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Impact of the inversion and air pollution on the number of patients with Covid-19 in the metropolitan city of Tehran

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ABSTRACT

There is a downward curve between increasing inversion altitude and the number of coronavirus patients during all periods. As temperature inversion altitude increases, the pollutants are dispersed in a greater thickness of the atmosphere and the concentration of the pollutants decreases on the earth’s surface. At the same time, the number of patients with Covid-19 reduces. Although investigation of the effect of severity of pollutants on the number of coronavirus patients showed poor significance level during the periods, a decreasing and increasing relationship was shown. in 1- and 9-14-day periods, the correlation coefficient was negative. As a result, the effect of the severity of pollutants and Covid-19 is not observed on 1- and 9-14-day periods. Conversely, during 2-8-day periods, a positive correlation coefficient was observed. Therefore, the time between infection with the virus and the onset of symptoms of this disease is between 2 and 8 days, in which the 3-day period showed the highest correlation. Considering the relationship between inversion altitude, the severity of pollutants and the number of patients during 2-5-day periods, it can be concluded that in the metropolitan city of Tehran, the maximum infection of this virus and the onset of symptoms is between 2 and 5 days.

1. Introduction

Pollution of metropolises is generally due to the topographical factors such as the enclosure of our urban environment between the high mountains, rising population, denser traffic congestion, industrial activities and so on. Among major atmosphere processors, temperature inversion in the boundary layer of the atmosphere and air stability can be noted. Air stability prevents the rise and displacement of the air masses and disrupts the refinement and displacement of ordinary air within the urban atmosphere and saturates the earth’s surface-atmosphere from pollutants. Severe inversions have direct and indirect effects on humans and their surrounding environment. When the height of the inversion is closer to the earth’s surface, it increases air pollution (Keikhosrovi and Lashkari, 2014; Barhari et al., 2014). Tehran is one of the most polluted cities globally where cardiovascular and respiratory diseases, stroke, and covid-19 infection are prevalent. Ambient air pollution can affect the spread of infections by extending virus exposure and susceptibility. Therefore, contaminated air with aerosols may increase the virus’s survival and increase the likelihood of infection. There exist various factors that possessing reasonable relationship with atmospheric pollutants, including series of meteorological parameters and ecological parameters. (Yu et al., 2021) Analyzed the Effects of aerosols and water vapour on spatial-temporal variations of the clear-sky surface solar radiation in China, they reached to this conclusion the strongest attenuation in clear-sky surface solar radiation due to...
aerosols occurs in April in most areas of China, while in June in North China and the Yangtze River Delta, water vapour most strongly attenuates the clear-sky surface solar radiation in July, and the monthly solar radiation losses due to water vapour are higher than those due to aerosols. The high aerosol and water vapour contents are the reasons why the clear-sky surface solar radiation in North China and the Yangtze River Delta in June are lower than those in May. (Zhang et al., 2021) Analyzed the Haze events at different levels in winters, they reached to this conclusion The occurrence of haze is found to be governed by the wind circulation and boundary layer in Beijing where the ground wind speed and the height of boundary layer decreased significantly with the development of haze. Compared with the boundary layer and wind, the relative humidity has a stronger impact on haze in Wuhan. (Fang et al., 2021) Compared with the boundary layer and wind, the relative humidity has a stronger impact on haze in Wuhan.

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Analyzed the Solar Brightening/Dimming over China’s Mainland: Effects of Atmospheric Aerosols, Anthropogenic Emissions, and Meteorological Conditions, The results show the following: (1) The annual average SSR values had a decline trend at a rate of \(-0.371\) Wm\(^{-2}\) yr\(^{-1}\) from 1984 to 2016 over China. (2) The aerosol optical depth (AOD) plays the main role in inducing variations in SSR over China, with \(r \text{ values of } -0.75\). Moreover, there are marked regional differences in the influence of anthropogenic emissions and meteorological conditions on SSR trends. (3) From a regional perspective, AOD is the main influencing factor on SSR in northeast China, Yunnan Plateau and surrounding regions, North China, and Loess Plateau, with \(r \text{ values of } -0.65, -0.60, -0.89, \text{ and } -0.50\).

