $p < 0.05$ for all variables). We used the Breusch-Pagan and Hausman test ($p = 0.1792 > 0.05$) to decide which model should be established to investigate the impact of air pollutant indicators on the number of Covid 19 cases, and we concluded that analyzing the data with the random effects model would yield more unbiased and consistent estimates. As a result, random-effect model predictions, which is the most appropriate method and includes White's standard error correction, are given in Table 3.

According to the random effect model estimation results used for panel data analysis in the study, the F value indicating the significance of the model was found to be statistically significant ($p = 0.0001 < 0.05$). When the significance of the variables in the model is examined, it is seen that PM_{10} value, population density and model fixed term are statistically significant ($p < 0.05$). According to these results, we can say that one-unit increase in PM_{10} concentrations result in an increase of 2.35 (95 % CI: 0.88,3.57) (approximately 2 people) in the number of corona cases, and one-unit increase in the population density cause an increase of 0.99 (95 % CI: 0.04,1.72) (approximately 1 person) in the number of corona cases at a 5 % significance level.

The linear regression results established to investigate the relationship between the daily PM_{10}, SO_2 levels and the daily Covid-19 case numbers at the regional level are given in Table 4. Accordingly, the models established for all regions except the Middle East Anatolia region were found to be significant, and it was observed that the number of daily Covid-19 cases increased as PM_{10} and SO_2 levels increased in almost all regions.

4. Discussion and conclusion

This study was carried out specifically for the purpose of examining the regional differences in the increase of Covid-19 cases in Turkey according to the PM_{10} and SO_2 elements and population density that cause air pollution. When studies on Covid-19 and other respiratory diseases are examined, they have proven that indicators such as economic activities, human interactions (population

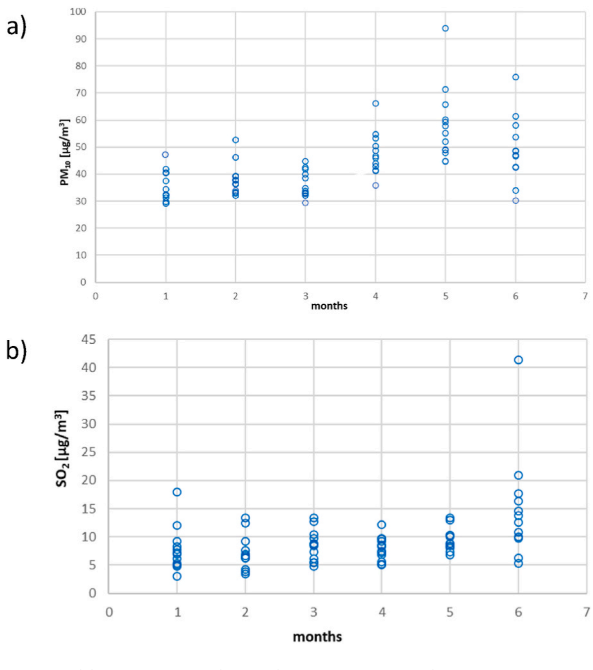

Fig. 2. Changes in mean monthly PM_{10} (a) and SO_2 (b) concentrations between June 2020 and November 2020.

