Original Article

The impact of COVID-19 on air pollution in Iran in the first and second waves with emphasis on the city of Tehran

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ABSTRACT:

Introduction: Air pollution is one of the biggest environmental problems that has gradually spread since the industrial revolution with the consumption of fossil fuels. This situation is more visible in the capitals of industrialized and densely populated countries and towns. In late 2019, with the outbreak of the Coronavirus from China around the world, governments imposed strict restrictions on traffic and transportation to combat the epidemic. With the reduction of consumption of petroleum products in the industry and transportation system, air pollution has decreased in many cities in the world.
Materials and methods: In this study, air pollution in the provinces of Iran has been collected and analyzed more than 4500 data. Data on 40 days of quarantine from 1 March to 9 April 2020 were examined.
Results: The results of this study show that the concentrations of pollutants CO, NO_2, PM_{10}, and $PM_{2.5}$ decreased by 11, 15, 10, and 6%, respectively, during the lockdown period; but, the SO_2 and O_3 concentration increased by 15 and 12%. The highest decrease in air pollution is related to Gilan province (-66) and the highest increase in pollution is related to Isfahan province (+37) percent. Calculations show that the Air Quality Index (AQI) has decreased by 6%, but in the second wave of the disease decreased by 75% compared to the lockdown period.
Conclusion: The Coronavirus crisis has shown that air pollution can be addressed through the proper implementation of environmental policies.

Introduction

The COVID-19 is one of the most acute respiratory diseases that spread from Wuhan, China, in late 2019, and to date, more than 26 million people worldwide been infected with the virus [1]. According to the Iranian Ministry of Health Information, the Coronavirus infected more than 378000 people in Iran [2].

To prevent the spread of the disease and to cut off its transmission chain, governments imposed severe restrictions on traffic and business activities. Thus COVID-19 left devastating economic and social impacts, and the only positive consequence was the improvement of the environmental situation. One of the unprecedented ecological impacts of Coronavirus was the change in air pollution in cities. Air pollution is caused by industrial activities and the use of fossil fuels in transportation. Air pollution has now become a significant crisis in many parts of the world, es-

pecially in developing countries. Tehran is one of the most polluted cities in the world. Despite air management measures such as car traffic plans and the expansion of public transportation, air pollution has not decreased significantly.

It was showed by some research that there is a significant relationship between deaths due to heart and respiratory diseases and air pollution in Tehran [3]. Tehran was one of the first areas where the fever broke out in late February 2020 and quickly became the center of the virus in Iran. By quarantining and closing offices, industries, markets, and transportation systems; gasoline consumption in Tehran has been reduced by 50%, according to the National Oil Company [4]. Also, traffic was reduced by 73%.[۵] Similar restrictions were imposed in other countries, resulting in reduced emissions of CO, NO_2, O_3, SO_2, and particulate matter. Thus, with the decrease in air quality index in many cities of the world, the quality of air improved.

The issue of improving air quality and reducing emissions during COVID-19 outbreaks has been the focus of many researchers. For example, researchers used the copernicus atmosphere monitoring service to analyze data of particulate matter ($PM_{2.5}$) in China they observed approximately 20-30% reduction in February 2020 (month average), when compared to monthly averages of February 2017, 2018, and 2019 [6]. Other researchers used the copernicus tropospheric monitoring instrument, and also data from one traffic station in Barcelona (Spain), provided by the local organization for atmospheric pollution monitoring, to assess air quality changes during the lockdown in the city of Barcelona [7]. Many researchers studied the emission status of pollutants in lookdown in Sao Paulo, Brazil [8]. NASA satellite data shows a decrease in NO_2 levels in northern Wuhan, China [9].

In Iran, research has been done on impact of the Coronavirus on air pollution. In a study by researchers, it was calculated changes in the concentration of air pollutants during the disease in Tehran [10]. Also, in a research, changes were examined in the amount of particular matter ($PM_{2.5}$ and PM_{10}) in Tehran during the illness [11]. In this study, the emission of air pollutants in the first and second periods of the disease in Iran emphasizing the city of Tehran, the capital of Iran will be investigated.

