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A survey on the correlation between PM$_{2.5}$ concentration and the incidence of suspected and positive cases of COVID-19 referred to medical centers: A case study of Tehran

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HIGHLIGHTS

- There was a significant correlation between PM$_{2.5}$ and suspected and positive cases.
- The average daily incidence of suspected cases was reported in the moderate level.
- The average daily incidence of positive cases was reported in the unhealthy level.
- Autumn had significant effects on the incidence of suspected and positive cases.

ABSTRACT

COVID-19, one of the greatest health challenges of the present century, has infected millions of people and caused more than 6 million deaths worldwide. The causative agent of this disease is the new virus SARS-CoV-2, which continues to spread globally and sometimes with new and more complex aspects than before. The present study is an observational study aimed to investigate the role of AQI; PM$_{2.5}$ and its relationship with the incidence of suspected cases (SC) and positive cases (PC) of COVID-19 at different levels of the air quality index (AQI) in Tehran, the capital of Iran in the period from Feb 20th, 2020 to Feb 22nd, 2021. Data on AQI were collected online from the air monitoring website of Air Quality Control Company under the supervision of Tehran Municipality. The data on suspected and positive cases were obtained from the Iranian Ministry of Health. The results and statistical analysis (Pearson correlation test) showed that with the increase of AQI level, the number of suspected cases (SC) and positive cases (PC), also increased ($P$-value $<$ 0.01). The average daily number of suspected and positive COVID-19 cases referred to medical centers, at different levels of the AQI was as follows: level II: yellow, moderate (SC: $N_{\text{ave}} = 466$; PC: $N_{\text{ave}} = 223$), level III: orange, unhealthy for sensitive groups (SC:...
1. Introduction

Nowadays, COVID-19 disease, as one of the most important viral pandemics as well as a serious threat to human health, has become one of the main challenges in the World Health Organization. Historically, epidemics, war, natural disasters, and other health care emergencies, have had adverse effects on physical and mental health in human societies (Brooks et al., 2020; Moloney et al., 2020; Morganstein et al., 2017). In the early days of the pandemic, due to the lack of specific drugs or vaccines, the primary focus was on symptomatic treatment and respiratory support for patients. Presently, with the availability of a range of vaccines, the rate of transmission and mortality has decreased in some countries. Although the World Health Organization (WHO) emphasizes the continuation of the vaccination process; the observance of the preventive protocols published by this organization until the complete cessation of transmission and reduction of pathogenicity of the virus is also emphasized. One of the main problems in taking appropriate preventive and curative measures in the face of COVID-19 disease is due to the newness of this disease so that the behaviors of this virus are not completely understood and it is progressing rapidly (Junior et al., 2020; Pequeno et al., 2020; Pettrilli et al., 2020; Yang et al., 2020). Recently, mutated species of the virus, such as the Delta, have been spreading with six times the transmission rate of the early coronavirus species (Kupferschmidt and Wadman, 2021). The presented reports show that the sum of various factors, including environmental, demographic, economic, and social factors, can play an important role in the spread of the virus (Poole, 2020; Ribeiro et al., 2020; Wang et al., 2020). At the beginning of the epidemic, most of the numerous studies conducted in different countries have focused more on describing the characteristics of COVID-19, the clinical signs and symptoms, and even the impact of different therapies (Cevik et al., 2020; Pettrilli et al., 2020; Rojo et al., 2020). Over time, more research has been done on the impact of environmental factors on coronavirus transmission (Chakrabarty et al., 2021; Du et al., 2021a; Rodríguez-Urrego and Rodríguez-Urrego, 2020; Zoran et al., 2020a). Air pollution is considered a very important risk factor due to its consequences such as increasing hospitalization in medical centers due to respiratory disease exacerbation, chronic obstructive pulmonary disease (COPD), asthma exacerbation, cardiovascular failure, and ultimately increasing mortality (Ballester and Nigüe, 2011; Brunekreef and Holgate, 2002). To determine the type of pollutant and its effect on human health, there is an indicator called the air quality index (AQI). The AQI is used to monitor short-term air quality in terms of pollution following environmental air quality standards. This index includes six pollutants such as sulfur dioxide (SO₂), nitrogen dioxide (NO₂), carbon monoxide (CO), ozone (O₃), fine particulate matter (PM₂.₅), and coarse particulate matter (PM₁₀) (Yin et al., 2019). Particulate matter (PM) including PM₁₀, PM₂.₅, and ultra-fine particulate matter (UFPM), as a combination of solid particles and liquid droplets suspended in the air, is considered to be one of the most important and influential pollutants on human health (Block and Calderón-Garciduenas, 2009). Guo et al. claimed that in 2015 India, more than one million people died due to air pollution caused by the release of particulate matter (Guo et al., 2017; Sharma et al., 2020). Since aerosols and especially particulate matter, as carriers of pathogens, can transmit diseases to others, especially in crowded places with inadequate ventilation (Akmetzhanov et al., 2020; Linton et al., 2020), the hypothesis that the particulate carries the virus in the air pollution conditions can be investigated. Our study aimed to evaluate the possible effect of increasing the AQI; PM₂.₅ on the incidence of suspected and positive cases of COVID-19 in Tehran province, Iran.