On December 31, 2019, China informed the World Health Organization of various unusual cases of pneumonia in Wuhan, a city in the capital of Hubei Province. On January 7, 2020, a new virus called SARS-CoV-2 was identified. On January 30, the World Health Organization declared a public health emergency around the world. In February, it began to spread in Iran, Italy and other countries. Subsequently, this became epidemic, and by the end of March, half the world’s population had been contaminated (Tosepu et al., 2020).

The recent coronavirus pandemic, called Covid-19, has raised global concern and led to complete quarantine in many countries (Gautam and Trivedi, 2020). Since its emergence, research on its transmission has been ongoing. It is claimed that the main route of transmission is indirect contact, i.e., contact with contaminated surfaces and then transmission of Covid-19 infection through the mouth, nose or eyes (Qu et al., 2020). Another mode of transmission is through respiratory droplets from one person to another (Li et al., 2020) where a certain amount of pathogens is inhaled by others while talking, coughing and sneezing (Yang et al., 2020).

For the transmission of Covid-19 by air, the World Health Organization first announced that the virus would remain in the air in a closed environment for two hours. Qu et al. (2020) reported another route of transmission through air dust. Absorption of air dust and particulate matter can help transmit the virus remotely. After several months since Covid-19 pandemic, a number of studies have found important evidence for a relationship between air pollution and the rate of infection and mortality. Thus, although the evidence presented is not 100% convincing, it is unwise not to take action when, based on the available evidence, we are 90% certain that air quality has a positive effect on Covid-19 pollution and its losses (Becchetti et al., 2021). Investigation of the relationship between the mortality level of acute coronavirus 2 syndrome and air pollution in Lombardy and Vamillia Romania showed that those living in an area with high levels of pollutants are prone to chronic respiratory diseases suitable for any infectious agent. These regions are among the most polluted regions in Europe with the highest mortality of the virus in the world. Also, exposure to air pollution even in healthy and young ones leads to a chronic inflammatory stimulus. Thus, we conclude that high levels of pollution in northern Italy should be considered as another factor for the high mortality rate recorded in that area (Conticini et al., 2020).

Air pollution also exacerbates potential and severity of coronavirus-like respiratory virus infection (Manisalidis et al., 2020; Pothirat et al., 2019).

As the World Health Organization declared, 4.2 million people died in 2016 due to air pollution. It should be noted that chronic respiratory and cardiovascular diseases may be associated with Covid-19, as virus-related mortality rate is higher among those with the disease. Accordingly, it is obvious that stimulating air quality can have positive effects on human life and well-being (Khomsi et al., 2021). Air Quality Index (AQI), pm2.5, NO2, and temperature are four variables that can enhance transmission of Covid-19, so personal protective equipment, especially a face mask, is strongly recommended for protection in highly polluted environments (Li et al., 2020). Air quality can lessen the adverse outcomes of Covid-19 in two ways, and long-term exposure to particulate matter (PM) may impair health in general and the lungs in particular. However, it cannot be ignored that pollutants may act as carriers of viruses (Becchetti et al., 2021).

The ongoing relationship between cardiopulmonary mortality and daily PM changes is well documented and many studies have been conducted since 1997 (Pope III et al., 2006). To the best of our knowledge, PM may be of human (sulfates, nitrates, ammonia, carbon, lead, and minerals) or natural (soil, dust, sea salt, bio-aerosols) origin. PM of human origin is made up of smaller particles (usually less than 2.5 \(\mu\)m in diameter) and is therefore more dangerous by penetrating respiratory tract, bronchi, and air sacs, while PM particles with a larger diameter (usually of natural origin) remain in the upper respiratory tract (Johnson et al., 2011). Therefore, air pollution produced by human activities is more dangerous to health than pm concentrations produced by atmospheric phenomena. The atmospheric parameters such as pollutants and local climate play an important role in the mortality rate due to Covid-19.

