COVID-19 Outbreak Related to PM$_{10}$, PM$_{2.5}$, Air Temperature and Relative Humidity in Ahvaz, Iran

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Abstract
In this study, we assessed several points related to the incidence of COVID-19 between March 2020 and March 2021 in the Petroleum Hospital of Ahvaz (Iran) by analyzing COVID-19 data from patients referred to the hospital. We found that 57.5% of infected referrals were male, 61.7% of deaths by COVID-19 occurred in subjects over 65 years of age, and only 2.4% of deaths occurred in younger subjects (< 30 years old). Analysis showed that mean PM$_{10}$ and PM$_{2.5}$ concentrations were correlated to the incidence of COVID-19 ($r = 0.547$, $P < 0.05$, and $r = 0.609$, $P < 0.05$, respectively) and positive chest CT scans ($r = 0.597$, $P < 0.05$, and $r = 0.541$, $P < 0.05$ respectively). We observed that a high daily air temperature (30–51 °C) and a high relative humidity (60–97%) led to a significant reduction in the daily incidence of COVID-19. The highest number of positive chest CT scans were obtained in June 2020 and March 2021 for daily air temperature ranging from 38 °C and 49 °C and 11 °C and 15 °C, respectively. A negative correlation was detected between COVID-19 cases and air temperature ($r = -0.320$, $P < 0.05$) and relative humidity ($r = -0.384$, $P < 0.05$). In Ahvaz, a daily air temperature of 10–28 °C and relative humidity of 19–40% are suitable for the spread of coronavirus. The highest correlation with the number of COVID-19 cases was found at lag3 ($r = 0.42$) and at lag0 with a positive chest CT scan ($r = 0.56$). For air temperature and relative humidity, the highest correlations were found at day 0 (lag0). During lockdown (22 March to 21 April 2020), a reduction was observed for PM$_{10}$ (29.6%), PM$_{2.5}$ (36.9%) and the Air Quality Index (33.3%) when compared to the previous month. During the pandemic period (2020–2021), the annual mean concentrations of PM$_{10}$ (27.3%) and PM$_{2.5}$ (17.8%) were reduced compared to the 2015–2019 period.

Keywords COVID-19 · PM$_{10}$ and PM$_{2.5}$ · Temperature · Relative humidity · Petroleum Hospital

Abbreviations
PM Particulate matters
MODIS Moderate Resolution Imaging Spectroradiometer
ARS Acute Respiratory Section
RE Respiratory emergency
PCR Polymerase chain reaction
CT-scan Computed tomography scan
EOC Emergency Operations Center
AQI Air quality index

1 Introduction
The COVID-19 outbreak globally progressed from Wuhan (China) in December 2019 to all regions of the world [15, 82]. The World Health Organization (WHO) confirmed more
than 118,000 COVID-19 cases in 114 countries and 4291 deaths on 11 March 2020 and declared the beginning of a new global pandemic (World Health Organization, 2020). The number of new cases increased sharply worldwide with 3,942,907 infected people and 271,646 deaths reported in May 2020 in more than 200 countries [82]. In Iran, approximately 9,000 COVID-19 cases and 354 deaths were reported on 11 March 2020 (https://behdasht.gov.ir). The first COVID-19 case in Iran was reported in Qom county on 19 February 2020 and on 23 February 2020 in Ahvaz [32, 68]. In Iran, the highest number of daily infected cases (14,051) and deaths (486) were reported on 27 and 16 November 2020, respectively (https://worldometers.info). With the virus spreading, the Iranian government started programs for reducing fatalities; one of these was lockdown. The first lockdown started on 22 March 2020. Hence, a reduction of air pollution was observed due to limited anthropogenic activities [58, 64].

COVID-19 is well known as an acute respiratory disease leading to pneumonia with symptoms including fever, cough and dyspnea [39] with a fatality rate of approximately 2–3% [38, 65]. COVID-19 primarily transmits from person to person in a closed environment due to reduced air ventilation [57], the lack of ultraviolet light which can inactivate the virus and a reduced dilution indoors when compared to outdoor air [17]. Male sex, advanced age, underlying disease and comorbidities may be associated with severe illness and a higher rate of mortality [7]. In addition, COVID-19 appears to be correlated to the increasing rate of thromboembolic events in hospitalized patients [17, 37, 53].

Many factors contribute to disease emergence, including climate change, globalization and urbanization; most of these factors are caused by humans [23]. Anthropogenic activities are a major issue of air pollution due to the emission of harmful pollutants and sources of transmissible disease agents [5, 22–24, 43, 44, 73]. Fine particles, with an aerodynamic diameter lower than 2.5 µm (PM$_{2.5}$) or 10 µm (PM$_{10}$), are mainly emitted from sources such as vehicles, energy industries and dust [35, 43] and have potentially the most significant effects on human health when compared to other air pollutants [25]. Particles, especially PM$_{2.5}$, are known to be responsible for different lung diseases and respiratory infections [45, 50, 56]. Previous studies showed that acute exposure to air pollutants increased the severity and the risk of hospital admissions for respiratory viral infections [28]. A good correlation was observed between air pollution and SARS-CoV-1 outbreak in China, furthermore, exposure to air pollution was shown to increase the transmission of viral infections [14, 18]. The transmission rate of SARS-CoV-2 could be affected by air pollution level, air temperature and relative humidity [27]. A study in Bangladesh indicated that high air temperature and relative humidity significantly reduced the transmission of COVID-19, while a peak of COVID-19 spread was observed at a mean temperature of 26 °C [36]. Some studies have reported a correlation between the spread of COVID-19, air pollution and some meteorological parameters [27, 36, 38, 54, 58, 66, 72, 79]. For the first time, this study investigated the relationships and time lag effects between PM$_{10}$ and PM$_{2.5}$ concentrations, daily hospital admissions for COVID-19, chest CT scans, air temperature and relative humidity in Ahvaz, Iran from March 2020 to March 2021.

## 2 Materials and Methods

### 2.1 The Study Area

Ahvaz (31° 19’ N 48° 40’ E), the capital city of Khuzestan province, is located in the southwest of Iran. This city covers an area of 185 km$^2$ and has approximately 1.2 million inhabitants [6, 33, 40]. Ahvaz experiences a hot desert climate with a long summer and short winter. The annual mean temperature is approximately 24.9 °C and sand and dust storms are common [34]. Iranian cities are ranked as the most polluted by PM$_{10}$ in the world [59, 72] and can be considered as a case study to investigate the effects of lockdown on PM levels. Figure 1 shows a map of Ahvaz and the Moderate Resolution Imaging Spectroradiometer (MODIS) of the city over Middle Eastern dust storms during summer 2021 with a backward trajectory of particulate matters (PM). Based on the annual PM$_{10}$ mean concentration, Ahvaz (372 µg m$^{-3}$ as the annual average in 2009) is the most polluted city in the world [55]. The high levels of PM in the air can be explained by industries located inside and around the city such as steel, gas and petroleum companies, oil refineries, and storms originating from the desert areas of Arabian countries [34].

