The spread of COVID-19 virus through population density and wind in Turkey cities

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HIGHLIGHTS

- Covid-19 can be transmitted via wind or air circulation.
- Population density and wind were major factors and explained 94% of the variance in virus spread.
- Wind effect on virus spread was fully mediated by population density.

GRAPHICAL ABSTRACT
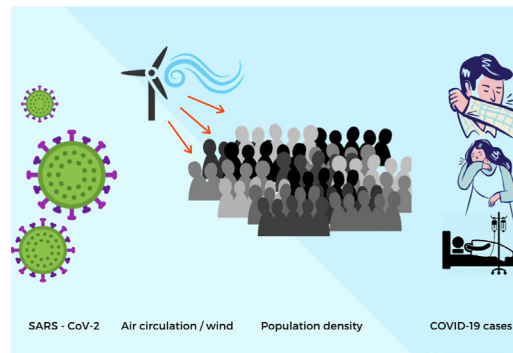
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ABSTRACT

Beyond the contact and respiratory transmission of the COVID-19 virus, it has recently been reported in the literature that humidity, temperature, and air pollution may be effective in spreading the virus. However, taking the measurements regionally suspects the accuracy or validity of the data. In this research, climate values (temperature, humidity, number of sunny days, wind intensity) of 81 provinces in Turkey were collected in March 2020. Also, the population, population density of the provinces, and average air pollution data were taken. The findings of the study showed that population density and wind were effective in spreading the virus and both factors explained for 94% of the variance in virus spreading. Air temperature, humidity, the number of sunny days, and air pollution did not affect the number of cases. Besides, population density mediated the effect of wind speed (9%) on the number of COVID-19 cases. The finding that COVID-19 virus, invisible in the air, spreads more in windy weather indicates that the virus in the air is one threatening factor for humans with the wind speed that increases air circulation.

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1. Introduction

Corona Virus Disease 2019 (COVID-19) emerged in Wuhan, China's Hubei province, in December 2019 and spread rapidly, causing the first pandemic of the 21st century. The etiology of the so-called

COVID-19 (CO: corona, VI: Virus, D: Disease, 2019) was found to be a novel coronavirus, *(severe acute respiratory syndrome koranaviüs-2 [SARS-CoV-2])"* (Chakraborty and Maity, 2020; https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/naming-the-coronavirus-disease-(covid-2019)-and-the-virus-that-causes-it; Zhou et al., 2020). In Turkey, the number of patients with COVID-19 virus in the process of time elapsed since the March 11, announcement of the first cases detected, has increased rapidly and

exceeded 120,000 in May (https://covid19bilgi.saglik.gov.tr/tr/). It is a priority to understand how COVID-19, which poses a global threat to control, prevents or minimizes infectious diseases, spreads worldwide in a short time, and shows the ways of transmission.

Since the advent of COVID-19, research on its transmission has been continued so far. The main route of transmission is claimed to be indirect contact, that is, contact with infected surfaces and then mediating the COVID-19 infection through the mouth, nose, or eyes (Qu et al., 2020). Therefore, in Turkey, as a precaution, the importance of handwashing has been emphasized and the use of cologne has been suggested in addition to hand disinfectants. The other has been described as being transmitted from person to person through respiratory droplets (Lai et al., 2020) that a certain amount of pathogens existing in the droppers produced by speech, coughing, sneezing can be inhaled by others (Yang et al., 2020). For this reason, the importance of providing social isolation has been highlighted, and staying alerts have been frequently included in social media, especially the Ministry of Health, healthcare professionals, and artists. Even in provinces with a high number of cases, curfews have been declared on weekends and holidays. The transmission of COVID-19 is likely to be similar to SARS, which was spread by contact, droplet, and airborne routes (Yu et al., 2004).

About the airborne transmission of COVID-19, the World Health Organization first announced the duration of the virus to remain in the air in an isolated environment for two hours period (World Health Organization, 2020). Wong et al. (2020) reported that SARS-CoV-2 does not spread by air and that nosocomial transmission can be prevented by basic infection control measures (SARS-CoV-2 is not spread by the airborne route, and nosocomial transmissions can be prevented through vigilant basic infection control measures). In Turkey, health authorities have also determined that social isolation, 1–2 m (≈3–6 ft) distance between people is a necessary measure and it will be sufficient to use the mask only by infected people. Setti et al. (2020) reported that studies are sufficient to support the airborne contamination of SARS-COV-2, that infected droplets can spread from the air far from two meters (6 ft) from person to person, and everyone's face mask in daily life activities and suggested that wearing it would be an effective protection. In Turkey nearly about a month after the identification of one patient with Covid-19 cases, people were imposed to wear masks.