Studies show that aerosols containing coronavirus, which are caused by coughing, sneezing and talking, are the main source of virus spread (Srivastava, 2021). This study confirms that air pollutant gases and the number of patients with Covid-19 are positively correlated. It also shows the negative impact of relative moisture on Covid-19. On the other hand, rainfall showed no correlation with Covid-19 spread, while the wind speed plays a positive role in its spread. Wind acts as a vital factor in the spread of infectious lung diseases (Ellwanger and Chies, 2018). Low wind speed is strongly correlated with cases of Covid-19 (Rendana, 2020). For the effect of carbon monoxide, Su et al. (2019) have stated that carbon monoxide can increase the risk of diseases such as influenza, so it can also have a positive effect on Covid-19. Air quality due to quarantine has significantly improved. During this period, a significant reduction in PM10, PM2.5, SO2, CO, NO2, BC, and VOCS can be observed, although quarantine has been associated with a significant increase in ozone (Srivastava, 2021). Quarantine has played an important role in improving air quality. However, many studies have shown that cities with poor air quality suffer greatly from Covid-19 pandemic (Wu et al., 2020).

A nonlinear dose-response relationship is between temperature and coronavirus transmission (Zhang et al., 2020). This study in the cities of southern China shows the negative impact of ambient temperature and air pollution on Covid-19 transmission. Given that
rising temperatures reduce air pollution, there were fewer people infected with the virus. The correlation between air quality index and cases of Covid-19 at temperatures between 10 and 20°C is stronger than other temperatures, and virus transmission in relation to air quality index is higher in relative moisture (RH) between 10 and 20% (Xu et al., 2020). Among the air components including minimum, maximum and average temperature and moisture content and precipitation level, only average temperature is correlated with Covid-19 pandemic (Tosepu et al., 2020). Long-term air quality data are significantly associated with Covid-19 cases in 71 Italian provinces, and further evidence suggests that chronic exposure to air pollution can trigger the spread of the virus (Fattorini and Regoli, 2020). During the 5-week quarantine in Ontario, Canada, the average ozone concentration reached its lowest level and nitrogen dioxide reduced, but pm2.5 level did not change (Adams, 2020). A significant reduction occurred in the concentration of air pollutants other than O3 during quarantine and there is a significant relationship between air pollution and the spread of Covid-19 (Coskun et al., 2021). The prolonged exposure to pollutants including PM10, PM2.5, and NO2 may lead to an increase in the number of patients daily. Quarantine not only reduces day-to-day infections by reducing personal contact with the person, but also delays the spread of the virus by reducing air pollution, which has a positive effect on controlling and reducing virus transmission. In Guangxi, southern China, normal pollutants in air reduced during quarantine compared to the same period during 2016–2019 (January 24 to February 9) while O3 gradually increased (Fu et al., 2020). The results show that prolonged exposure to ozone and other climatic factors can affect Covid-19 transmission and onset, but its severity and mortality depend on other factors. To explain, mean daily temperature, maximum daily ozone concentration, average relative moisture, and cloud percentage had a significant positive relationship with the newly confirmed Covid-19 cases, and none of these variables showed a significant relationship with new deaths due to Covid-19 (Adhikari and Yin, 2020). Particulate matter Analysis, Air Quality Index, and coronavirus data from January 1 to April 30, 2020, were considered to determine the effect of air pollution on the rapid release of Covid-19 in Lombardy, Milan, Italy (Zoran et al., 2020). This study, with the evidence of a negative correlation between Covid-19 and relative moisture, shows that arid climate exacerbates the spread of coronavirus, with no positive correlation with air temperature. In addition, it reinforces the speculation that the warm season does not stop the spread of Covid-19. It also shows that short-term or chronic exposure to particulate matter has a negative impact on the body’s immune system against viruses and bacteria. This finding shows the importance of air quality improvement in order to increase body’s immunity to viruses like the coronavirus.