### 2.2 COVID-19 Data

An Acute Respiratory Section (ARS) or Respiratory Emergency (RE) unit was created in the Emergency Service at the Ahvaz Petroleum Hospital, located at the north of Ahvaz, for new daily cases with COVID-19 symptoms. Samples were taken by polymerase chain reaction (PCR); to evaluate chest symptoms, we used computed tomography scans (CT scan). Daily samples were recorded by the official group in the ARS and then the results were reported by the laboratory to the statistical team at the Emergency Operations Center (EOC). The results were recorded daily, including date, first name, surname, age, sex, PCR test result and chest CT scan, and if need be, fatality date. Patients who were referred for chest CT scans were screened for COVID-19 symptoms, and symptomatic patients were supported by a surgical mask and placed in an isolation room. All hospital referral data were taken from the Research and Education Center of Petroleum
Hospital. More than 15,000 positive PCR and 10,400 positive chest CT scans were analyzed during the study period. We retrieved all data from 21 March 2020 until 20 March 2021.

2.3 Environmental Data

Air quality monitoring data were provided by Ahvaz's Environmental Protection Agency (A-EPA). Due to obsolete or incomplete observations for several air pollutants, we restricted our regional analysis to two major air pollutants: hourly PM$_{10}$ and PM$_{2.5}$ concentrations (µg m$^{-3}$) (http://khzdoe.ir/rha). Additional meteorological parameters, including hourly air temperature and relative humidity in Ahvaz from 21 March 2020 to 20 March 2021 were provided by the Meteorological Organization for four monitoring stations located in Ahvaz. Only background monitoring stations with at least 75% of validated hourly

Fig. 1 The location of study area, a MODIS of Ahvaz over a Middle Eastern dust storms on summer 2021 and b backward trajectory of particulate matters
data in a year were included to calculate valid daily averages [42].

2.4 Air Quality Related to PM$_{10}$, PM$_{2.5}$ and Lockdown

By using daily PM$_{10}$ and PM$_{2.5}$ concentrations, we investigated PM$_{10}$ versus PM$_{2.5}$ and the ratio PM$_{2.5}$/PM$_{10}$. To consider the short-term effects of meteorological parameters [72], the PM$_{10}$ and PM$_{2.5}$ mean concentrations during the COVID-19 pandemic (2020–2021) were compared to previous years (2015–2019). We defined three time periods: before (21 February to 21 March 2020), during (22 March to 21 April 2020) and after lockdown (22 April to 21 May 2020). In addition, the air quality index (AQI) was calculated.

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AQI = \frac{IN_{HI} - IN_{LO}}{B_{HI} - B_{LO}} \times (C - B_{LO}) + IN_{LO},
\]

where, $IN_{HI}$ and $IN_{LO}$ represent the AQI value, $B_{HI}$ and $B_{LO}$ are breakpoint concentrations more than or less than $C$, and $C$ is the concentration of each pollutant. This parameter can be divided into six categories including good, satisfactory, moderate, poor, very poor, and severe depending on whether the AQI respectively falls between 0–50, 51–100, 101–200, 201–300, 301–400, and 401–500.

2.5 Statistical Analyses

Data were tested for normality with the Kolmogorov–Smirnov one-sample D test. The non-parametric Spearman test was used to analyze correlations between variables and applied to daily data: PM$_{10}$, PM$_{2.5}$, temperature, relative humidity, COVID-19 cases, and positive chest CT scans. Statistical significance was set at $P < 0.05$ and statistical analyses were performed with Excel.

3 Results

3.1 Hospital Admissions Information

Of the 15,280 COVID-19 cases admitted to the Petroleum Hospital from 21 March 2020 to 20 March 2021 (Table 1), 57% of patients were male with an average age of 50.1 years; the average age of women was slightly higher (50.5 years). Among those with a positive PCR result, 40.0% of males and 46.8% of females experienced underlying diseases. With regards to the number of deaths, 56.6% were male; the average age of deaths for both male and female was similar (66.5 years).

| Percentage (%) | Male | Female |
|----------------|------|--------|
| Average age (years) | 50.1 | 50.5 |
| People with underlying disease (%) | 40.0 | 46.8 |
| COVID-19 fatality rate (%) | 56.6 | 43.4 |
| Average age of deaths (years) | 66.5 | 66.5 |

The highest number of patients were with the age ranges of 35–39 and 55–59 years, 12.3% and 11.3% of the total number of hospital admissions, respectively. Children (< 9 years) represented 0.1% of the total number of patients. Analysis showed that 61.7% of deaths by COVID-19 occurred in subjects over 65 years; 2.4% of people < 30 years of age died in Petroleum Hospital. The highest number of fatalities occurred in subjects who were 70–79 years of age. Furthermore, 35.9% of patients died in the 30–64 years age range (Table 2).

3.2 Time-Series Variations of PM$_{10}$ and PM$_{2.5}$

The highest daily PM$_{10}$ and PM$_{2.5}$ concentrations were observed on 18 March 2021 (396.4 µg m$^{-3}$) and on 6 May 2020 (121.6 µg m$^{-3}$), respectively (Fig. S1). In Ahavz, the highest (160.84 and 67.68 µg m$^{-3}$) and the lowest (51.27 and 25.79 µg m$^{-3}$) monthly PM$_{10}$ and PM$_{2.5}$ mean concentrations were also observed in October 2020 for PM$_{10}$, and in January 2021 for PM$_{2.5}$ (Fig. S2). The annual mean concentrations of PM$_{10}$ and PM$_{2.5}$ were 119.6 and 38.2 µg m$^{-3}$, respectively, showing that PM$_{10}$ and PM$_{2.5}$ concentrations exceeded the annual limit value established by the WHO Air Quality Guideline for the protection of human health (50 and 25 µg m$^{-3}$, respectively). A significant correlation between the daily mean concentrations of PM$_{10}$ and PM$_{2.5}$ was identified ($r = 0.75$, $P < 0.01$), with an average PM$_{2.5}$/PM$_{10}$ value of 0.32 (Fig. 2a, a' Table 3).