Materials and methods

According to the WorldoMeters database, Iran has a population of about 84 million people [12], 31 provinces and air pollution is the most important in its capital (Fig. 1). Air pollution data has been prepared by the Iranian air quality monitoring system [13]. There are more than 150 air pollution monitoring stations in Iran that record the concentration of pollutants and Air Quality Index (AQI) daily in this database. The obtained data are recorded every day as an online index at 11 o'clock. After collecting AQI data in all provinces of Iran, changes in air quality in the lockdown period of 2020 (1 March-9 April) compared to the average of the same period of 2017-2019 were identified. To investigate air quality in all provinces of Iran due to the large volume of data, only AQI has been studied. However, to detect the impact of the second wave of the disease on air pollution, the AQI of four provinces in the second wave (21 June-21 July) was examined and changes were calculated.

The city of Tehran with a geographical position of 35°41'10.37" N and 51°25'5.00" E has been
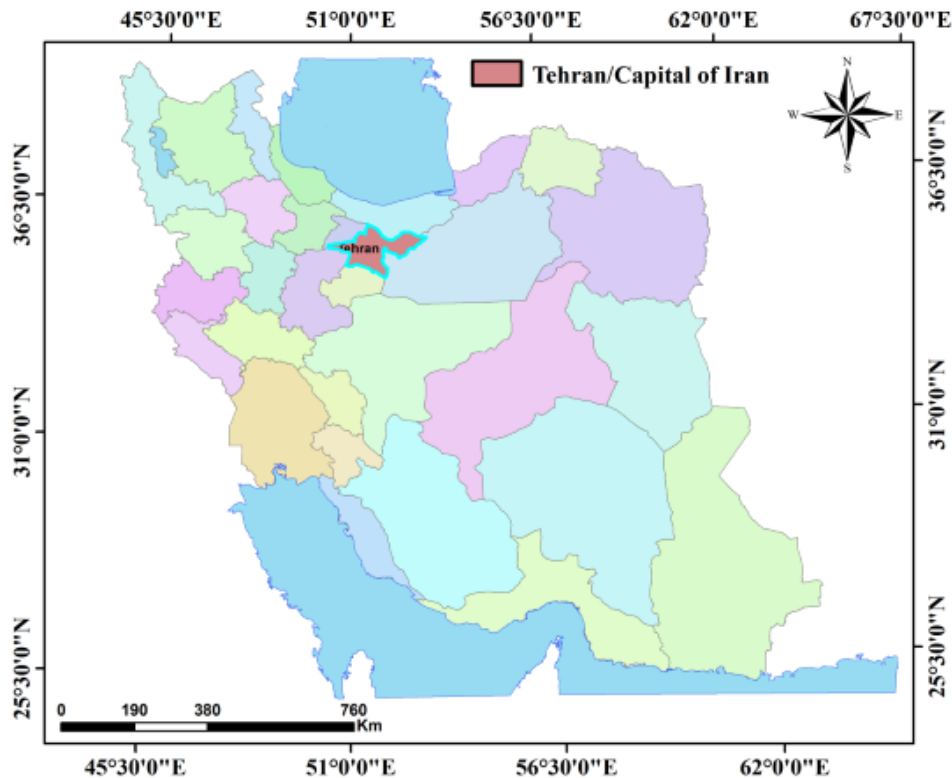
Fig.1. Geographical map of Iran

the capital of Iran for more than 200 years. There are 12 active air quality monitoring stations in this city and their information is transmitted to the monitoring system (Fig. 2).