2. Data and methodology

In this study, first the location of air pollution measuring stations (Fig. 1) and data related to air pollution during the period (2020/10/01–2021/01/01) were received from the Air Quality Control Office of Tehran. Then, based on air quality index, the number of dangerous days of air pollution in 3 months was investigated and analyzed for air pollutants, including particulate matter (PM2.5-PM10 microns), ozone (O3), sulfur dioxide (SO2), and nitrogen dioxide (NO2). In general, AQI is an index for daily air quality reporting. This index informs people about the quality of the air (whether it is clean or polluted) and provides the related health effects. In other words, AQI addresses the health effects of exposure to polluted (unhealthy) air. Air Quality Index (AQI) is calculated for five major air pollutants: particulate matter, nitrogen dioxide, surface ozone, carbon monoxide and sulfur dioxide. To elaborate, Air Quality Index (AQI) is divided into six categories, each of which relates to different levels of human health, as illustrated in Table 1. The parameters listed in Table 1 that show the breakpoints for AQI are calculated by the following equation.

\[ IP = \frac{IHI - ILO}{BPHI - BPLO} (CP - BPHI) + ILO \] (1)
Table 1
Air quality status based on AQI index.

| Air quality status                  | AQI       | Breakpoints |
|-------------------------------------|-----------|-------------|
|                                     |           | NO2(PMM)    | SO2(PMM)    | CO(PMM)     | PM10(PMM)   |
|                                     |           | One hour   | 24 h        | 8 h         | 24 h        |
| Clean                               | 50-0      | 0.0-0.053  | 0-0.034     | 0-4.4       | 0-54        |
| Healthy (Medium)                    | 100-51    | 0.054-0.1  | 0.035-0.144 | 4.5-9.4     | 55-154      |
| Unhealthy for sensitive groups      | 150-101   | 0.101-0.36 | 0.145-0.224 | 9.5-12.4    | 155-254     |
| Unhealthy                           | 200-151   | 0.361-0.640| 0.225-0.304 | 12.5-15.4   | 255-354     |
| Extremely Unhealthy                 | 300-201   | 0.65-1.24  | 0.305-0.604 | 15.5-30.4   | 355-424     |
| Dangerous                           | 300 <     | 1.25-2.04  | 0.605-0.805 | 30.5-50.04  | 425-604     |

\[ \text{IP} = \text{air quality index for pollutants } p \]
\[ \text{CP} = \text{concentration measured for pollutant } p \]
\[ \text{BPHI} = \text{breakpoint higher than or equal to CP according to Table 1.} \]
\[ \text{BPLO} = \text{breakpoint lower than or equal to CP according to Table 1.} \]
\[ \text{IHI} = \text{AQI value corresponding to BPHI according to Table 1.} \]
\[ \text{ILO} = \text{AQI value corresponding to BPLO according to Table 1 (Ellis, 2010).} \]

The information obtained from air pollution measuring stations, according to the Table of national standards for open air quality and air quality index, became the standard mean time concentration. In these standards, a maximum concentration of 8 h is used for carbon monoxide, a maximum concentration of 1 h is used for nitrogen dioxide, and an average concentration of 24 h is used for particulate matter and carbon dioxide. In order to monitor the concentration of CO during 24 h, average maximum concentration is selected three times and used to convert into air quality index (Lashkari et al., 2020; Kermani et al., 2017).

According to the index value and Table 1, air quality can be understood in the last 24 h. It can be reported according to the index of each pollutant. Still, for the overall air condition, the maximum index, i.e., the highest AQI, which usually belongs to pollutants PM_10, PM_2.5, and CO, is used. Therefore, if the AQI index is less than 50, the air condition is considered clean, between 51 and 100 it is considered healthy, between 101 and 150 unhealthy for sensitive groups, between 151 and 200 unhealthy for all groups, between 201 and 300 extremely unhealthy and above 300, it is regarded dangerous.

To investigate temperature inversion conditions, first the number of days of polluted air in the metropolitan city of Tehran (before a full two-week holiday in December) was determined. Then, Skew-T diagrams of those days were prepared from the site (Atmospheric Sounding) and inversion layer altitude was determined. Then, relying on the statistics of Covid-19 virus, we investigated the health conditions of patients during different periods monitoring temperature inversion altitude and the severity of pollutants using Pearson correlation coefficient. We also examined the increasing and decreasing trend of the number of Covid-19 patients under inversion conditions and different pollutants.