3.3 Correlation Analyses Between PM$_{10}$, PM$_{2.5}$, COVID-19 Cases and Positive Chest CT Scans

The temporal pattern of monthly PM$_{10}$ and PM$_{2.5}$ versus COVID-19 cases and positive chest CT scans showed that with an increase of PM$_{10}$ and PM$_{2.5}$ concentrations, the rate of COVID-19 cases and positive chest CT scans also increased, especially from October 2020 to March 2021. The highest and lowest monthly average COVID-19 (79.36, 21.4 cases) and positive chest CT scans (31.93, 3.15 cases) were in March 2021 and April 2020 for COVID-19 with PM$_{10}$ and PM$_{2.5}$ respectively (124.45 and 93.15 µg m$^{-3}$) and on June 2020 and January 2021 for positive chest CT scans with
PM$_{10}$ and PM$_{2.5}$ concentrations of 31.93 and 3.15 µg m$^{-3}$, respectively (Fig. S3). The PM$_{10}$ and PM$_{2.5}$ concentrations were correlated with the number of COVID-19 cases: $r = 0.47$ ($P < 0.05$), and $r = 0.41$ ($P < 0.05$), respectively (Fig. 3a–b’, Table 3). Furthermore, the PM$_{10}$ and PM$_{2.5}$ concentrations were both correlated with positive chest CT scans ($r = 0.59$, $P < 0.05$ and $r = 0.56$, $P < 0.05$ respectively).

### 3.4 Temporal Variations of Temperature and Relative Humidity

The relationship between air temperature (°C) and relative humidity (%) are shown in Fig. 4. The highest daily temperature and relative humidity were 51.5 °C and 97%, respectively, on 30 July 2020 and 2 December 2020. The daily times series showed that an increasing temperature led to reduced relative humidity reaching a peak during summer for temperature and winter for relative humidity. Furthermore, the monthly variations showed that July 2020 with a mean air temperature of 47.8 °C and a relative humidity of 27% was the warmest during the time period of this study. The highest monthly average relative humidity 80% was identified in December 2020 with a mean temperature of 20.3 °C (Fig. S4). Multivariate analysis showed that the mean temperature was significantly associated with relative humidity (Table 3). The interaction between air temperature was negatively correlated ($r = −0.81$, $P < 0.01$) with relative humidity (Fig. 4a, a’, Table 3).
3.5 Meteorological Parameters, COVID-19 Incidence and Positive Chest CT Scans

The highest number of declared COVID-19 cases was observed when the daily air temperature and relative humidity ranged between 10.3 and 28.0 °C and between 19 and 40% respectively in February–March 2021. The lowest number of COVID-19 cases was registered when the relative humidity exceeded on average 60% with a mean air temperature of 20–30 °C in Ahvaz. The lowest average number of positive chest CT scans was observed for relative humidity ranged from 65 to 80% with 3.1–4.3 cases on average. The highest positive chest CT scan was obtained in June 2020 and March 2021 for daily air temperature ranging from 38 to 49 °C and 11 to 15 °C, respectively. In these two peaks, relative humidity ranged between 10–25% and 19–30%.
respectively. Higher relative humidity (> 60%) strongly reduced the number of positive chest CT scan (see Fig. S5).

The results of correlation between air temperature and relative humidity with COVID-19 cases and positive chest CT scan of patients admitted to the Petroleum Hospital during March 2020 to March 2021 are shown in Fig. 5a–b’. A negative correlation was found between COVID-19 incidence with air temperature \((r = -0.33, P < 0.05)\) and relative humidity \((r = -0.35, P < 0.05)\). There was no association between air temperature and positive chest CT scans \((r = 0.32, P > 0.05)\) while the relative humidity and positive chest CT scans were negatively correlated \((r = -0.82, P < 0.01)\).

### 3.6 Time Lag Effect

A higher correlation \((r = 0.60)\) was identified between daily PM\(_{10}\) concentrations at day + 10 and the number of COVID-19 cases at day 0 (Table 4), while the highest correlation with positive chest CT scans was observed on day 0 \((r = 0.59)\). For daily PM\(_{2.5}\), the highest correlation with the number of COVID-19 cases was found between lag3 \((r = 0.42)\) and lag0 with positive chest CT scans \((r = 0.56)\).

For air temperature and relative humidity, the highest correlations were found on day 0 (lag0).

### 3.7 Air Quality and the Effect of Lockdown

The mean PM\(_{10}\) and PM\(_{2.5}\) concentrations and the AQI were calculated before, during and after lockdown from 21 February to 21 May 2020 (Fig. 6). Before the lockdown, the mean PM\(_{10}\) and PM\(_{2.5}\) concentrations and the AQI were 114.5 and 40.5 µg m\(^{-3}\) and 168, respectively. The reduction during the lockdown period (established from 22 March to 21 April 2020) was 29.6%, 36.9% and 33.3%, respectively. From 22 April 2020 to 21 May 2020, the AQI in Ahvaz increased by 66.1%; this was similar to the PM\(_{10}\) (+ 63.6%) and PM\(_{2.5}\) (+ 61.3%) concentrations.

A comparison of PM\(_{10}\) and PM\(_{2.5}\) mean concentrations between the pre-COVID-19 pandemic from 2015 to 2019 was carried out between 2020 and 2021 (Table 5). During the COVID-19 period, the annual PM\(_{10}\) and PM\(_{2.5}\) mean concentrations were reduced by 27.3% and 17.8%, respectively, when compared to the 5-years time period.

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**Fig. 5** Correlation between average a air temperature and a’ relative humidity with new cases of COVID-19 admitted to the Petroleum Hospital, and b, b’ positive chest CT scan in Ahvaz between March 2020 and March 2021
In the Middle Eastern regions, the annual PM\textsubscript{10} and PM\textsubscript{2.5} mean concentrations typically ranged from 72 to 303 and 11 to 35 µg m\textsuperscript{-3}, respectively [34]. Over the 2015–2019 period, the annual PM\textsubscript{10} mean concentrations ranged from 155.8 to 178.3 µg m\textsuperscript{-3} while the PM\textsubscript{2.5} mean concentrations ranged from 43.5 to 50.7 µg m\textsuperscript{-3}. In 2020–2021, during the COVID-19 pandemic, the annual PM\textsubscript{10} and PM\textsubscript{2.5} mean concentrations were 119.6 and 38.2 µg m\textsuperscript{-3}, respectively. The poor and continuous deterioration in air quality in Ahvaz is due to the presence of several industries inside and around the city and dust storms from Arabian countries [4, 20, 41, 73]. The PM\textsubscript{2.5}/PM\textsubscript{10} ratio in the Middle East is due to the high levels of PM during dust storms and ranges from 0.21 to 0.59 [42]. Our analysis revealed a PM\textsubscript{2.5}/PM\textsubscript{10} of 0.32 in Ahvaz from March 2020