2. Materials and method

2.1. Study area

According to the data obtained from Tehran Air Quality Control Company, almost all year round, PM₂.₅ has been reported as an indicator pollutant. Therefore, in this study, the AQI in terms of PM₂.₅ has been investigated. The present study was conducted in the form of an observational study in Tehran province, Iran. This city is considered as one of the most polluted cities in the world in the emission of pollutants, including particulate matter (PM₂.₅) (Delavar et al., 2019). Tehran has a population of more than 13 million people with more than four million vehicles, three million motorcycles, and has various industrial and commercial centers which are located between latitude 35° 41’ 39.80” N and longitude 51° 25’ 17.44” E (Vakili et al., 2015).

2.2. Data collection

Data related to the air quality index (AQI), for one year (from Feb 20, 2020, to Feb 22, 2021) were collected daily through the online monitoring site of Air Quality Control Company under the supervision of Tehran Municipality. Out of a total of 32 air pollution measuring stations in Tehran city, only 20 monitoring stations had data available. The AQI is divided into six levels in terms of the impact of various pollutants on human health. Level I: green, good(0–50) (, II: yellow, acceptable (51–100); III: orange, unhealthy for sensitive groups (101–150); IV: red, unhealthy (151–200); V: purple, very unhealthy (201–300); VI: brown, dangerous (300 and higher). Data on suspected and positive cases of COVID-19 disease were obtained from the Ministry of Health and Medical Education of Iran on April 20, 2021.

2.3. Association between AQI (PM₂.₅) with suspected and positive cases

In this study, two hypotheses have been tested using AQI in terms of PM₂.₅ as well as the obtained data related to suspected and positive cases.

The first hypothesis: An increase in the AQI in terms of PM₂.₅ is associated with an increase in the number of suspected cases referred to medical centers. Therefore, due to the possible presence of definite cases (Positive cases based on PCR test) and hidden cases (cases that are carriers or suspected cases that have hidden their disease for some reasons such as fearing losing a job, money, quarantine for the whole family, etc.), there is a possibility of virus transmission in these centers. The basis for considering this hypothesis was similar studies that examined the relationship between PMs and SARS-CoV-2 as well as the role of PMs as carriers of viruses. The results of a study conducted in the industrial city of Lombardy in Italy showed that air pollution (with the presence of PMs) causes systemic inflammation and provides a route for the entry of the SARS-CoV-2 virus (Conticini et al., 2020). Chinese researchers claim that exposure to particulate matter increases both the prognosis of SARS and its risk of death (Cui et al., 2003). Reche et al. proved that the presence of viruses in marine particles and Saharan dust is higher than that of bacteria (52-fold–28-fold, respectively) and that air masses affect the proportion and duration of their residence in the atmosphere. Hence, PMs as carriers of the virus are effective in

\[ N_{ave} = 564; PC: N_{ave} = 275, \text{ and Level IV: red, unhealthy (SC: } N_{ave} = 558; PC: N_{ave} = 294). \]
spreading viral infections (Reche et al., 2018).