Pearson correlation coefficient calculates the correlation between two distance and/or ratio variables and the values are +1 and −1. If the value obtained is positive, it means that the changes in the two variables occur in the same direction, i.e., by increasing each variable, the other variable increases too. If the value of r is negative, that is, the two variables act in the opposite direction, a rise in one variable reduced the value of the other variable. A zero value indicates no relationship between the two variables, +1 signifies a strong positive correlation, and −1 means a strong negative correlation.

Pearson coefficient is calculated based on the following formulas.

\[ r = \frac{\sum(x - \overline{x})(g - \overline{g})}{N \delta x \times g} \]  \hspace{1cm} (2)

\[ \delta x = \sqrt{\frac{\sum (x - \overline{x})^2}{n}} \]  \hspace{1cm} (3)

\[ \delta g = \sqrt{\frac{\sum (g - \overline{g})^2}{n}} \]  \hspace{1cm} (4)

where n is the number of data and \( \delta g \) is the standard deviation of the data.

3. Results

3.1. Investigation of severe pollution based on AQI

During the statistical period (from October 1 to the end of December 2020), based on air quality index, the metropolitan city of Tehran is classified with 51 days in the acceptable range and 39 days in the unhealthy range for sensitive groups. Before the national holidays, with severe restrictions in December, the number of polluted days for sensitive groups reached 19 days, with 13 days with access to temperature inversion data determined for this study. Fig. 2 shows air quality index (AQI) in the study samples. According to
this figure, the average air quality index (AQI) on October 11, 2020, in the metropolitan city of Tehran is between 66 and 162. On this day, out of a total of 33 active stations in the city, 16 stations showed less than 2.5 μm of particulate matter and two stations above 100 of No2. Meanwhile, the University of Industry station with an index of 163 had an unhealthy condition for all health groups. On October 12, 2020, the northwestern, western and a small part of the northeastern of the metropolitan city of Tehran recorded the highest level of pollutants. On this day, out of a total of 33 air quality measuring stations, 22 stations had less than 2.5 μm of particulate matter and NO2 was above 100. On October 13, 2020, the northwestern, western, southern, central and small parts of the northeastern of the metropolitan city were unhealthy for sensitive groups in terms of air quality index. In general, 70% of the stations have

Fig. 2. Pollutant concentrations in the metropolitan city Tehran, based on air quality index.
unhealthy conditions on this day. On October 14, 2020, the average index (AQI) is between 78 and 153. On this day, the southern, central, western and northwestern parts of the metropolitan city had critical conditions, with NO2 and particulate matter less than 2.5 μm above the threshold. On October 15, 2020, most polluting nuclei have been drawn to the southwestern, southern and central Tehran. Air quality index is between 81 and 151. High concentrations of particulate pollutants and NO2 have caused such conditions. On October 16, 2020, 77% of air quality monitoring stations report unhealthy concentrations of pollutants for vulnerable groups. This condition is caused by high concentrations of PM2.5 pollutants and NO2. On this day (Fig. 2), the highest accumulation of pollutants is observed in the southeast, center, southwest and especially the southern part of the metropolitan city. According to the pollutant distribution map of Tehran on October 17, 2020, due to air stability and the accumulation of pollutants a few days ago is almost unhealthy in the whole city of Tehran because the average AQI is between 92 and 157. The pattern of pollutants on October 18, 21, 23, 26 and 27, 2020, are almost similar. In these few days, the highest accumulation of pollutants is observed in the southwestern half, especially in the southern part. On December 3, PM 10 and PM2.5 has the highest concentration compared to other pollutants, and after this pollutant, the amount of NO 2 is above the standard and has caused undesired conditions in more than 96% of stations.