Qu et al. (2020) stated that another transmission path could be from dust in the air. The adsorption of dust and particulate matter in the air can contribute to the long-range transport of the virus. It has also been noted that this new virus can be seasonal. For instance, Sajadi et al. (2020) pointed out that humidity and temperature are important in the seasonal spread of coronaviruses. Ficetola and Rubolini (2020) also found that COVID-19 cases strongly affected the change in the growth rate of the world. Ma et al. (2020) stated that these parameters affected COVID-19 mortality. Chen et al. (2020) claimed that wind speed, as well as temperature and relative humidity, were effective in the spread of the virus. Bashir et al. (2020) found that mean temperature, minimum temperature, and air quality were significantly associated with the COVID-19 outbreak. Recent research examining the relationship between weather and COVID-19 considering nine cities in Turkey, showed that the highest correlations were observed for population, wind speed 14 days ago, and temperature on the day, respectively (Şahin, 2020).

Given the fact the threat of the COVID-19 outbreak is not limited to any country or region and it spreads very rapidly, the impact of meteorological parameters on this spread is an issue which is of worth researching. A research taking sensitive measurements is needed to correctly understand the spread of the COVID-19 virus. In Turkey, the data based on provinces and even neighborhoods and streets have been open to sharing by the Ministry of Health since the 1st of April. On the other hand, one can observe that there is information on a regional basis in European countries, and information on a city basis is not shared publicly (see also COVID-19 map in the world). In this study, data on a city basis were taken and enabled us to evaluate the effect of this virus in a detailed way. This research also tries to reveal the effect of climate and demographic values on the spread of the COVID-19 virus. From the findings summarized above, population density is expected to increase virus spread. In the literature, it is expected that the temperature will have a virus spread explanation value, based on the finding that air temperature affects the virus spread. If the virus is resistant to airborne, it is conceivable that the speed of the wind increases this spread. Also, wind speed is expected to play a mediating role between population density and virus spread. In addition, there is an expectation that the virus will decrease on sunny days in summer. If this is the case, the spread or the number of cases should be low in cities with a high number of sunny days. If this is the case, the number of sunny days is expected to play a mediator role between population density and virus spread.

2. Method

2.1. Sample

The sample of this research consists of demographic and climate data of 81 provinces in Turkey.

2.2. Data collection

In this research, after the Ministry of Health shared the sages on 1 April 2020 on a provincial basis, the climate data announced by the meteorology for a month (during March) was taken by the first researcher and the average of the data was taken (https://www.meteoblue.com/tr/hava/historyclimate/climateobserved/bolu_t%c3%bcrkiye_750516). Population and population density data were also collected according to the provinces announced by TURKSTAT. Air pollution was based on the 2019 data of the Ministry of Environment and Urbanization prepared by the Chamber of Environmental Engineers (http://cmo.org.tr/resimler/ekler/9d62b3a2bb620a4_ek.pdf) because the 2020 data was not available.

3. Results

Turkey has seven different regions, namely Black Sea Region (North), Marmara Region (North-west), Agean Region (West), Mediterranean Region (South), Central Anatolia Region, East Anatolia Region, and Southeastern Anatolia Region (See Fig. 1a). Research suggests that three major climates occur in Turkey (Deniz et al., 2011; Iyigun et al., 2013; Selek et al., 2018). These, as is known, are Terrestrial Climate, Black Sea, and Mediterranean Sea Climates (see Fig. 1b).

In this research, the population of the city and the population density, which is the number of people per square meter, were taken as demographic variables. As geographic variables, the altitude of the province, airport status, and being near the sea were taken. As climate variables, precipitation amount, temperature, wind speed, number of sunny days, and air pollution values were taken. The dependent variable was the number of coronavirus cases. Correlation values between variables were given in Table 1.

3.1. Regression analysis

As can be seen from the correlation Table 1 in this study, variables, or predictors that have significant relationships with COVID-19 cases are considered as important. This significance is an important point for prediction. Some variables have a moderate relationship power of 0.29 to 0.50 (See Cohen, 1992). The important point here is that these variables have statistically significant relationships with the number of COVID-19 cases. The statistical significance here determines the inclusion of these variables in the regression analyses.