The second hypothesis: In unhealthy weather conditions, PM$_{2.5}$ reduces the COVID-19 incubation period, the appearance of symptoms, and increases the number of new positive cases, or aggravates the symptoms in definitive patients who have already tested positive. Given that there is a direct relationship between the length of the incubation period and the sensitivity of the immune system (Huang et al., 2021), hence PM$_{2.5}$ with negative effects on the immune system (Zhu et al., 2021), may indirectly affect the reduction of the incubation period.

Due to the similarity of some physical symptoms such as respiratory problems in the face of air pollutants with the symptoms of COVID-19 in unhealthy weather conditions, most of the time, people with the above symptoms are considered suspected cases, and after the test, their disease status is determined.

2.4. Statistical approach

Using the SPSS 26.0 package software (IBM Corp, Armonk, NY, USA), the collected data were analyzed. Initially, the data were tested for normality using the Kolmogorov–Smirnov test. The test results showed that the data obtained in this had a normal distribution. The Pearson correlation test was used to investigate the relationship between the AQI; PM$_{2.5}$ and the variables of suspected and positive cases. The method of generalized estimating equations (GEE) has been used to compare the effect of seasons on the number of suspected and positive cases referred to medical centers. In this model, winter was considered as a reference season due to less fluctuation (in terms of the number of suspected and positive cases) than other seasons. All statistical data were analyzed at a p-value of 0.05.

3. Result

Our study investigated the possible role of PM$_{2.5}$ as a carrier of the virus in increasing referrals to medical centers and its effect on the number of suspected and positive cases at different levels of AQI. Data on the AQI, number of suspected and positive cases in the period from February 20th, 2020 to February 20th, 2021, were collected and analyzed. During the study period, the AQI was never in the good (Brooks et al.), very unhealthy (purple), or hazardous (maroon) categories. According to Table 1, out of 187,602 suspected cases with similar symptoms to COVID-19, 94,711, 72,216, and 20,675 cases were referred to health centers in moderate (yellow), unhealthy for sensitive groups (orange), and unhealthy for all, respectively. The number of days in the year when the weather was moderate (yellow), unhealthy for the sensitive groups (orange), and unhealthy were 200, 128, and 37 days, respectively. However, the highest number of referrals to medical centers was recorded for moderate (yellow) conditions where the weather was healthy. Analysis of the average number of daily referrals showed that when the AQI was in an unhealthy (orange) for sensitive groups conditions, the most suspected referrals (N$_{avg}$/day = 564) were reported. The same trend has been true for the average daily referral of unhealthy conditions, with an average of 558 referrals per day.

The results of Table 1, show that out of 91,442 positive cases of COVID-19 disease, the highest number of cases (45,264), was recorded when the AQI was in a healthy condition for 200 days. Comparison of AQI status showed that the average number of positive cases recorded daily in unhealthy conditions was higher than in another status (N$_{avg}$/ day = 294). From February 20 to the end of the first half of March 2020 (Fig. 1), a regular and proportional trend was observed between the AQI and the occurrence of suspected and positive cases. Among the reasons for the increase in suspected cases of referral to medical centers, the unknown disease and symptoms similar to COVID-19 disease with the symptoms of exposure to air pollutants can be mentioned. According to Fig. 1, from March 15 to 30, 2020, the AQI and the number of suspected and positive cases had a decreasing and balanced trend.

Fig. 2 shows several peaks in the number of suspected cases that completely overlap with the AQI graph. In this figure, unlike the first figure, in most days, a steady trend and sometimes a decrease in the number of positive cases was observed. During this period, strict regulations at the entrances and exits of cities regarding the curfew, as well as teleworking for government employees and reducing working hours in all occupations except essential jobs such as medical centers have been effective in stabilizing and reducing the number of positive cases.