In the Tehran, data on air pollutants (CO, O_3, NO_2, SO_2, $PM_{2.5}$, PM_{10}) and air quality index (AQI) over 40 days from 1 March to 9 April 2017-2019 were collected and compared with 2020 data relating to the period of COVID-19 outbreak and restrictions. Then the data of the second wave period are compared to the first wave. The second wave of the disease is scheduled from June 21 to July 21. After analysis and calculations, the diagrams have been drawn with Excel 2016. Then, changes in CO and NO_2 concentrations in Tehran regions were examined separately, legends of NO_2 and CO emission changes in Tehran regions were drawn by ArcGIS 10.6. Data analysis in

ArcGIS was performed in two stages, first, data interpolation in regions was done with the IDW technique. Inverse distance weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a locationally dependent variable. This method assumes that the variable being mapped decreases in influence with distance from its sampled location. For example, when interpolating a surface of consumer purchasing power for a retail site analysis, the purchasing power of a more distant location will have less influence because people are more likely to shop closer to home [14].

Then, using the zonal statistics technique, the average of CO and NO_2 data in each region (each region=one polygon) was calculated and brought.
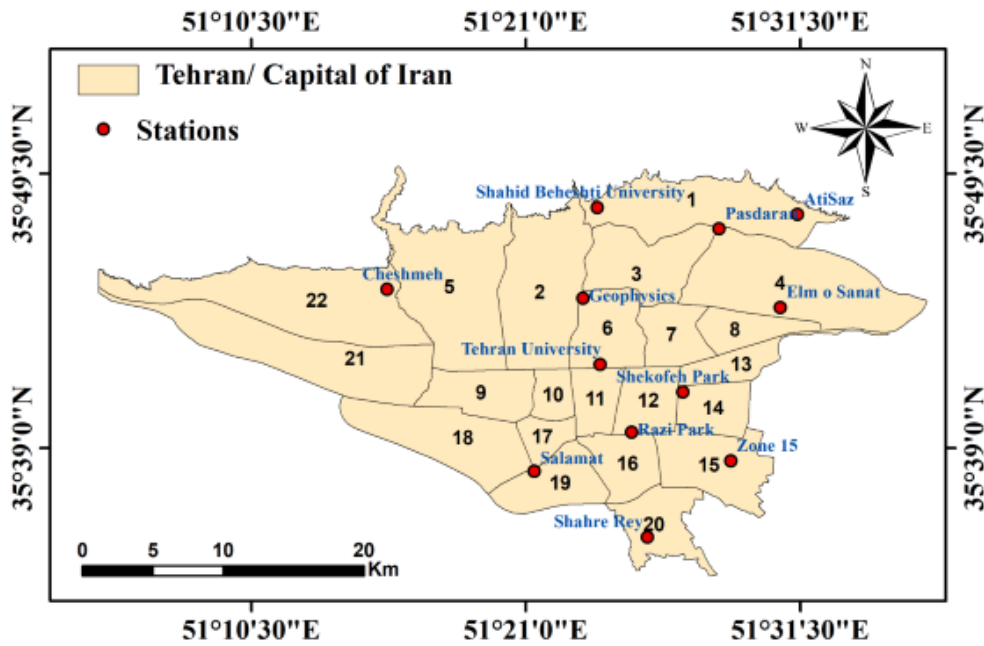
Fig. 2. Location of air pollution monitoring stations in different regions of Tehran

With the zonal statistics tool, a statistic is calculated for each zone defined by a zone dataset, based on values from another dataset (a value raster). A single output value is computed for every zone in the input zone dataset [15]. Pollutant emission changes are indicated by changes in color. Stations that recorded data irregularly will no longer be reviewed.

Results and discussion

Impact of lockdown period in provinces of Iran

Traffic restrictions were imposed in Iran from mid-March and lasted up to 40 days. The bus and subway transportation system were shut down. In some provinces, we have seen an increase in air pollution compared to previous years. Reducing fuel consumption and traffic in cities led to a relative improvement in air pollution. So, AQI had a declining trend in many cities in Iran (Table 1).

Table 1. Changes in air quality index in the first wave of the disease in the provinces of Iran (Lockdown period) (March-April, 2020), The sign (+) means to increase and the sign (-) means

decrease air pollution.