(a)

TERRESTRIAL CLIMATE

MEDITERRANEAN SEA CLIMATE

BLACK SEA CLIMATE
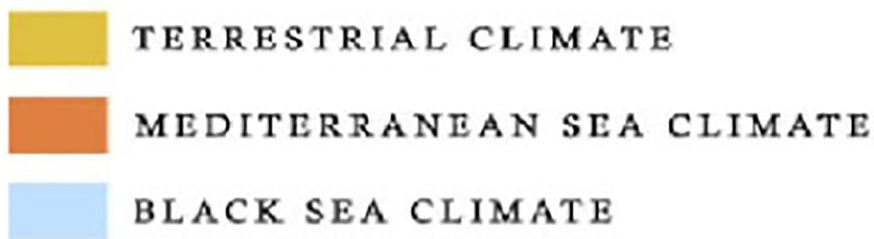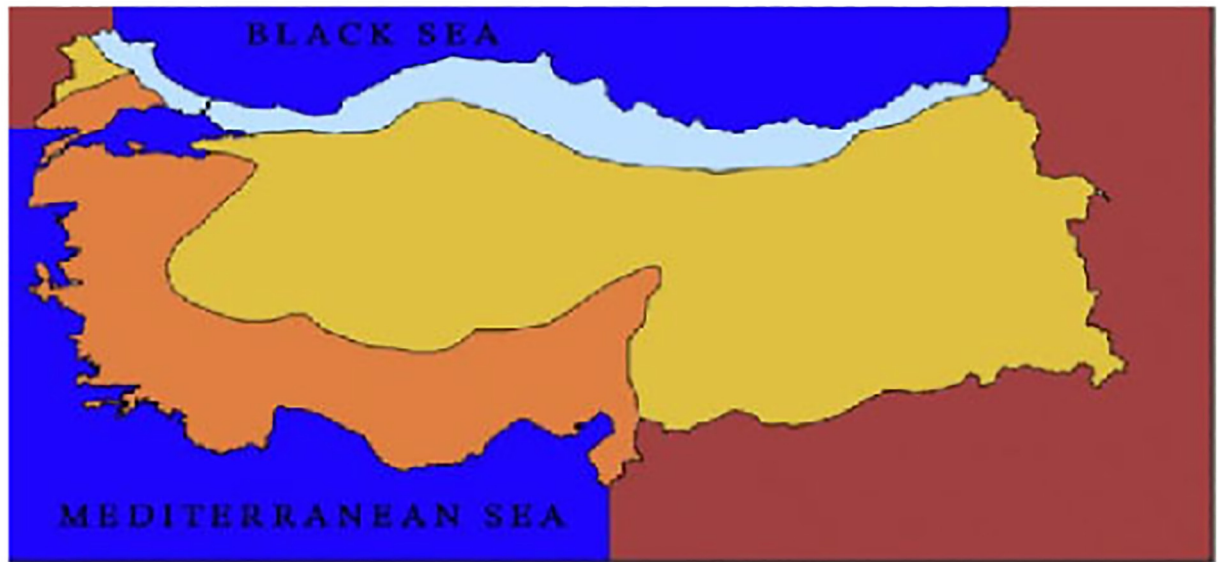
(b)

Fig. 1. a,b. Regions (Fig. 1a) and climates (Fig. 1b) in Turkey.

Table 1
Means and correlations of demographical, geological and climate variables.

	Mean	1	2	3	4	5	6	7	8	9	10	11
1.Population	1,025,918.60	–										
2.Population density (per person/km^2)	125.92	0.92**	–									
3. Number of airports	0.57	0.60**	0.52**	–								
4.Being near sea	–	0.28*	0.30*	−0.19*	–							
5. Altitude (metre)	687.54	−0.24*	−0.28*	−0.05	−0.69**	–						
6.Rain (mm)	65.73	−0.08	−0.01	−0.10	0.33**	−0.15	–					
7.Temperature (°C)	6.7	0.20	0.16	0.08	0.45**	−0.81**	0.07	–				
8.Wind speed (km/h)	10.91	0.20	0.26*	0.09	0.14	0.75**	−0.09	−0.17	–			
9. Sunny days	5.06	0.07	−0.08	0.06	−0.29**	0.30**	−0.34**	0.20	−0.35**	–		
10. Air polution (μg/m^3)	62.45	−0.04	−0.06	0.01	−0.14	0.00	−0.23*	0.23*	−0.30**	0.31**	–	
11. Cases	180.75	0.92**	0.97**	0.51**	0.20	0.20	−0.04	0.05	0.30**	0.05	−0.08	–