In Fig. 3, unlike the previous two figures, the AQI fluctuated in the medium (yellow) range on most days. The number of suspected cases was in line with the AQI but was accompanied by a greater range of fluctuations, which naturally this increase in the number of suspected cases caused a change in the number of positive cases. The availability of more diagnostic tests for screening and identification of positive cases as soon as possible during this period has also been effective in increasing the number of positive cases. From November 1st to November 3rd, with the AQI reaching the unhealthy (orange) range for sensitive groups, a sharp peak in the number of suspected cases was seen; subsequently, the number of suspected cases reached 1500 per day on November 3. Fig. 4 shows several peaks in the AQI that fluctuate at different levels. From December 30 to January 1, 2021, and from January 12 to January 15, the AQI was in an unhealthy region. In this figure, as in Fig. 2, an overlap between the AQI and the peak number of suspected cases can be seen. In Fig. 4, the slope of the number of positive cases initially fluctuated following the number of suspected cases and the quality index, but over time it first underwent a steady trend and then gradually decreased. The results of Pearson’s correlation test were used to determine the relationship between suspected cases and positive cases with AQI; PM$_{2.5}$ are presented in Table 2. The correlation analysis showed that there was a positive and significant correlation between AQI; PM$_{2.5}$ and suspected cases (r = 0.162, p < 0.01), as well as between AQI; PM$_{2.5}$ and positive cases (r = 0.221, p < 0.01). Based on the results of intragroup correlation, a very strong, positive, and significant correlation can be observed between suspected and positive cases (r = 0.686, p < 0.01).

Seasonal comparisons of the incidence of suspected and positive cases are shown in Table 3 and Table 4. Based on the results of Table 3, in conditions when the AQI was in the healthy (yellow) status, the highest number of suspected and positive cases was observed in summer. However, in summer, the number of suspected cases increased significantly from an average of 636 people per day in healthy AQI status to an average of 926 people per day during AQI conditions that were unhealthy for sensitive groups. Similarly, the average daily number of

| Air quality index | Feb 20th, 2020 to Feb 22nd, 2021 (368 days) |
|-------------------|---------------------------------------------|
|                   | N of days | Suspicious cases | Positive cases | Total |
| AQI; Health importance (Values of Index) | | | | |
| Good (0-50) | 203 | 94,711 | 45,264 | 139,975 |
| Moderate (51-100) | 37 | 20,675 | 10,875 | 31,550 |
| Unhealthy Sensitive Groups (101-150) | 128 | 72,216 | 35,303 | 107,519 |
| Unhealthy Sensitive Groups (151-200) | 187,602 | 91,442 |
positive cases also increased. Since in summer and autumn the AQI was not in the unhealthy status, therefore, comparisons were made for the other two seasons, spring and winter. Our findings showed that in the unhealthy condition for the sensitive groups (orange) and the unhealthy condition (red) there was a significant increase in the number of suspected cases referred to medical centers. In unhealthy situations for sensitive groups (orange) in the spring, the average number of daily referrals of suspected cases to medical centers increased from 366 to 607 people per day. The same upward trend was observed when the AQI was in the unhealthy range, and the daily average number of suspected cases increased dramatically to 868 in the spring. In winter, in unhealthy conditions, an increasing trend was observed in referring suspected cases compared to yellow and orange conditions to medical centers. A comparison of the effect of the seasons on the incidence of suspected and positive cases using the generalized estimating equations (GEE) is shown in Table 4.

Because of what is called a lack of public support or non-observance of health protocols by the people, several peaks were observed in the graph of the number of suspected and positive cases. The occurrence of these high-risk behaviors has intensified the number of suspected cases when the AQI was in unhealthy conditions in terms of PM$_{2.5}$ concentration (Figs. 1 and 4). On the other hand, the results showed that whenever people paid attention to the protocols announced by health organizations, the number of positive cases had a constant and
decreasing trend (Figs. 2 and 4), with the beginning of the Iranian New Year (Nowruz) and the departure of a percentage of the city’s population to travel, the AQI (due to less traffic) decreased and consequently, the occurrence of positive and suspicious cases had a decreasing trend (Fig. 1; March 15 to 30, 2020). From April 20th to May 3rd by implementing quarantine or May 24th to Jun 22nd with law enforcement of commute prohibition in the city and at the entrance and exit of Tehran, the AQI has decreased and consequently, the number of suspected and positive cases has also decreased. By contrast, from July 24 to July 26 before the implementation of quarantine or Oct 11th to Nov 5th with the resumption of jobs, in addition to increasing the exposure and contact of carriers and healthy people, increasing the AQI as a result of the use of private cars and public transportation may also have affected the number of suspicious and positive cases. referred to medical centers. At the end of March, the variable curve had an upward trend again. Among the reasons for this peak in the graph can be mentioned the end of the New Year holidays and the return of passengers, increased traffic load, increased emissions of air pollutants, especially the simultaneous presence of several pollutants such as tropospheric ozone (O3), and finally increase the AQI and reach the level unhealthy. Also, the possible contamination of passengers during the trip has been due to the possible increase of more suspected and positive cases. On the other hand, in the periods from May 24th to Jun 23rd, when the AQI was in healthy condition for most days and weeks, the number of positive cases was in a constant and sometimes decreasing trend (Fig. 2). By contrast, Fig. 4 showed that even though the AQI was in the unhealthy range for weeks, the number of positive cases was still changing in a constant and sometimes decreasing trend. One of the most important reasons for this declining trend, even in unhealthy conditions, is the observance of health protocols, education, and increasing public awareness.