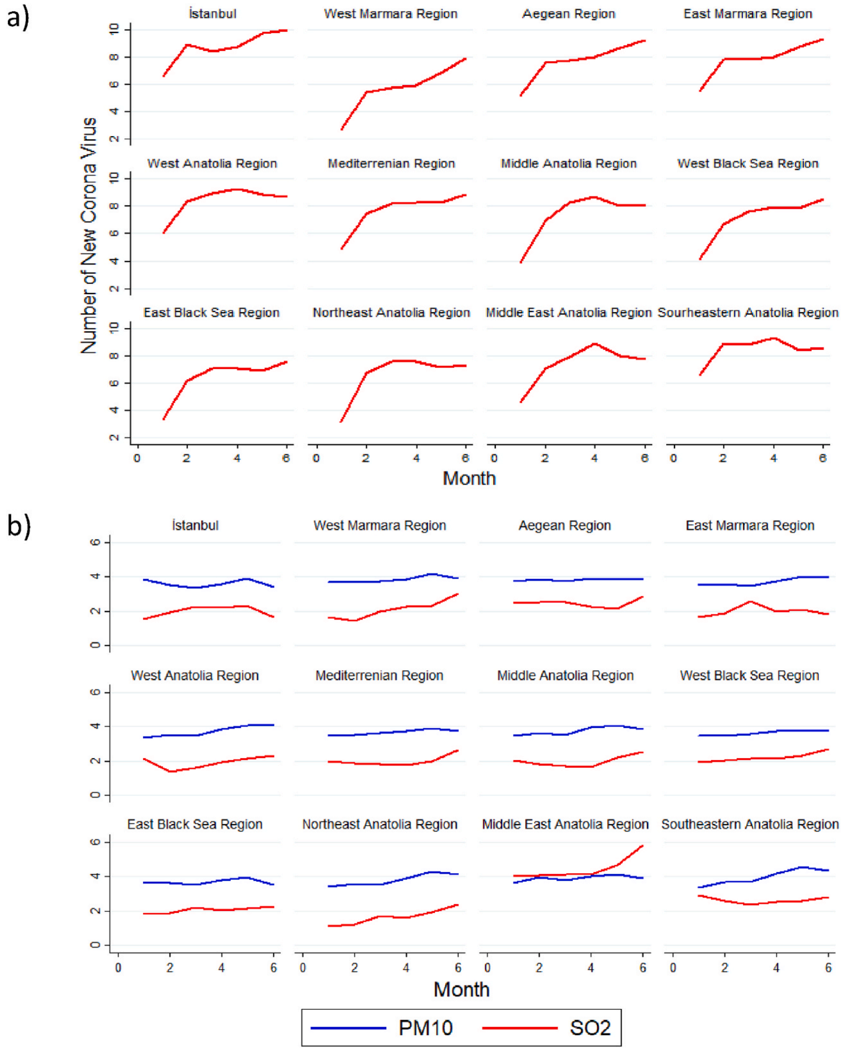

Fig. 3. Change of Covid-19 cases (a), PM_{10} and SO_2 concentrations (b) over time by region.

Table 3
Estimated results from the panel data model with random effect of the monthly PM_{10}, SO_2 and population density on Covid-19 cases.

Dependent variable: Number of Covid-19 cases					
Method: Generalized LS with random effect					
Period: 1–6 months					
Number of horizontal sections (NUTS1 Region): 12					
Total number of observations in the panel:72					
Variable	**Coefficient**	**Robust Error**	**Z statistic**	***p-value***	***95 % Conf. Int.***
PM_{10}	2.35	0.64	3.64	<.001*	0.88,3.57
SO_2	0.29	0.29	0.99	0.323	−0.23,1.44
Population density	0.99	0.36	2.72	0.006*	0.04,1.72
Fixed	−4.47	2.20	−2.04	0.042*	−9.78,-1.01
Weighted Statistics					
F statistic = 37.48					
p-value = 0.0001*					

*: $p < 0.05$.

density) and air pollution in the region are effective in the increase of this type of diseases [32].

In the study, it is aimed to investigate the effects of daily new corona cases per 1000 people, PM_{10} and SO_2 air pollution indicators and population density for 12 regions at NUTS level 1 between June 29, 2020 and November 23, 2020. Since the data set includes both

Table 4
Estimated results from the linear regression model of the PM_{10} and SO_2 on daily Covid-19 cases.

Region	PM_{10} (β; p)	SO_2 (β; p)	Model (p)	95 % Conf. Interval	
				PM_{10}	SO_2
Istanbul	0.108; 0.453	0.363; 0.002	0.0070	−0.17,0.39	0.14,0.59
West Marmara	0.308; 0.145	0.979; 0.000	0.0000	−0.11,0.72	0.77,1.18
Aegean	−0.050; 0.835	0.453; 0.010	0.0291	−0.53,0.42	0.11,0.79
East Marmara	1.048; 0.000	0.532; 0.000	0.0000	0.78,1.31	0.32,0.74
West Anatolia	0.165; 0.037	0.171; 0.003	0.0000	0.01,0.32	0.06,0.28
Mediterranean	0.373; 0.012	0.722; 0.000	0.0000	0.08,0.66	0.51,0.93
Middle Anatolia	0.532; 0.001	−0.286; 0.072	0.0030	0.22,0.83	−0.06,0.02
West Black Sea Region	0.583; 0.003	1.193; 0.000	0.0000	0.21,0.96	0.86,1.52
East Black Sea Region	−0.103; 0.373	2.515; 0.000	0.0000	−0.33,0.13	2.14,2.89
Northeast Anatolia	0.273; 0.002	0.720; 0.000	0.0000	0.10,0.44	0.55,0.89
Middle East Anatolia	0.108; 0.472	0.098; 0.160	0.2698	−0.19,0.40	−0.03,0.23
Southeastern Anatolia	0.319; 0.000	0.279; 0.000	0.0000	0.29,0.49	0.15,0.41

time dimension and cross-sectional data panel regression models were used in statistical analysis. When we examine the random effects model estimates including White's standard error correction, we can say that PM_{10} air pollution concentrations and population density are positively related to the number of Covid-19 cases. Accordingly, it can be said that the increase in PM_{10} concentrations and population density increases the number of corona cases ($p=<0.001$, $\beta = 2.35$; $p = 0.006$, $\beta = 0.99$, respectively). Similar to the findings of this study, there are studies showing that there is a relationship between exposure to PM_{10} concentration and the number of Covid-19 cases and deaths. Bianconi et al. [33] investigated the effect of PM_{10} and $PM_{2.5}$ concentrations on the number of Covid-19 cases and death in 110 provinces of Italy, and as a result, they found a positive relationship between PM_{10} and Covid-19 death and number of cases (cases: $\beta = 0.61$, $p = 0.031$; death: $\beta = 0.61$, $p = 0.029$, respectively). Hutter et al. [34], in their study in Vienna, Austria, found that exposure to PM_{10} concentration was associated with the risk of Covid-19 diagnosis (hazard ratio (HR) = 1.44). Czwojdzińska et al. [16], in their study conducted in Poland in November 2020, found that PM_{10} concentration and population density had an effect on being infected with Covid-19 ($R^2 = 0.468$). Hyman et al. [14] showed in their study in the United Kingdom that a one-unit increase in PM_{10} was associated with an increased risk of Covid-19-related hospitalization and death; [OR (95 % CI: 1.20 (1.18–1.22)) and (95 % CI: 1.41 (1.34–1.48))].