$N = 81$ *$p < .05$ ** $p < .001$.
Note: 1 = Population, 2 = Population density (per person/km^2), 3 = Number of airports, 4 = Being near sea, 5 = Altitude (metre), 6 = Rain (mm), 7 = Temperature (°C), 8 = Wind speed (km/h), 9 = Sunny days, 10 = Air polution (μg/m^3), 11 = Cases.

As can be seen in Table 2, in this model population, density, wind, and airport variables accounted for 95% of the variance of the coronavirus cases. However, due to the high correlation between population and population density as well as the one between population density and the number of airports and the variables that contained some degree of multicollinearity problem (Variance inflation factor values are 7.19 and 6.56 respectively and close to the limit score), the number of population and airports variables were dropped out. When population and airport variables were excluded, the remaining variables (density and wind speed) accounted for 94% of the variance of the coronavirus cases, and the best predictor was density, based on β values (Table 2).

3.2. Mediation analyses

Mediation analyses were conducted to test a theoretical model of the relationships between density, wind speed, and COVID-19 cases since they were significantly related to each other. At this point, two plausible outcomes might be evident. Therefore, we hypothesized that wind speed might play a mediator role between density and cases. If wind speed is a powerful variable, it can play a mediator role in the relationship between population density and cases. On the other hand, if population density is a very strong variable, it can eliminate the mediator role of wind speed. Second, density might play a mediator role between wind and cases. According to Baron and Kenny (1986) criteria, the four conditions were met for mediation:(1) the independent variable [X] must significantly predict the mediator [M] (i.e., Path *a*), (b) the mediator [M] must significantly predict variations in the dependent variable [Y] (i.e., Path *b*), and (c) when Paths '*a*'and '*b*' are controlled, a previously significant relation between the independent [X] and dependent [Y] variables [Path c] is no longer significant (full mediation), or weakened (partial mediation). Hayes

(2017) also questioned the concepts of full or partial mediation and advocated for these terms, along with the classical mediation steps approach. Thus all analyses were done with Hayes PROCESS macro model (Model 4) with the bootstrapping of 5000 samples. Figs. 2a and 2b illustrate a conceptual diagram of the mediation models (Hayes, 2017).

According to the first model, although the beta coefficient between initial density and COVID-19 cases was 0.97, when wind speed was added, the beta coefficient decreased to 0.95. The Sobel test showed that this decrease was not significant (Sobel $Z = 1.46$, $p = .14$). Therefore, the wind speed had no mediating role in the relationship between density and COVID-19 cases.

According to the second model, although the beta coefficient between initial wind speed and COVID-19 cases was 0.30 (explained variance was 0.09 due to wind speed), the beta coefficient decreased to 0.05 when density was added into the equation. The Sobel test showed that this decrease was significant (Sobel $Z = 17.23$, $p = .0001$). Therefore, density was a full mediator in the relationship between wind speed and COVID-19 cases. The total, direct and indirect effects of wind variable on the number of cases were illustrated in Table 3.

4. Discussion

In this study, the role of demographic, geographic, and climate variables on COVID-19 spread was tried to be clarified for the first time in the literature. Due to the fact that the previous studies could not measure precisely and they consist of a small number of samples, in this study, a relatively more sensitive measurement was taken on a city basis and the number of samples was increased. In this research, the role of a wide variety of variables was tried to be clarified for the first time. This situation has great importance in terms of both

Table 2
Hierarchical multiple regression analysis summary for populationi density, airports and wind variables predicting COVID-19 cases.