The results of statistical analysis showed that at a 95% confidence interval, the seasons as an independent variable (except summer) have a significant effect on the incidence of suspected cases of COVID-19 disease referred to medical centers (P-value < 0.05). Although the effect of summer on the number of suspected cases was not statistically significant, due to its positive coefficient (CI: %95, B = 24.53), like other seasons, it had a direct effect on the incidence. The highest and the lowest effects are related to autumn (CI: %95, B = 408.94), and spring

### Table 2
Pearson correlation coefficient between suspected and positive cases with AQI; PM2.5

| Table 2 |  |
| --- | --- |
| Pearson Correlation (p values) |  |
| AQI; PM2.5 | Suspected cases | Positive cases |
| AQI | 1.000 | .162** (.002) | .221** (.001) |
| Suspected cases | .162** (.002) | 1.000 | .686** (.001) |
| Positive cases | .221** (.001) | .686** (.001) | 1.000 |

![Fig. 4. AQI and the incidence of suspected and positive cases; Nov 22 to Feb 22, 2021.](image)

### Table 3
Seasonal comparison of suspected and positive cases in different situations of AQI; PM2.5

| Table 3 |  |
| Season | AQI (51–100) | AQI (101–150) | AQI (151–200) |
| --- | --- | --- | --- |
| Healthy (Yellow) | Unhealthy for Sensitive Groups (Orange) | Unhealthy (Red) |  |
| N_{day} | Suspected cases | Positive cases | N_{day} | Suspected cases | Positive cases | N_{day} | Suspected cases | Positive cases |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Spring | 54 | 19,758 (Nave/day = 366) | 9044 (Nave/day = 167) | 26 | 15,794 (Nave/day = 607) | 6099 (Nave/day = 234) | 13 | 11,284 (Nave/day = 868) | 1982 (Nave/day = 152) |  |
| Summer | 60 | 38,151 (Nave/day = 636) | 17,408 (Nave/day = 290) | 32 | 29,644 (Nave/day = 926) | 14,224 (Nave/day = 444) | 4 | The AQI was not observed in this situation. |  |
| Autumn | 52 | 24,948 (Nave/day = 462) | 11,174 (Nave/day = 215) | 39 | 14,926 (Nave/day = 382) | 7685 (Nave/day = 197) | 2 | The AQI was not observed in this situation. |  |
| Winter | 48 | 19,113 (Nave/day = 398) | 15,632 (Nave/day = 325) | 29 | 9527 (Nave/day = 328) | 4232 (Nave/day = 145) | 13 | 5357 (Nave/day = 412) | 3961 (Nave/day = 304) |  |

### Table 4
Seasonal comparison results using generalized estimation equations (GEE).

| Table 4 |  |
| Season | Suspected cases | Positive cases |
| --- | --- | --- |
| B | CI (95%) | P-value | B | CI (95%) | P-value |
| Winter | Reference season | 21.45 | −51.432 | 94.332 | 0.010 | 35.28 | 14.67 | 55.89 | 0.001 |
| Spring | 24.53 | −41.567 | 90.634 | 0.467 | −71.67 | −107.509 | −35.8443 | 0.001 |
| Autumn | 408.94 | 343.209 | 474.682 | 0.001 | 83.43 | 47.799 | 119.070 | 0.001 |

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(CI: %95, B = 21.45) seasons, respectively. Despite being significant, the negative coefficients of the summer (CI: %95, B = -71.67), and winter (CI: %95, B = -47.02) seasons showed an opposite effect on the positive cases.