3.2. Investigation of temperature inversions in study samples

Based on the composition of the atmosphere in different layers and the interactions within it, the vertical temperature gradient is not the same in all layers of the atmosphere. In the lower troposphere layer, which is the lowest layer and the closest layer to the earth’s surface, under normal conditions, the temperature reduces from the earth’s surface upwards. Sometimes, normal conditions are disturbed due to various reasons and the temperature does not reduce by increasing altitude and sometimes increases, this condition of the atmosphere is called temperature inversion. Under these conditions, there is no upward movements within the troposphere within the inversion layer, and the closer this inversion layer is to the earth’s surface and the greater its depth and thickness, the more it prevents smog and dust from spreading to the upper layers of atmosphere. In the case of temperature inversion, the air becomes stable and particles accumulate within the inversion layer, intensifying the severity of air pollution. To investigate inversion altitude, Skew-T diagrams of the studied days were extracted. Skew-T is a standard thermodynamic diagram. This diagram shows a graphical representation of pressure, density, temperature and water vapour in a way that depicts the changes in the base energy of the atmosphere. This diagram is drawn for a point on the ground up to the entire layer of the troposphere. With its temperature and behavior in the atmospheric column, inversion altitude and duration as well as intensity can be investigated. Fig. 3 shows Skew-T diagrams on October 11, 2020, in Tehran. As shown, the increasing trend of temperature is observed from the ground level to 1220 m, but from 1220 m upwards, the decreasing trend of temperature is observed up to the level of 850 hPa. Therefore, from the ground to about 1220 m, there is a strong stability in the atmosphere of Tehran, and from the ground to 1248 m, wind speed is zero according to Skew-T diagram and pollutants cannot move from polluting sources. As a result, air quality index on this day at most pollution measuring stations is higher than normal. Therefore, by this method, temperature inversion altitude was investigated for all selected days (13 days). Table 2 shows inversion altitude, the severity of pollutants, and the number of patients during different periods on selected days.
Table 2
Inversion altitude, average air quality index and the number of patients with Covid-19 during 1–14 day periods.

| Day         | Inversion height (meters) | Average index (AQI) | Number of patients with Covid – 19 virus (after the date of temperature inversion) in periods of 1 to 14 days |
|-------------|---------------------------|---------------------|----------------------------------------------------------------------------------------------------------------|
|             |                           |                     | 1   2 3 4 5 6 7 8 9 10 11 12 13 14                                                                               |
| 11.10.2020  | 1220                      |                     | 518 318 177 291 212 84 181 258 226 159 242 107 118 175                                                      |
| 12.10.2020  | 1314                      |                     | 318 177 291 212 84 181 258 226 159 242 107 118 175 282 209                                                      |
| 13.10.2020  | 1383                      |                     | 177 291 212 84 181 258 226 159 242 107 118 175 282 209                                                      |
| 14.10.2020  | 1327                      |                     | 291 212 84 181 258 226 159 242 107 118 175 282 209                                                      |
| 15.10.2020  | 1258                      |                     | 212 84 181 258 226 159 242 107 118 175 282 209 466 414                                                      |
| 16.10.2020  | 1248                      |                     | 84 181 258 226 159 242 107 118 175 282 209 466 414                                                      |
| 17.10.2020  | 1403                      |                     | 181 258 226 159 242 107 118 175 282 209 466 414                                                      |
| 18.10.2020  | 1397                      |                     | 258 226 159 242 107 118 175 282 209 466 414                                                      |
| 19.10.2020  | 1229                      |                     | 242 107 118 175 282 209 466 414 296 250 521 721 376 360 582 531 410 625 606 623 |
| 20.10.2020  | 1220                      |                     | 118 175 282 209 466 414 296 250 521 721 376 360 582 531 410 625 606 623 |
| 21.10.2020  | 1258                      |                     | 209 466 414 296 250 521 721 376 360 582 531 410 625 606 623 |
| 22.10.2020  | 1220                      |                     | 466 414 296 250 521 721 376 360 582 531 410 625 606 623 |
| 23.10.2020  | 1258                      |                     | 360 582 531 410 625 606 623 534 341 323 530 495 427 |
3.3. Investigation of the relationship between inversion altitude and the number of patients with Covid-19