	B	SE	β	T	p	95%Cl Lower-Upper		VIF
Constant	−377.138	45.518		−8.285	0.0001	−467.80	−286.48	6.41
Population	0.000	0.000	0.20	2.83	0.006	0.000	0.000	7.19
Density	2.50	0.22	0.78	11.56	0.0001	2.06	2.93	6.56
Airports	−33.71	57.30	−0.02	−0.59	0.56	−147.84	80.42	1.57
Wind speed	25.33	12.18	−0.06	2.08	0.04	1.06	49.59	1.08
Model 1: Adj. $R^2 = 0.95$. F (4, 76) = 340.19. $p < .0001$								
Constant	−445.76	137.42		−3.24	0.002	−719.35	−172.17	
Density	3.06	0.09	0.96	33.64	0.0001	2.88	3.24	1.07
Wind speed	22.13	12.56	0.05	1.94	0.05	−2.93	47.18	1.07
Model 2 (airports and population excluded): Adj. $R^2 = 0.94$. F (2,78) = 626.90, $p < .0001$.								
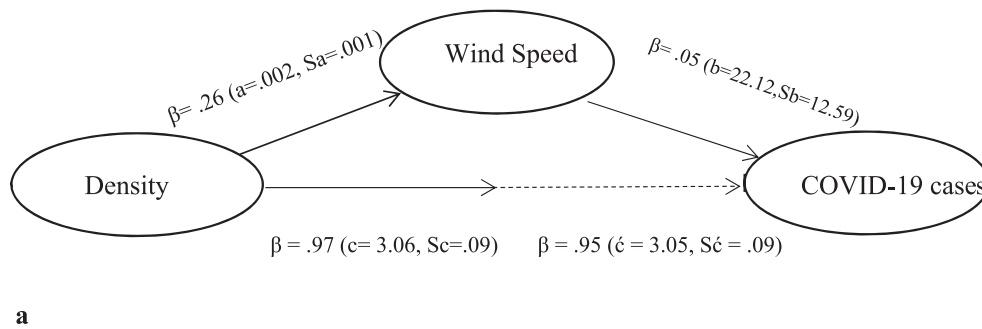
Fig. 2a. Mediation Role of Wind Speed for the Relationship between Density and COVID-19 cases Note: Unstandardized coefficients (a, b, c, and ć pathway coefficients and standard errors) were shown in parentheses.

theoretical and application areas. The results of the research showed that population density and wind explain 94% of the variance in COVID-19 propagation. On the other hand, variables such as temperature, rain, number of sunny days, air pollution, and altitude were not found to be related. This emerging finding provides a new contribution to general-scale research findings. The most consistent finding reported by the literature (Lai et al., 2020; Şahin, 2020) is that this study revealed that population density is the most important and the first factor in virus spread.

Another important finding revealed by this research was that wind was another important factor in virus spread. Wind speed explained 9% variance of the spread or the number of cases. This explanation indicates that wind is a moderately important factor. This can be explained by the fact that the virus hangs in the air (Wang and Du, 2020; WHO, 2020). It is not known how long the virus hangs in the air with the current measuring devices. The most important reason for this is the difficulty of measuring it in the air. If the wind has a moderate effect on the number of cases, this indicates that the virus remains in the air at certain times. It is difficult to control the spread of the virus in windy weather. Depending on the intensity of the wind and the direction of flow, the COVID-19 virus can be transported. Indeed, the research finding points to the fact that it can be transmitted to people in places where the population density is high. On the other hand, the wind alone does not affect the number of cases. Mediator variable is the number of people in a field. In cases where the wind speed is high, the virus spread increases if the population is dense in an area. In places where the wind blows 30 km or more per hour, if the population density is high, the probability of transmission of the virus to people increases. In this case, curfews should be also taken into account depending on the wind speed. Going out on windy days will increase the spread of the virus. In spring and autumn, when the wind speed is high, this risk will be high. This situation may explain why the cases are seen more in Spain. The effect of desert winds is high in Spain. For instance, the average wind speed was 13 km/h and sometimes reached

34 km/h in Madrid in March. The influence of gulf flow and winds are high (average was 22 km/h in March) in New York, USA. This situation needs to be investigated in further studies.