4. Discussion

In the present study, some influential confounding variables including individual behaviors (observance or non-observance of health protocols), holidays (national and religious), cultural habits (traveling, family gatherings and gatherings on various occasions), social policies (quarantine, curfew, traffic laws, employment) that have influenced the relationship between particulate matter and the incidence of suspected and positive cases were examined. Qualitative information about confounding variables indicates their important role in increasing or decreasing suspected and positive cases. Behavioral factors such as social distance, wearing a mask, home quarantine for patients, the use of disinfectants, as one of the confounding variables can play a decisive role in increasing or decreasing the incidence of suspected and positive cases. According to local authorities, as well as similar studies, due to ignorance, misconceptions, and misunderstandings about viral pandemics, some people are reluctant to follow health protocols (Habibzadeh and Stoneman, 2020; Liem et al., 2020; Rafeemanesh et al., 2020; SoleimanvandiAzar et al., 2021). Vacation variables and cultural habits have an increasing effect on the incidence of suspected and positive cases. Contrary to the warnings of health officials, attending gatherings on various occasions and the tendency to travel in personal vehicles during the holidays as two high-risk health behaviors have increased the exposure of carriers to healthy people, and may have been effective in suspected and positive cases referred to medical centers. Social policies are one of the most important confounding variables, which play a decisive role by enforcing laws such as quarantine, city-wide traffic laws, banning traffic at the entrances and exits of cities, and organizing businesses. The results showed that whenever social policies were implemented by local authorities, we were faced with a decrease in the incidence of suspected and positive cases. Strict quarantine rules, categorization, and organization of occupational activities have reduced referrals to medical centers due to reduced exposure of healthy people to carriers and infected people.

Despite the fact that in winter, due to the cold weather and the increasing prevalence of contagious viral diseases such as colds and flu, we expected that the number of suspected cases referred to medical centers would be higher than in other seasons; In contrast, in spring and summer, the average daily incidence of suspected cases was higher than in winter and autumn. Among the most important reasons for this increasing trend are the resumption of some jobs, the start of some pollution-producing industries, and finally the increase in traffic load and air pollution. In addition to increasing gatherings, performing high-risk health behaviors with the onset of warm seasons and the tendency to be outdoors in polluted air can speed up the referral process. This claim can be seen in the present results in Table 3. Based on the results of the GEE (Table 4), with the gradual decrease of air temperature in autumn, we saw an epidemiological pattern of increasing the prevalence of suspected and positive cases of COVID-19; This was in accordance with the results of some studies that claimed that the prevalence of infection and the incidence of positive cases of COVID-19 disease increased with the onset of the cold season ( Araujo and Naimi, 2020; Choi et al., 2021; Kaplin et al., 2020). However, our findings of winter were inconsistent with some studies. Paying more attention to health warnings, observing health protocols (personal protection, social distancing), contrary to expectations, we faced a decrease in suspected and positive cases in winter. Differences in some results on the effect of season on the prevalence of COVID-19, in addition to the unknown viral behaviors; It can also be affected by a combination of social, biological, and environmental factors. Overall, what should be considered as an important principle in all viral epidemics is that performing high-risk behaviors, not paying attention to health warnings, or not taking the nature of a viral epidemic seriously in any situation can exacerbate the epidemic (Mutation and behavior change).

According to the above, the two hypotheses in this study can be examined. The authors of this study in the form of two hypotheses claimed that increasing the AQI in terms of PM$_{2.5}$ increases the number of suspected and positive cases of COVID-19 disease. So, increasing the AQI in the presence of pollutants such as PM$_{2.5}$ is more likely to reduce the incubation period or worsen the symptoms in patients who have already tested positive. The analysis of the graphs and data in Table 1 as well as the results of statistical analysis show the correctness of both hypotheses presented in this study. However, regarding the second part of the first hypothesis, which was claimed to refer to medical centers due to the presence of infected people (hidden and definite) providing the conditions for virus transmission, no evidence was available to the authors as to how many of the positive cases referred to the medical centers were new or their second test was positive.