During the first wave of the disease, 21 of the 31 provinces of Iran experienced a reduction in air pollution. The highest decrease in air pollution is related to Gilan province (-66) and the highest increase in air pollution is associated with Isfahan province (+37). Three provinces of Sistan and Baluchestan, Kohgiluyeh, and Boyer-Ahmad and Mazandaran have been removed from the calculations due to lack of information on pollutants in the first wave. The cause of the increase in air pollution in the other eight provinces (West Azarbaijan, Isfahan, Bushehr, North Khorasan, Fars, Qazvin, Qom and Hamedan) is still not completely clear. Still, it can be related to more personal car traffic and travel, because the subway in the cities of Isfahan and Shiraz were closed and traffic with cars increased. In Iran, five cities of Tehran, Mashhad, Shiraz, Isfahan, and Tabriz have subways. All subways except the Tehran were closed and the result of this situation can be seen in the increase of air pollution in Shiraz and Isfahan (Table 2).

Table 1. Changes in air quality index in the first wave of the disease in the provinces of Iran (Lockdown period) (March-April, 2020), The sign (+) means to increase and the sign (-) means decrease air pollution

Ro	Province	AQI average 2017-2019	Lockdown period (2020)	AQI changes (%)
1	East Azarbaijan	63.1	52.62	-17
2	West Azarbaijan	58.17	64.36	+10
3	Ardabil	66.08	38.72	-42
4	Isfahan	60.34	82.8	+37
5	Alborz	68.97	57.12	-17
6	Ilam	60.57	37.6	-38
7	Bushehr	90.34	91.26	+1
8	Tehran	71.4	67.2	-6
9	Chaharmahal va Bakhtiari	60.08	26.43	-56
10	Southern Khorasan	52.72	34.36	-35
11	Khorasan Razavi	77.29	66.37	-15
12	North Khorasan	54.98	67.17	+22
13	Khuzestan	98.18	93	-6
14	Zanjan	55.19	47.72	-14
15	Semnan	62.18	50.2	-19
16	Sistan and Baluchestan	-	-	-
17	Fars	59.57	74.12	+24
18	Qazvin	51.73	59.7	+14
19	Qom	61.16	68.02	+11
20	Kurdistan	55.01	30.48	-45
21	Kerman	65.46	64.76	-1
22	Kermanshah	51.13	45.58	-11
23	Kohgiloyeh and Boyerahmad	-	-	-
24	Golestan	46.26	21	-55
25	Gilan	74.59	25.17	-66
26	Lorestan	89.48	70.97	-21
27	Mazandaran	-	-	-
28	Markazi	73.77	62.77	-15
29	Hormozgan	94.53	49.17	-48
30	Hamedan	65.38	68.78	+5
31	Yazd	70.85	54.3	-24

Table 2. Changes in the quality index in the second wave compared to the first wave of the disease in important cities of Iran (June 21-July 21)

Provinces	First wave (Lockdown period)	Second Wave	AQI changes (%)
East Azarbaijan (Tabriz)	52.62	54	+25
Isfahan	82.8	95.67	+15.5
Khorasan Razavi	66.37	84.25	+27
Fars (Shiraz)	74.12	79.19	+7

The first wave of the disease in Tehran (lockdown period)

The level of CO emissions during the quarantine period decreased by 11% compared to the same period in 2017-2019 (Fig. 3a). O_3 concentration increased by about 12% compared to the average of three years ago (Fig. 3b). NO_2 gas, which is one of the most important air pollutants, decreased by 15% during the quarantine period in Tehran compared to 2017-2019 (Fig. 3c). SO_2, mostly the result of industrial activity, increased by 15% in the period of disease outbreak compared to 2017-2019 (Fig. 3d). The emission of PM_{10} particles in the air of Tehran during the quarantine period compared to 2017-2019 decreased by 10% and emission of $PM_{2.5}$ decreased by 6% (Fig. 3e and Fig. 3f). The average air quality index (AQI) in 2017, 2018, and 2019 will be 72.65, 86.45, and 55.15, respectively, and the average of all three data will be 71.41. The average data of this index in the same period of 2020 was calculated at 67.2 (Fig. 3g). Comparing the 2020 average with three years ago, it can be seen that AQI has decreased by 6%, which means that air quality has improved by only 6% during the Coronavirus lockdown period.