### Table 4

Correlation coefficient (Spearman’s test) between daily PM\textsubscript{10} and PM\textsubscript{2.5} mean concentrations, air temperature, and relative humidity with positive chest CT scan and COVID-19 cases at different time lags (0–13 days)

|               | PM\textsubscript{10} vs COVID | PM\textsubscript{10} vs CT scan | PM\textsubscript{2.5} vs COVID | PM\textsubscript{2.5} vs CT scan | T vs COVID | T vs CT scan | RH vs COVID | RH vs CT scan |
|---------------|-------------------------------|---------------------------------|-------------------------------|---------------------------------|------------|-------------|-------------|---------------|
| lag0          | 0.47                          | 0.59                            | 0.41                          | 0.56                            | −0.33      | 0.32        | −0.35       | −0.82         |
| lag1          | 0.35                          | 0.55                            | 0.30                          | 0.52                            | −0.24      | 0.30        | −0.23       | −0.63         |
| lag2          | 0.50                          | ns                              | 0.40                          | ns                              | −0.26      | 0.28        | −0.22       | −0.63         |
| lag3          | 0.55                          | ns                              | 0.40                          | ns                              | −0.24      | 0.28        | −0.20       | −0.62         |
| lag4          | 0.43                          | ns                              | 0.40                          | ns                              | −0.22      | 0.29        | −0.22       | −0.63         |
| lag5          | 0.47                          | ns                              | 0.24                          | ns                              | −0.22      | 0.28        | −0.21       | −0.61         |
| lag6          | ns                            | ns                              | ns                            | ns                              | −0.21      | 0.27        | −0.23       | −0.61         |
| lag7          | ns                            | ns                              | ns                            | ns                              | −0.23      | 0.27        | −0.27       | −0.60         |
| lag8          | ns                            | ns                              | ns                            | ns                              | −0.22      | 0.28        | −0.21       | −0.58         |
| lag9          | ns                            | ns                              | ns                            | ns                              | −0.23      | 0.27        | −0.21       | −0.60         |
| lag10         | 0.60                          | ns                              | ns                            | ns                              | −0.22      | 0.28        | ns          | −0.60         |
| lag11         | 0.47                          | ns                              | ns                            | ns                              | 0.28       | ns          | −0.59       |               |
| lag12         | 0.55                          | ns                              | ns                            | ns                              | 0.26       | −0.20       | −0.58       |               |
| lag13         | ns                            | ns                              | ns                            | ns                              | 0.26       | −0.22       | −0.55       |               |

The strongest correlations are shown in bold (ns not significant, $P > 0.1$)

![Fig. 6](image-url) Mean PM\textsubscript{10} and PM\textsubscript{2.5} concentrations and air quality index (AQI) before (21 February to 21 March 2020), during (22 March to 21 April 2020) and after lockdown (22 April to 21 May 2020) in Ahvaz, Iran

**4 Discussion**

In the Middle Eastern regions, the annual PM\textsubscript{10} and PM\textsubscript{2.5} mean concentrations typically ranged from 72 to 303 and 11 to 35 µg m\textsuperscript{-3}, respectively [34]. Over the 2015–2019 period, the annual PM\textsubscript{10} mean concentrations ranged from 155.8 to 178.3 µg m\textsuperscript{-3} while the PM\textsubscript{2.5} mean concentrations ranged from 43.5 to 50.7 µg m\textsuperscript{-3}. In 2020–2021, during the COVID-19 pandemic, the annual PM\textsubscript{10} and PM\textsubscript{2.5} mean concentrations were 119.6 and 38.2 µg m\textsuperscript{-3}, respectively. The poor and continuous deterioration in air quality in Ahvaz is due to the presence of several industries inside and around the city and dust storms from Arabian countries [4, 20, 41, 73]. The PM\textsubscript{2.5}/PM\textsubscript{10} ratio in the Middle East is due to the high levels of PM during dust storms and ranges from 0.21 to 0.59 [42]. Our analysis revealed a PM\textsubscript{2.5}/PM\textsubscript{10} of 0.32 in Ahvaz from March 2020.
Epidemiological studies have confirmed the association of PM with respiratory diseases and found that fine PM could potentiate viral transmissions [48, 73, 78]. Furthermore, viral replication in the respiratory system is enhanced by the negative effects of PM on the integrity of the human respiratory barrier [48]. The influenza and respiratory syncytial viruses remain in the air for a long period after becoming attached to PM, this allows viruses to be transmitted by the airborne route [51]. In this study, both the PM$_{10}$ and PM$_{2.5}$ concentrations were positively correlated with the incidence of COVID-19 (chest CT scans and PCR tests). The incidence of COVID-19 increased with rising PM$_{10}$ and PM$_{2.5}$ concentrations [82] and a high frequency of PM$_{10}$ concentration peaks (exceeding 50 µg m$^{-3}$) resulted in an accelerated spread of COVID-19, thus suggesting a “boost effect” with regards to viral infectivity [71]. The increase in outdoor air PM$_{10}$ and PM$_{2.5}$ concentrations was positively associated with an increased risk of COVID-19 transmission [9]. Reference [48] reported a significant correlation between PM$_{10}$ ($r^2=0.15$), PM$_{2.5}$ ($r^2=0.23$) and the incidence of COVID-19 between the 26th of January and the 29th of February 2020 in Wuhan and XiaoGan (China).

A 1 µg m$^{-3}$ increase in long-term PM$_{2.5}$ exposure is related to a 15% increase in the risk of death by COVID-19 [79]. Reference [81] reported a positive association between the incidence of COVID-19 and both PM$_{2.5}$ ($r=0.48$) and PM$_{10}$ ($r=0.49$) concentrations in Wuhan (China). Following an increase of 10 µg m$^{-3}$ in PM$_{10}$ and PM$_{2.5}$, the mortality rate of COVID-19 increased by 0.83% and 0.86%, respectively [81]. Similarly, in Europe, positive relationships were found between PM$_{10}$, PM$_{2.5}$, and the fatality rate of COVID-19 [26]. Other studies have reported that short-term PM$_{2.5}$ exposure is positively correlated to the risk of respiratory infection by COVID-19 among people in Canada and New York [3, 76]. In the present study, higher correlations were found between PM$_{10}$, PM$_{2.5}$, and chest CT scans compared to PCR tests. In China, only 3% of admitted patients had negative PCR tests while having positive chest CT scans [80]. However, PCR tests are easy to perform and provide fast results, thus enabling the rapid diagnosis of COVID-19 [1].