The results of statistical analysis using Pearson correlation coefficient showed that there was a positive and significant correlation between AQI; PM$_{2.5}$ and referral of suspected cases to medical centers (r = 0.162, p < 0.01), AQI; PM$_{2.5}$ with positive cases (r = 0.221, P$_{value}$<0.01), and also suspected cases with positive cases (r = 0.686, P$_{value}$<0.01). Due to the unknown and lack of accurate and complete information about the impact of the environment on coronavirus transmission, studies have so far only mentioned the role of some environmental and meteorological factors such as the effect of temperature, humidity, and precipitation) in causing epidemics of COVID-19 (Pequeno et al., 2020; Sobral et al., 2020). Our findings were consistent with the results of similar studies that claimed that there was a significant association between exposure to PM$_{2.5}$ and the occurrence of new cases of COVID-19 disease (Andrée, 2020; Du et al., 2021b; Zoran et al., 2020b). The results of some similar studies showed that there is a significant relationship between increasing the concentration of pollutants such as PM$_{10}$, NO$_2$ and O$_3$ in the death of COVID-19 (Chakraborty et al., 2020; Marquès et al., 2021; Sanchez-Piedra et al., 2021). However, in the study of Konstantinoudis et al., no association was found between PM$_{2.5}$ and COVID-19 mortality (Konstantinoudis et al., 2021). In the second hypothesis of the present study, it was claimed that exposure to suspended particles may be effective in reducing the incidence of new positive cases by reducing the incubation period. Since the reduction of the incubation period and the appearance of symptoms of the disease indicate the evolution and multiplication of the virus in the host body; Therefore, this claim of the present study was consistent with the results of the study of Hendryx et al. on the effect of suspended particles on the development of the disease (Hendryx and Liao, 2020; Sanchez-Piedra et al., 2021). What could be seen in our results based on the data obtained was the increase in the number of suspected and positive cases in the days when the AQI was in unhealthy conditions. Therefore, the claim of the authors of this study was based solely on the analysis of graphs, tables, and data. To avoid any bias in the study, it is necessary to explain that the results obtained in the present study can be a clue, and to prove the accuracy of the above results requires further research in the future.

Among the limitations we faced were the lack of full access to information and statistics of some patients and medical centers, as well as the unavailability of information on the quantitatively confounding variable, AQI of some meteorological and environmental stations. Another limitation of this study was the precise definition of suspected cases. Due to the complex behaviors of this new strain of coronavirus, we have seen the appearance of various or similar symptoms of other diseases such as influenza in people who later tested positive. Therefore, it seemed logical to classify people with suspicious symptoms into a group of suspected cases, apart from any prejudice.
5. Conclusion

Due to the importance of the role of air pollution as one of the effective environmental factors in the spread of viral epidemics, this study has investigated the role of increasing the AQI; PM2.5 on the incidence of suspected and positive cases of COVID-19 disease. Based on the results of the present study, strict regulations such as quarantine and curfew, compliance with health protocols, teleworking and reduction of working hours, avoidance of risky behaviors, especially on days when the AQI is in unhealthy conditions, can be effective in reducing the number of suspected and positive cases. The results of the analysis of statistical tests showed that there is a positive and significant relationship between AQI (with the presence of PM2.5) and referral of suspected cases to medical centers and positive cases incidence (p-value <0.01). Seasonal comparisons indicated an increase in the incidence of suspected and positive cases in hot seasons due to non-compliance with health protocols, and in contrast, in winter we faced an increase in widespread warnings from health organizations about compliance with protocols to reduce the incidence of COVID-19. The authors hope that the results of the present study, by creating an environmental perspective, will encourage other researchers to further study the role of environmental factors, especially particulate matter (PM10, PM2.5, and UFPM), as a health-threatening pollutant in creating viral epidemics.

Ethical approval

The study sampling protocol was approved by the Ethics Committee of the Shiraz University of Medical Science (IR.SUMS.REC.1399.877).

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Author statement

All authors contributed to the study’s conception and design. Material preparation, data collection, and analysis were performed by Fallah Hashemi, Lori Hoepner, Farahnaz Soleimani Hamidinejad, Alireza Akhmetzhanov, A.R., Mizumoto, K., Jung, S-m, Linton, N.M., Omori, R., Nishiura, H., Brooks, S., Webster, R., Smith, L., Woodland, L., Wesely, S., Greenberg, N., et al., 2020. The psychological impact of quarantine and how to reduce it: rapid review of the evidence. SSRN Electron. J. 9:551-593.

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