The second wave of the disease in Tehran

CO emission in the second wave of the disease decreased by 3% compared to the first wave of the disease (lockdown period) (Fig. 3a). O_3 emissions tripled (+301) (Fig. 3b), NO_2 increased by 1.66 times (66%) (Fig. 3c), SO_2 increased by 1.05 times (5%) (Fig. 3d), PM_{10} increased by 1.48 times (48%) (Fig. 3e) and $PM_{2.5}$ increased by 1.3 times (30%) (Fig. 3f). AQI in the second wave of the disease increased by 1.75 times (75%) compared to the first wave (Fig. 3g). The average concentration of total pollutants in the second wave compared to the first wave shows an increase of 1.6 (+60) (Fig. 3h). The changes in pollutants and AQI in the first and second waves are given in Table 3.
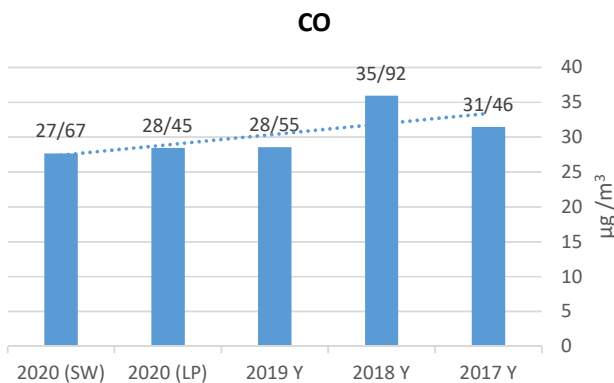

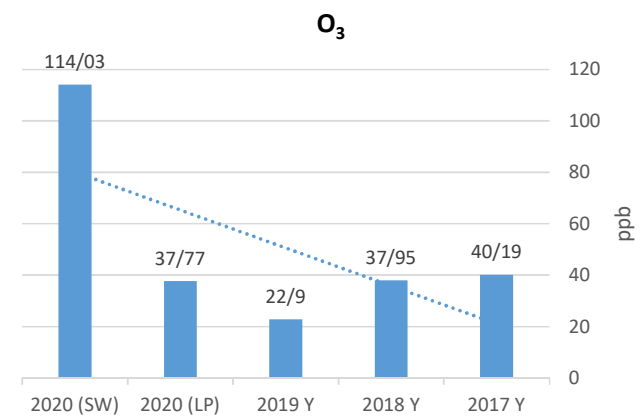**Fig. 3 a. Changes in CO concentration in Tehran, LP=Lockdown period, SW=Second wave**