The mean temperature and air quality were previously shown to be significantly associated with the COVID-19 pandemic in New-York [10]. Air temperature and relative humidity are the most important meteorological parameters affecting COVID-19 mortality and the air temperature is known to be correlated to the spread of COVID-19 [16, 54, 63]. In this study, we also found that high daily air temperature (30–51 °C) and high relative humidity (60–97%) led to a significant reduction in the daily incidence of COVID-19. High air temperature and relative humidity appear to have an inhibitory effect on COVID-19 transmission. The virus was transmitted more efficiently in Ahvaz at a daily air temperature of 10–28 °C with a relative humidity of 19–40%. In Milan (Italy), [82] showed there was a negative association between daily air temperature and relative humidity with the number of new cases of COVID-19. In Wuhan, the daily temperature ($r^2=0.14$) was inversely correlated to the incidence of COVID-19 [48]. Reference [8] reported that cities with a mean air temperature lower than 24 °C were all at high-risk of COVID-19 transmission while [13] showed that the most suitable air temperature for the spread of coronavirus was 13–24 °C with a relative humidity of 50%. Our findings are in line with this previous research.

Lockdown due to the COVID-19 pandemic reduced industrial activities, transport and energy consumption [38].

### Table 5: Annual PM$_{10}$ and PM$_{2.5}$ mean concentrations during the pre-pandemic period (2015–2019) and during the COVID-19 period (2020–2021) in Ahvaz

| Years    | PM$_{10}$ (µg m$^{-3}$) | PM$_{2.5}$ (µg m$^{-3}$) |
|----------|-------------------------|--------------------------|
| 2015     | 167.2 ± 13.0            | 49.1 ± 48.5              |
| 2016     | 178.3 ± 21.2            | 50.7 ± 68.6              |
| 2017     | 159.2 ± 27.4            | 44.3 ± 33.2              |
| 2018     | 161.0 ± 96.1            | 44.8 ± 57.1              |
| 2019     | 155.8 ± 56.0            | 43.5 ± 12.8              |
| 2015–2019| 164.5 ± 80.9            | 46.5 ± 44.0              |
| 2020–2021| 119.6 ± 24.0            | 38.2 ± 37.1              |

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to March 2021. Depending on the fraction of coarse dust in the air, this ratio may undergo change [29, 42]. This low value is typical of regions dominated by geological dust in contrast to rural areas where combustion processes involving coal or wood burning show predominance [30].

Approximately 61.7% of deaths by COVID-19 occurred in subjects over 65 years of age in Petroleum Hospital and only 2.4% of deaths occurred in younger subjects (those < 30 years of age). Reference [61] showed that 80% of deaths by COVID-19 occurred in adults over 65 years of age in the United States and concluded that most deaths were found in the 60–69-year age group in five European countries (Italy, Spain, France, Germany and the Netherlands). In Italy, the fatality rates ranged from less than 3% in subjects < 60 years of age to more than 30% in people > 80 years of age [74]. The large differences in fatality rates by age are associated to higher rates of chronic comorbidities in older populations [74, 75]. Our study confirms previous results [17] which reported that males were more at risk of COVID-19. Preliminary studies were performed to assess the effects of air pollution (e.g., PM$_{10}$, PM$_{2.5}$) and meteorological parameters (e.g., air temperature, relative humidity) on the spread of COVID-19 [48, 82]. We are still far from fully understanding COVID-19 epidemiology, so conducting different studies could help enhance our understanding of this disease.

Epidemiological studies have confirmed the association of PM with respiratory diseases and found that fine PM could potentiate viral transmissions [48, 73, 78]. Furthermore, viral replication in the respiratory system is enhanced by the negative effects of PM on the integrity of the human respiratory barrier [48]. The influenza and respiratory syncytial viruses remain in the air for a long period after becoming attached to PM, this allows viruses to be transmitted by the airborne route [51]. In this study, both the PM$_{10}$ and PM$_{2.5}$ concentrations were positively correlated with the incidence of COVID-19 (chest CT scans and PCR tests). The incidence of COVID-19 increased with rising PM$_{10}$ and PM$_{2.5}$ concentrations [82] and a high frequency of PM$_{10}$ concentration peaks (exceeding 50 µg m$^{-3}$) resulted in an accelerated spread of COVID-19, thus suggesting a “boost effect” with regards to viral infectivity [71]. The increase in outdoor air PM$_{10}$ and PM$_{2.5}$ concentrations was positively associated with an increased risk of COVID-19 transmission [9]. Reference [48] reported a significant correlation between PM$_{10}$ ($r^2=0.15$), PM$_{2.5}$ ($r^2=0.23$) and the incidence of COVID-19 between the 26th of January and the 29th of February 2020 in Wuhan and XiaoGan (China).

A 1 µg m$^{-3}$ increase in long-term PM$_{2.5}$ exposure is related to a 15% increase in the risk of death by COVID-19 [79]. Reference [81] reported a positive association between the incidence of COVID-19 and both PM$_{2.5}$ ($r=0.48$) and PM$_{10}$ ($r=0.49$) concentrations in Wuhan (China). Following an increase of 10 µg m$^{-3}$ in PM$_{10}$ and PM$_{2.5}$, the mortality rate of COVID-19 increased by 0.83% and 0.86%, respectively [81]. Similarly, in Europe, positive relationships were found between PM$_{10}$, PM$_{2.5}$, and the fatality rate of COVID-19 [26]. Other studies have reported that short-term PM$_{2.5}$ exposure is positively correlated to the risk of respiratory infection by COVID-19 among people in Canada and New York [3, 76]. In the present study, higher correlations were found between PM$_{10}$, PM$_{2.5}$, and chest CT scans compared to PCR tests. In China, only 3% of admitted patients had negative PCR tests while having positive chest CT scans [80]. However, PCR tests are easy to perform and provide fast results, thus enabling the rapid diagnosis of COVID-19 [1].