We applied multiple linear regression analysis to examine whether air pollution concentration by region affects the daily number of Covid-19 cases. Accordingly, we detected a positive relationship between air pollution indicators and the number of Covid-19 cases in almost all regions except the Eastern Anatolia region. A one-unit increase in daily SO_2 concentration in the Eastern Black Sea Region causes an increase of 2515 people (95 % CI: 2,14,2.89) (approximately 3 individuals) in the daily number of Covid-19 cases. It can be said that one unit of daily SO_2 concentration in the Western Black Sea Region will cause an increase of 1193 people (95 % CI: 0.86.1.52) (approximately 1 person) in the daily number of Covid-19 cases. Likewise, it can be said that a one-unit increase in daily PM_{10} concentration in the East Marmara region will cause an increase of 1048 people (95 % CI: 0.78.1.31) (approximately 1 person) in the number of daily Covid-19 cases. It can be interpreted that a one-unit increase in PM_{10} concentration in the Western Black Sea Region will cause an increase of 0.583 people (95 % CI: 0.21.0.96) (approximately 1 person) in the daily number of Covid-19 cases. Accordingly, people living in the Western Black Sea Region are more affected by PM_{10} and SO_2 concentrations than those living in other regions. This situation can be thought to be caused by the coal mines and industrial factories in the region.

The fact that the number of daily cases for NUTS1 regions has not been shared since the first day of the corona virus in Turkey, and that the shared data consists of only sick (PCR test positive) cases, that is, not including asymptomatic cases, leads to some limitations in interpretation. In addition, although it is thought that some variables such as temperature, health infrastructure, compliance of the public with security measures and economic activities may affect the number of Covid-19 cases, these data for the examined period could not be included in the model because they were not shared openly on official websites. The inclusion of these variables in the model for future studies is very important for the measures and policies to be developed by the government.

As a result, since air pollution and population density will have negative effects especially for all other respiratory diseases, apart from the corona virus epidemic, studies should be carried out to prevent the global society from being exposed to these risk factors.

- It can be said that it is very important to update the National Air Monitoring Network coordination to include the entire population and to provide regular and complete data in order to more clearly determine air pollution concentrations that trigger respiratory diseases throughout Turkey. In addition, sharing the data obtained from these stations with the public on a regional and regular basis and informing the public about the measures that can be taken will help reduce diseases and deaths from environmental pollution.
- According to the results obtained from the study, it was observed that the PM_{10} concentration was above the national legislation limit (40 $\mu g/m^3$), especially in the West Marmara, Aegean, East Marmara, West Anatolia, Middle Anatolia, East Black Sea Region, Northeast Anatolia, Middle East Anatolia, Southeastern Anatolia regions. In this context, studies can be carried out to review the national legislative boundaries and bring them to the WHO boundaries, and a new national legislative limit can be determined and legal arrangements can be made for all businesses to comply with this legislation.

- In addition to vehicle exhaust measurements applied to prevent environmental pollution in Turkey, it is necessary to improve public transportation systems and take measures for vehicles with high exhaust emissions in order to prevent the increase in the number of vehicles used in regions with high population density, especially in the Istanbul region.
- According to the findings of the studies, it is seen that PM_{10} and SO_2 concentrations are quite high in Middle East Anatolia and Southeastern Anatolia regions compared to other regions. These regions are among the underdeveloped regions in Turkey. In this context, it can be thought that the high coal consumption in the region, the climatic conditions of the region, agricultural and industrial activities increase the air pollutant concentrations in the region. In addition to the development agencies and different political investments opened by the government for the development of underdeveloped regions, it is necessary to develop activities to increase the use of clean fuel, especially in these regions, to regularly ensure emission controls in industrial facilities, to enact new laws for businesses and to make environmental regulations to increase green areas.

In conclusion, some regulations and policies need to be developed by states regarding the environmental pollutant concentrations that all governments face. Some of the measures that can be implemented in this context can be listed as follows: planning to improve the ecological efficiency of urban warming, accelerating efforts to reduce fossil fuel consumption, to develop production in green industry and agriculture, making arrangements in public transport systems to reduce individual car use, conversion of factory wastes used in industrial production, inclusive and accurate measurements of air pollutant concentrations by governments, developing different environmental strategies as a result of regional analyses, and organizing trainings, policies and advertisements to inform the public about the causes and consequences of air pollutant concentration.

Data availability

The datasets analyzed during the current study are available in the official website of the Turkish Ministry of Health and of the Ministry of Environment and Urbanization (https://covid19.saglik. gov.tr/TR- 68444/gunluk-rapor–daily-report.html; https://sim.csb.gov.tr/STN/STN_Report/DataBank).

CRediT authorship contribution statement

Elif Yıldırım: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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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