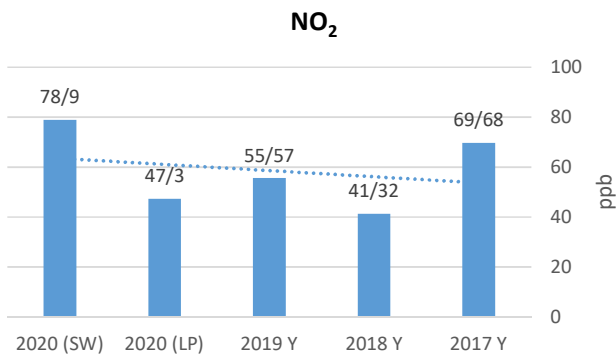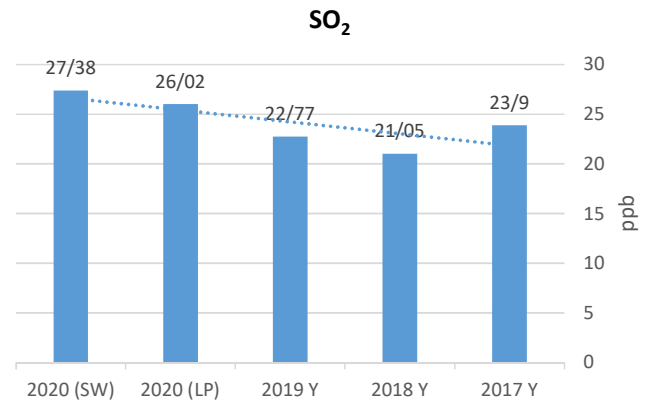**Fig. 3 b. Changes in O_3 concentration in Tehran, LP=Lockdown period, SW=Second wave**
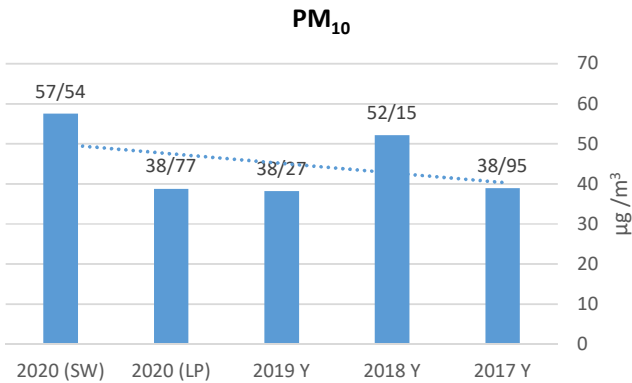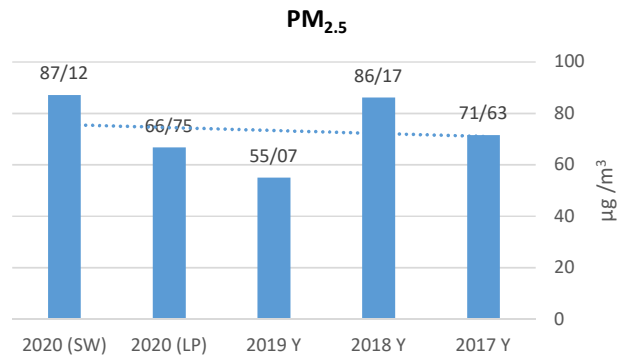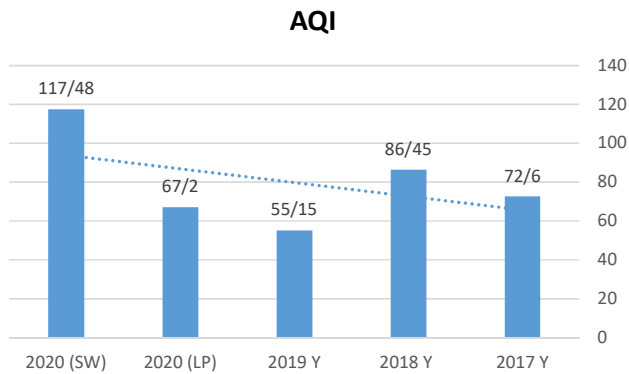
NO$_2$

Fig. 3c. Changes in NO$_2$ concentration in Tehran, LP=Lockdown period, SW=Second wave

SO$_2$

Fig. 3d. Changes in SO$_2$ concentration in Tehran, LP=Lockdown period, SW=Second wave

PM$_{10}$

Fig. 3e. Changes in PM$_{10}$ concentration in Tehran, LP=Lockdown period, SW=Second wave

PM$_{2.5}$

Fig. 3f. Changes in PM$_{2.5}$ concentration in Tehran, LP=Lockdown period, SW=Second wave

AQI

Fig. 3g. Changes in AQI in Tehran, LP=Lockdown period, SW=Second wave
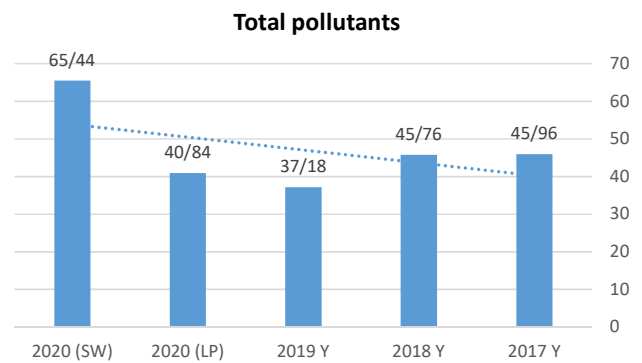
Total pollutants