The mean temperature and air quality were previously shown to be significantly associated with the COVID-19 pandemic in New-York [10]. Air temperature and relative humidity are the most important meteorological parameters affecting COVID-19 mortality and the air temperature is known to be correlated to the spread of COVID-19 [16, 54, 63]. In this study, we also found that high daily air temperature (30–51 °C) and high relative humidity (60–97%) led to a significant reduction in the daily incidence of COVID-19. High air temperature and relative humidity appear to have an inhibitory effect on COVID-19 transmission. The virus was transmitted more efficiently in Ahvaz at a daily air temperature of 10–28 °C with a relative humidity of 19–40%. In Milan (Italy), [82] showed there was a negative association between daily air temperature and relative humidity with the number of new cases of COVID-19. In Wuhan, the daily temperature ($r^2=0.14$) was inversely correlated to the incidence of COVID-19 [48]. Reference [8] reported that cities with a mean air temperature lower than 24 °C were all at high-risk of COVID-19 transmission while [13] showed that the most suitable air temperature for the spread of coronavirus was 13–24 °C with a relative humidity of 50%. Our findings are in line with this previous research.

Lockdown due to the COVID-19 pandemic reduced industrial activities, transport and energy consumption [38].
| Study location | Methodology | Variation % | Main point | References |
|----------------|-------------|-------------|------------|------------|
| **PM$_{10}$** | **PM$_{2.5}$** | | | |
| Delhi | Three stations in Delhi were selected at three periods from 1 January to 24 March | $-63.5$ | $-69.4$ | Due to decrease in human activities and social distances, the PM$_{10}$ and PM$_{2.5}$ concentrations were decreased | [31] |
| Salé city | PM$_{10}$ before (11–20 March) and during (21 March 21 to 2 April) lockdown was measured | $-75$ | | The emissions rate from vehicle exhaust and industrial activities were significantly reduced in this time, which contribute to the decrease in the concentrations of particles | [62] |
| Valencia | The percentage change at lockdown and same time over 2017–2019 was assessed | $-13$ | $-32$ | PM$_{10}$ and PM$_{2.5}$ were decreased at Valencia during COVID-19 lockdown due to reduction in traffic and fuel combustion | [72] |
| Guangdong | Data from 101 air quality monitoring sites were collected for comparison among before and during lockdown | $-51.5$ | $-37.8$ | All considerable data PM$_{10}$, PM$_{2.5}$, O$_3$, and NO$_2$ were reduced by change in human-made impacts. After lockdown the NO$_2$ concentration was remarkably increased | [49] |
| Kolkata | Two years data 2019 and 2020 were obtained from State Pollution Control Board, as well as trajectory analysis was done by HYSPLIT | $-36.7$ | $-43.7$ | In comparison with 2019, the PM$_{10}$ and PM$_{2.5}$ were declined. It is clear lockdown plays a significant role to reduce particles concentration | [12] |
| Bengaluru | Monthly air pollution concentration in March, April, and May 2020 were compared with that of 2019 to clarify the effect of restricted emissions | $-40.2$ | $-33.9$ | Due to restriction on anthropogenic activity, emission sources were declined, thus the PM concentration was reduced at Bengaluru | [46] |
| Hanoi | The data of pre-lockdown (10–31 March) and lockdown (1–22 April) were analyzed to the assess of variation in pollutants concentrations | $-55$ | | Results showed that a drastic negative relationship was observable between the boundary layer height and the daily mean PM$_{2.5}$ from industrial activities | [60] |
| Seoul | A comparison between data 2020 with three years ago | $-25.4$ | $-36$ | The comparison with the previous three years showed a drop in PM. The rapid decline in the traffic (30% to 70%) led to an improvement in air quality | [70] |
In Ahvaz, males over 65 years of age were at high risk of COVID-19. In this study, several parameters were analyzed to provide additional evidence relating to the relationship between particle pollution (PM$_{10}$ and PM$_{2.5}$), meteorological parameters (air temperature and relative humidity) and COVID-19 incidence between May 2020 and May 2021 in Ahvaz (Iran). Significant correlations between daily PM$_{10}$ and PM$_{2.5}$ concentrations were identified. We found a positive relationship between PM$_{10}$ and PM$_{2.5}$ with COVID-19 incidence and positive chest CT scans, thus yielding further evidence that air pollution provides a favorable context for the spread of the SARS-CoV-2 virus [19, 82]. The interaction between daily air temperature was negatively correlated with relative humidity. In Ahvaz, an air temperature between 10 and 28 °C and a relative humidity between 19 and 40% were found to be most suitable for the spread of coronavirus. However, a high daily air temperature (> 30 °C) and relative humidity (> 60%) significantly reduced the incidence of COVID-19. Air quality was notably improved during the COVID-19 lockdown; this led to a large reduction in PM$_{10}$, PM$_{2.5}$ and AQI when compared to mean concentrations over the previous 5 years (2015-2019).

### 5 Conclusion

In Ahvaz, males over 65 years of age were at high risk of COVID-19. In this study, several parameters were analyzed to provide additional evidence relating to the relationship between particle pollution (PM$_{10}$ and PM$_{2.5}$), meteorological parameters (air temperature and relative humidity) and COVID-19 incidence between May 2020 and May 2021 in Ahvaz (Iran). Significant correlations between daily PM$_{10}$ and PM$_{2.5}$ concentrations were identified. We found a positive relationship between PM$_{10}$ and PM$_{2.5}$ with COVID-19 incidence and positive chest CT scans, thus yielding further evidence that air pollution provides a favorable context for the spread of the SARS-CoV-2 virus [19, 82]. The interaction between daily air temperature was negatively correlated with relative humidity. In Ahvaz, an air temperature between 10 and 28 °C and a relative humidity between 19 and 40% were found to be most suitable for the spread of coronavirus. However, a high daily air temperature (> 30 °C) and relative humidity (> 60%) significantly reduced the incidence of COVID-19. Air quality was notably improved during the COVID-19 lockdown; this led to a large reduction in PM$_{10}$, PM$_{2.5}$ and AQI when compared to mean concentrations over the previous 5 years (2015-2019).

### Supplementary Information

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### Author Contributions

YOK and PS conducted the experiments, analyzed the data, created the figures and tables, and drafted the manuscript. Reviewing and editing, and project administration was conducted by BD, HM1 and SS. MHF gathered data and reviewed the manuscript. Reviewing, editing and validation was the responsibility of SSM and HM2. MODIS and HYSPLIT providing was by last author HM3 and PMB. All authors read and approved the final manuscript.

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### Data Availability Statement

Not applicable.

### Declarations

#### Conflict of Interest

The authors have no conflicts of interest to report.

#### Ethical Approval

The current study was approved by the ethical committee of the Research and Education Center of Ahvaz Petroleum Hospital.

#### Consent for Publication

Not applicable.