In this research, any evidence for the effect of air pollution was not found. Air pollution is more prominent in Northern European regions where heavy industry is seen. Air pollution in Turkey decreased significantly with natural gas. The rate of air pollution is high in cities where coal fuel is used. The fact that this pollution is not related to the number of cases indicates that the air pollution rate is not high enough to affect the virus. Air pollution data reflect average values in a year. Unfortunately, we were not able to access the data on a monthly basis. This may have covered results that would be statistically significant. All data, except air pollution, are taken with monthly values. As an another issue, air pollution levels in Turkey do not have very dangerous values. The heavy industry in Turkey is mostly located in the western region. There are two important cities (Istanbul and Kocaeli: see north-western region) in Turkey. The number of cases is high in these cities. However, it is unlikely to draw a statistical conclusion with data from only two cities. This does not mean that air pollution does not affect COVID-19 cases. There is a possibility that dust and air pollution have to irritate nasal passages and make the viral infection much easier. We found that air pollution was moderately correlated with temperature, rain, and wind. The relationship between air pollution and risk of dying from COVID-19- should be more evident in the winter season than the spring season. All data were collected in the spring season in the current research. More recent research suggests the relationship between long-term exposure and risk of dying from COVID-19 in Italy and the USA (Fattorini and Regoli, 2020; Wu et al., 2020). Cities in the world with high air pollution should be compared in future studies. This is the most important limitation of this research.

The effect of sunny days on the number of cases was also not found in this study. There is a belief among people that virus spread will decrease when sunny days increase. There is some research evidence that the average temperature is related to COVID-19 (Şahin, 2020).
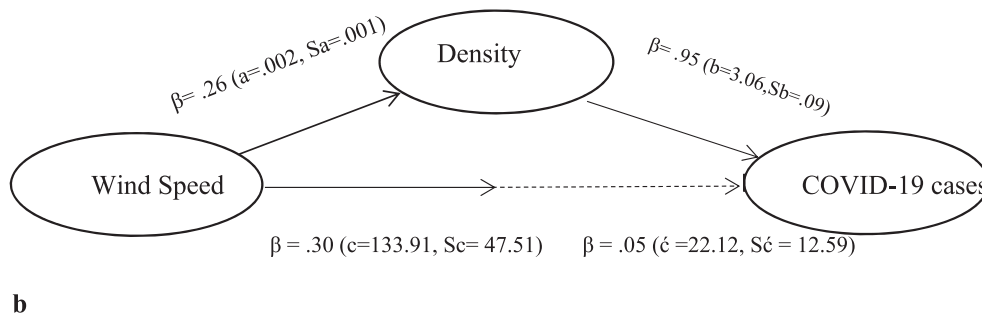
Fig. 2b. Mediation Role of Density for the Relationship Between Wind Speed and COVID-19 Cases. Note: Unstandardized coefficients (a, b, c, and ć pathway coefficients and standard errors) were shown in parentheses.

Table 3
Mediation analysis results.

Independent variable	Dependent variable	Total Effect[a]	Direct Effect[b]	Indirect Effect[c]
Wind speed	COVID-19 cases	0.30** [0.14/0.30]	0.05* [0.02/0.05]	0.25* [0.11/0.25]

The table includes standardized beta coefficients; The variables in square brackets were standardized. Beta coefficients were lower (pre-cut value) and upper (post-cut value) limit values; upper and lower values were calculated within the 95% confidence interval.
** $p < .01$.
[a] Total of direct and indirect effects.
[b] The effect of the independent variable that does not depend on the external density tool role on the case.
[c] The effect of the independent variable via density on the number of cases.

There is a difference between our study and the previous study in the sense that our study included all cities in Turkey that shows all four seasonal characteristics and diverse temperature values, whereas the previous study had mostly data of the cities from the Western region of Turkey. This diversity in climate might eliminate the effect of temperature. Also, taking average measurements in March may be an important factor in this study. Taking measurements in the summer will clarify this issue.

In this study, only March 2020 data were obtained. The observation time for the data was too short. However, this is the month when the virus has just begun to spread. The fact that future studies take into account other months will further enlighten the issue. This study was based on only 81 provinces. Sampling can be included in the districts. However, it may be difficult to access climate data on a district basis.

In sum, the findings of the study showed that population density and wind, which accounted for 94% of the variance in virus spreading, had a great impact in spreading the virus spread or the number of cases. Besides, population density had a full mediator role for the relationship between wind speed and the virus spread. In conclusion, the finding that COVID-19 virus is invisible in the air, spreads more in windy weather indicates that the virus in the air is one threatening factor for humans with the wind speed that increases air circulation.

CRediT authorship contribution statement

Prof. Dr. Hamit COŞKUN, Ph.D: Conceptualization, Methodology, Software, Writing.
Prof. Dr. Nazmiye YILDIRIM, Ph.D: Data curation, Writing- Original draft preparation.
Prof. Dr. Samettin GÜNDÜZ, Ph.: Investigation.

Declaration of competing interest

The authors declare no conlict of interests.

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