Pearson correlation coefficient and significance level (P-value) were used to investigate the relationship between inversion altitude, infection severity and number of patients. Notably, the symptoms of coronavirus do not appear on the same day in the infected person. To investigate the relationship between inversion altitude and the number of patients with Covid-19, the latent disease periods were defined. The latent period of Covid-19 means the time between the onset of the virus infection and the onset of symptoms. This duration usually varies between 1 and 14 days. Therefore, inversion altitude and the severity of infection were investigated by the number of patients during 1–14-day periods (Tables 3 and 4). According to Table 3, a relationship was found between increasing inversion altitude and the number of coronavirus patients during all periods. This means that by increasing inversion altitude, the number of patients with Covid-19 has reduced. As temperature inversion altitude increases, the pollutants are dispersed in a greater thickness of the atmosphere and the concentration of the pollutants reduces on the earth’s surface. At the same time, the number of patients with Covid-19 reduces. During the 4-day period (latency period), this relationship is significant at $p = 0.041$. To investigate the effect of pollutants on the number of Covid-19 patients, first the average AQI was calculated based on Fig. 2 for all selected days, and then the correlation and the level of significance with the number of Covid-19 patients were examined during different periods. Undoubtedly, air pollution damages the respiratory system, and this condition weakens the body’s immune system against coronavirus. Therefore, there is a direct relationship between these two factors (severity of pollutants and the number of patients). According to Table 4, Pearson correlation coefficient between the two factors (severity of pollutants and number of patients) during different periods revealed negative and positive correlations. During the periods with the negative correlation, the severity of the pollutants does not affect the number of patients. Inspecting the periods, we find that this negative relationship has occurred between 1- and 9–14-day periods. This means that a person infected with coronavirus is not diagnosed on the first day, and 9–14-day periods are not associated with the severity of the pollutant on the day it occurs. On the one hand, there is a positive correlation coefficient during 2–8-day period. Therefore, the time between infection with the virus and the onset of symptoms of this disease is between 2 and 8 days based on study days and the intensity of concentrations of pollutants in the metropolitan city of Tehran, among which 3-day period shows the highest correlation. Although the significance level (P-value) is weak during 2–8-day periods, it still shows an increasing relationship. Therefore, considering inversion altitude and the number of patients with a significant relationship on Day 4 and the high correlation coefficient (between severity of pollutants and patients) during 2–5-day periods, it can be concluded that the maximum coronavirus infection and the onset of symptoms occur between 2 and 5 days.

Fig. 4 shows two Tehran metropolitan inversion cases at an altitude of 1500 and 1000 m above the ground. In both cases, as the altitude increases, the temperature increases too, i.e., the air adjacent to the earth’s surface is colder than the higher altitudes; in this case, the vertical displacement of the atmosphere is stopped, and the ground surface air becomes stable. This condition is called temperature inversion. Since air pollutant sources permanently insert their pollutants into the surface layer, the contaminants’ concentration in these conditions increases drastically. Air pollution reaches its most substantial level when the phenomenon of inversion remains for longer periods. In fact, prolonged inversion layer creates a stable and inhabited buffer that prevents the mixing of this surface with higher levels. By increasing the concentration of pollutants under it, air pollution intensifies. As the figure suggests, the height of inversion directly impacts the intensification and reduction of contaminants on the ground. When the height of the temperature inversion decreases, the pollutants are dispersed in a smaller thickness of the atmosphere; and the concentration of contaminants on the ground surface will increase. On the contrary, increasing the height of the inversion decreases will mix at a higher altitude than the mixing layer; thus, the density of contaminants on the ground will decrease. Accordingly, in lower inversion attitudes, as pollutants in the stable atmosphere are denser, the Covid-19 virus has a longer shelf-life in the infected layer, which can affect more

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Table 3

Correlation and P-value between inversion altitude and the number of patients with Covid-19 during different periods.