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References

1. Abbasi-Oshaghi E, Mirzaei F, Farahani F, Khodadadi I, Tayebinia H. Diagnosis and treatment of coronavirus disease 2019 (COVID-19): laboratory, PCR, and chest CT imaging findings. Int J Surg. 2020;79:143–53.
2. Achebak H, Petetin H, Quijal-Zamorano M, Bowdalo D, Garcia-Pando CP, Ballester J. Trade-offs between short-term mortality attributable to NO$_2$ and O$_3$ changes during the COVID-19 lockdown across major Spanish cities. Environ Pollut. 2021;286:117220.
3. Adhikari A, Yin J. Short-term effects of ambient ozone, PM$_2.5$, and meteorological factors on COVID-19 confirmed cases and deaths in Queens, New York. Int J Environ Res Public Health. 2020;17:4047.
4. Amoatey P, Khaniabadi YO, Sicard P, Siddiqi SA, De Marco A, Sulaiman H. Temporal incidence and prevalence of bronchitis and morbidities from exposure to ambient PM$_2.5$ and PM$_10$. Environ Justice. 2021;14:267–76.
5. Amoatey P, Sicard P, De Marco A, Khaniabadi YO. Long-term exposure to ambient PM$_2.5$ and impacts on health in Rome, Italy. Clin Epidemiol Global Health. 2020;8:511–5.
6. Amoatey P, Takkastan A, Sicard P, Hopke PK, Baawain M, Omidvarborna H, Allabayri S, Esmaielzadeh A, De Marco A, Khaniabadi YO. Short and long-term impacts of ambient ozone on health in Ahvaz, Iran. Hum Ecol Risk Assess. 2019;25:1336–51.
7. Anbari K, Siccardi P, Comiti GO, Ferrante M. The role of air pollution (PM and NO$_2$) in COVID-19 spread and lethality: a systematic review. Environ Res. 2020;191:110129.
8. Anis A. The effect of temperature upon transmission of COVID-19 (2019-nCoV) infection in 2020. MedRiv. 2020. https://doi.org/10.1101/2020.02.12.20022715.
9. Baboli Z, Neisi N, Babaei AA, Ahmadi M, Sorooshian A, Birgani YT. Goudarzi G. On the airborne transmission of SARS-CoV-2 and relationship with indoor conditions at a hospital. Atmos Environ. 2021;261:118563.
10. Bashir MF, Ma B, Komal B, Bashir MA, Tan D, Bashir M. Correlation between climate indicators and COVID-19 pandemic in New York, USA. Sci Total Environ. 2020;728:138835.
11. Benchirf A, Wehida A, Tahri M, Shubbar RM, Biswas B. Air quality during three covid-19 lockdown phases: AQI, PM$_2.5$ and NO$_2$ assessment in cities with more than 1 million inhabitants. Sustain Cities Soc. 2021;74:103170.
12. Bera B, Bhattacharjee S, Sengupta N, Saha S. Variation and dispersal of PM$_10$ and PM$_2.5$ during COVID-19 lockdown over Kolkata metropolitan city, India investigated through HYSPLIT model. Geosci Front. 2022;13:101291.
13. Bu J, Peng D-D, Xiao H, Yue Q, Han Y, Lin Y, Hu G, Chen J. Analysis of meteorological conditions and prediction of epidemic trend of 2019-nCoV infection in 2020. MedRxiv. 2020. https://doi.org/10.1101/2020.02.12.20022715.
14. Cai Q-C, Lu J, Xu Q-F, Guo Q, Xu D-Z, Sun Q-W, Yang H, Zhao G-M, Jiang Q-W. Influence of meteorological factors and air pollution on the outbreak of severe acute respiratory syndrome. Public Health. 2007;121:258–65.
15. CDC COVID-19 Response Team. Preliminary estimates of the prevalence of selected underlying health conditions among patients with coronavirus disease 2019—United States, February 12–March 28, 2020. Morb Mortal Wkly Rep. 2020;69:382–6.
16. Chen N, Zhou M, Dong X, Qu J, Gong F, Han Y, Qiu Y, Wang J, Liu Y, Wei Y. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. The Lancet. 2020;395:507–13.
17. Copat C, Cristaldi A, Fiore M, Grasso A, Zuccarelli P, Santo Signorelli S, Conti GO. Assessing the effect of COVID-19 pandemic on air quality in Italy and relationship with indoor conditions at a hospital. Atmos Environ Justice. 2021;14:267–76.
18. Czwojdzińska M, Terpińska M, Kuźniarski A, Płaczkowska S, Piwowar A. Exposure to PM$_2.5$ and PM$_10$ and COVID-19 infection rates and mortality: a one-year observational study in Poland. Biomed J. 2021;44:S25–36.
19. Daryanoosh M, Goudarzi G, Rashidi R, Keishams F, Hopke PK, Mohammadi MJ, Nourmoradi H, Sicard P, Takkastan A, Vosoughi M. Risk of morbidity attributed to ambient PM$_10$ in the western cities of Iran. Toxin Rev. 2018;37:313–8.
20. Dastoorpoor M, Goudarzi G, Khanjani N, Idani E, Aghababaeian H, Bahrampour A. Lag time structure of cardiovascular deaths attributed to ambient air pollutants in Ahvaz, Iran. 2008–2015. Int J Occup Med Environ Health. 2018;31:459–73.
21. De Marco A, Amoatey P, Khaniabadi YO, Sicard P, Hopke PK. Mortality and morbidity for cardiopulmonary diseases attributed to PM$_2.5$ exposure in the metropolis of Rome, Italy. Eur J Intern Med. 2018;57:49–57.
22. De Marco A, Garcia-Gomez H, Collalti A, Khaniabadi YO, Feng Z, Proietti C, Sicard P, Vitale M, Anav A, Paolotti E. Ozone modelling and mapping for risk assessment: an overview of different approaches for human and ecosystems health. Environ Res. 2022;211:113048.
23. De Marco A, Sicard P, Feng Z, Agathokleous E, Alonso R, Araminiene V, Augustaitis A, Badea O, Beasley JC, Branquinho C. Strategic roadmap to assess forest vulnerability under air pollution and climate change. Glob Change Biol. 2022;28:5062–85.
24. De Marco A, Sicard P, Feng Z, Agathokleous E, Alonso R, Araminiene V, Augustaitis A, Badea O, Beasley JC, Branquinho C. Strategic roadmap to assess forest vulnerability under air pollution and climate change. Glob Change Biol. 2022;28:5062–85.
25. Dettori M, Deiana G, Balleto G, Borruso G, Muragante B, Arghitru A, Azara A, Castiglia P. Air pollutants and risk of death due to COVID-19 in Italy. Environ Res. 2021;192:110459.
26. Domingo JL, Marqués M, Rovira J. Influence of airborne transmission of SARS-CoV-2 on COVID-19 pandemic. A review. Environ Res. 2020;188:109861.
27. Domingo JL, Rovira J. Effects of air pollutants on the transmission and severity of respiratory viral infections. Environ Res. 2020;188:109650.
28. Engelbrecht JP, McDonald EV, Gillies JA, Jayanty R, Casuccio A, Sulaiman Al Habib Medical Journal (2022) 4:182–195
during COVID-19 lockdown phases in Delhi, India. Mapan. 2022. https://doi.org/10.1007/s12647-021-00506-5.
32. Gilani S, Roditi R, Naraghi M. COVID-19 and anosmia in Tehran, Iran. Med Hypotheses. 2020;141:109757.
33. Goudarzi G, Hopke PK, Yazdani M. Forecasting PM2.5 concentration using artificial neural network and its health effects in Ahvaz, Iran. Chemosphere. 2021;283:131285.
34. Goudarzi G, Hopke PK, Yazdani M. The impact of lockdown on air quality over major cities across the globe during COVID-19 pandemic. Urban Clim. 2020;34:100719.
35. Goudarzi G, Hopke PK, Yazdani M. Air quality modeling for health risk assessment of ambient PM10, PM2.5 and  SO2 in Iran. Hum Ecol Risk Assess Int J. 2021;19(5):1298–310.
36. Goudarzi G, Hopke PK, Yazdani M. Concentrations and health effects of short-and-long-term exposure to PM2.5, NO2, and O3 in ambient air of Ahvaz city, Iran (2014–2017). Ecotoxicol Environ Saf. 2019;180:542–8.
37. Goudarzi G, Hopke PK, Yazdani M. A 10-year assessment of ambient fine particles and related health endpoints in a large Mediterranean city. Chemosphere. 2021:278:130502.
38. Goudarzi G, Hopke PK, Yazdani M. Concentrations and health effects of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
39. Goudarzi G, Hopke PK, Yazdani M. Concentrations and health effects of air pollutants and associated health outcomes in two polluted cities of the Middle East. J Environ Health Sci Eng. 2022. https://doi.org/10.1007/s00477-022-02286-z.
40. Goudarzi G, Hopke PK, Yazdani M. Impact of Covid-19 lockdown on PM2.5,  SO2,  NO2, O3, and trace elements in PM2.5 in Hanoi. Vietnam Environ Sci Pollut Res. 2022;29:41875–85.
41. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
42. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
43. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
44. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
45. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
46. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
47. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
48. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
49. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
50. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
51. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
52. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
53. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
54. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
55. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
56. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
57. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
58. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
59. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
60. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
61. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
62. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
63. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
64. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
65. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
66. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
67. Goudarzi G, Hopke PK, Yazdani M. Concentration of air pollutants as toxic matter in urban and rural areas of Ahvaz. Toxin Rev. 2018;37:243–50.
from air pollution in the United States. Res Rep Health Eff Inst. 2000;94:5–79.

68. Sayadi M, Moghbeli F, Mehrjoo H, Mahaki M. A Linear Study of the Spread of COVID-19 in China and Iran. Front Health Inform. 2020:9:32.

69. Schwartz J. The distributed lag between air pollution and daily deaths. Epidemiology. 2000;11:320–6.

70. Seo JH, Jeon HW, Sung UJ, Sohn J-R. Impact of the COVID-19 outbreak on air quality in Korea. Atmosphere. 2020;11:1137.

71. Setti L, Passarini F, De Gennaro G, Barbieri P, Perrone MG, Piaz- zalunga A, Borelli M, Palmisani J, Di Gilio A, Piscitelli P. The potential role of particulate matter in the spreading of COVID-19 in Northern Italy: first evidence-based research hypotheses. MedRxiv. 2020:368(3): m1165368.

72. Sicard P, De Marco A, Agathokleous E, Feng Z, Xu X, Paolelli E, Rodriguez JJD, Calatayud V. Amplified ozone pollution in cities during the COVID-19 lockdown. Sci Total Environ. 2020;735:139542.

73. Sicard P, Khaniabadi YO, Perez S, Gualtieri M, De Marco A. Effect of O3, PM 10 and PM 2.5 on cardiovascular and respiratory diseases in cities of France, Iran and Italy. Environ Sci Pollut Res. 2019;26:32645–65.

74. Signorelli C, Odone A. Age-specific COVID-19 case-fatality rate: no evidence of changes over time. Int J Public Health. 2020:65:1435–6.

75. Signorelli C, Odone A, Gianfredi V, Bossi E, Bucci D, Oradini-Alacreu A, Frascella B, Capraro M, Chiappa F, Blandi L. COVID-19 mortality rate in nine high-income metropolitan regions. Acta Bio Medica: Atenei Parmensis. 2020:91:7.

76. Stieb DM, Evans GJ, To TM, Brook JR, Burnett RT. An ecological analysis of long-term exposure to PM2.5 and incidence of COVID-19 in Canadian health regions. Environ Res. 2020;191:110052.

77. WorldHealthOrganization. Director-General’s opening remarks at the media briefing on COVID-19 – 11 March. 2020. https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020.

78. Wu J-Z, Ge D-D, Zhou L-F, Hou L-Y, Zhou Y, Li Q-Y. Effects of particulate matter on allergic respiratory diseases. Chronic Dis Transl Med. 2018;4:95–102.

79. Wu Y, Jing W, Liu J, Ma Q, Yuan J, Wang Y, Du M, Liu M. Effects of temperature and humidity on the daily new cases and new deaths of COVID-19 in 166 countries. Sci Total Environ. 2020;729:139051.

80. Xie X, Zhong Z, Zhao W, Zheng C, Wang F, Liu J. Chest CT for typical 2019-nCoV pneumonia: relationship to negative RT-PCR testing. Radiology. 2021;52:200343.

81. Yao Y, Pan J, Liu Z, Meng X, Wang W, Kan H, Wang W. Temporal association between particulate matter pollution and case fatality rate of COVID-19 in Wuhan. Environ Res. 2020;189:109941.

82. Zoran MA, Savastru RS, Savastru DM, Tautan MN. Assessing the relationship between surface levels of PM2.5 and PM10 particulate matter impact on COVID-19 in Milan, Italy. Sci Total Environ. 2020;738:139825.

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