| Periods(day) | Pearson coefficient | P_Value | Chart |
|-------------|---------------------|---------|-------|
| 1           | -0.296              | 0.326   |       |
| 2           | -0.072              | 0.815   |       |
| 3           | -0.190              | 0.535   |       |
| 4           | -0.572              | 0.041   |       |
| 5           | -0.411              | 0.163   |       |
| 6           | -0.397              | 0.179   |       |
| 7           | -0.385              | 0.193   |       |
| 8           | -0.352              | 0.239   |       |
| 9           | -0.402              | 0.173   |       |
| 10          | -0.492              | 0.087   |       |
| 11          | -0.280              | 0.355   |       |
| 12          | -0.352              | 0.238   |       |
| 13          | -0.465              | 0.109   |       |
| 14          | -0.409              | 0.165   |       |
The addition of any element that is dangerous for human, animal, and plant life is considered as air pollution. In the case of temperature inversion, air becomes stable and particles accumulate within inversion layer, increasing the severity of air pollution. The World Health Organization (WHO) estimates that air pollution causes about seven million early deaths annually. The prevalence of COVID-19 has further reinforced the risk because air pollution can increase the risk of respiratory diseases and increase their severity. Air pollution and COVID-19 can cause various problems such as asthma, pulmonary disorders, heart disease, stroke, diabetes, hypertension, liver, skin and eye infections, cancer, and neurological diseases because it is one of the most significant causes of death. According to some experts, specialists, and the World Health Organization, increasing the concentration of pollutants, including particulate matter, can affect the spread of the coronavirus. As a contaminant of metropolises, particulate matter is caused by direct emissions and chemical reactions. This pollutant generally reduces air quality and turns skies dusty on the cold days of the year. The coronavirus spread can be exacerbated by atmospheric pollutants, especially particulate matter of less than 2.5 μm (Li et al., 2020). Aerosols containing the coronavirus caused by coughing, sneezing, and talking are the primary sources for the spread of the virus (Srivastava, 2021). Therefore, air pollution increases the risk of the Covid-19. There is a direct link between air pollution and the spread of COVID-19 and the possibility of higher mortality rate. Also, air pollutants weaken the immune system and thus can pave the way for the disease. Reportedly, each unit increase in the concentration of particulate matter of less than 2.5 μm increases by 8–15% the death toll of Covid-19 infected patients. In this research, investigation of air pollution data since October 1 to the end of December 2020 in terms of air quality index shows the metropolitan city of Tehran with 51 days in the acceptable range and 39 days in the unhealthy range for sensitive groups; also, clean air was not observed during 90 days. On days with the concentrations of pollutants above the allowed level, the levels of PM10, PM2.5 and NO2 had the highest percentage of pollution compared to other pollutants. Given that the symptoms of coronavirus do not appear on the same day in the infected person, 1–14-day periods were set to investigate the relationship between inversion altitude, the severity of pollutants and the number of Covid-19 patients. In 13 case studies of temperature inversion altitude, a downward curve was observed between higher inversion altitude and the number of coronavirus patients during all periods (in the 4-day period, this relationship is significant at $P = 0.041$). This means that the number of patients with Covid-19 has reduced by increasing inversion altitude. As temperature inversion altitude rises, the pollutants are dispersed in a greater thickness of the atmosphere and the concentration of the pollutants on the earth’s surface reduces. At the same time, there are fewer patients with Covid-19. Investigation of the effect of the severity of pollutants on the number of patients with Covid-19 during different periods showed that Pearson correlation coefficients between the two factors (severity of pollutants and number of patients) are negative and positive. Although the significance level ($P$-value) is weak during the periods, it still shows a decreasing and increasing relationship. A negative relationship was observed during 1- and 9–14-day periods. As a result, the effect of the severity of pollutants and Covid-19 virus was not observed during 1- to 9-14-day periods. Conversely, during 2–8-day periods, a positive correlation coefficient was found. Therefore, the time between infection with the virus and the onset of symptoms is between 2 and 8 days based on study days and the intensity of concentrations of pollutants in the metropolitan city of Tehran, among which the 3-day period shows the strongest correlation.
Declaration of competing interest

None.

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