Fig. 3h. Changes in the concentration of total pollutants in Tehran, LP=Lockdown period, SW=Second wave

Table 3. The ratio of pollutant emissions in the first wave of the disease to the second wave in Tehran

	AQI	PM$_{2.5}$ ($\mu g/m^3$)	PM$_{10}$ ($\mu g/m^3$)	SO$_2$ (ppb)	NO$_2$ (ppb)	O$_3$ (ppb)	CO ($\mu g/m^3$)	Total pollutant
First wave (Lockdown period)	67.2	66.75	38.77	26.02	47.3	37.77	28.45	40.84
Second wave	117.48	87.12	57.54	27.38	78.9	114.03	27.67	65.44
Changes (%)	+75	+30	+48	+5	+66	+301	-3	+60

The results of this study are consistent with the research of Sharma et al. (2020). They surveyed pollutant concentrations in six Indian cities and found that there was a 43, 31, 10, and 18% reduction in PM$_{2.5}$, PM$_{10}$, CO and NO$_2$ during the disease period. The change in SO$_2$ concentration was also reported to be negligible [16]. Many researchers also calculated 75, 49, and 96% reduction of PM$_{10}$, SO$_2$, and NO$_2$ pollutants in Sale city (Morocco) [17]. Besides, in the report of other researchers, on Chinese cities it was found a reduction of 9.23, 6.73, 5.35, and 30.97 $\mu g/m^3$ of PM$_{2.5}$ pollutants in Beijing, Shanghai, Guangzhou, and Wuhan [18].

Changes in CO and NO$_2$ concentrations in Tehran regions during the second wave of the disease

The two main agents of fire and car fuel combustion are CO emissions [19]. The share of cars in large cities in the production and emission of air pollutants is about 70%, and this share is mainly due to fossil fuels [20].

To investigate the concentration of CO and NO$_2$ in different areas of Tehran and their distribution, the data of each station were examined separately. Out of 12 air pollution monitoring stations in Tehran, only 8 stations had NO$_2$ (Table 4) and CO sensors (Table 5). With the reduction of restrictions and the beginning of reopening, intra-city traffic increased again, and as shown in Fig. 4

and Fig. 5, vehicle traffic increased the concentration of CO and NO$_2$. The NO$_2$ legends in Fig. 4 show that the concentration of this pollutant in areas such as Shahre Rey and Shahid Beheshti University has increased much in the second wave of the disease. The NO$_2$ concentration in the second wave did not decrease in any area, indicating that the quarantine situation had greatly reduced this pollutant. The region that has experienced the lowest rate of increase in emissions is the Tehran University. CO legends in Fig. 5 show that the Tehran University and Cheshmeh areas had the highest increase in emissions in the second wave of the disease. Unlike NO$_2$, CO emissions in some areas have decreased in the second wave. The highest reduction in CO emissions in the second wave is related to the areas of Shahid Beheshti University and Atisaz. It seems that increasing the use of private cars and reducing the use of the public transportation system will increase the emission of CO and NO$_2$ pollutants. Because the emission of these two pollutants is largely related to car fuel.

Conclusion

The outbreak of COVID-19 has shown that controlling air pollution is possible and that governments need to do more to combat it. Because air pollution, in addition to physical and psychological damage, damages ecosystems, animals, and

Table 4. Changes in NO$_2$ concentrations (ppb) in 8 regions of Tehran

Station	Zone 15	Elmo sanat	Salamat	Atisaz	Geophysics	Shahre Rey	Shahid Beheshti University	Tehran University
Second wave	91	64.91	64.41	71.66	74.79	96.2	86.93	42
Lockdown period	46.82	55.53	55.85	39.22	60.72	31.8	41.29	40.22
Changes (%)	+94	+17	+24	+82	+23	+302	+207	+4

Table 5. Changes in CO concentrations (μg/m^3) in 8 regions of Tehran

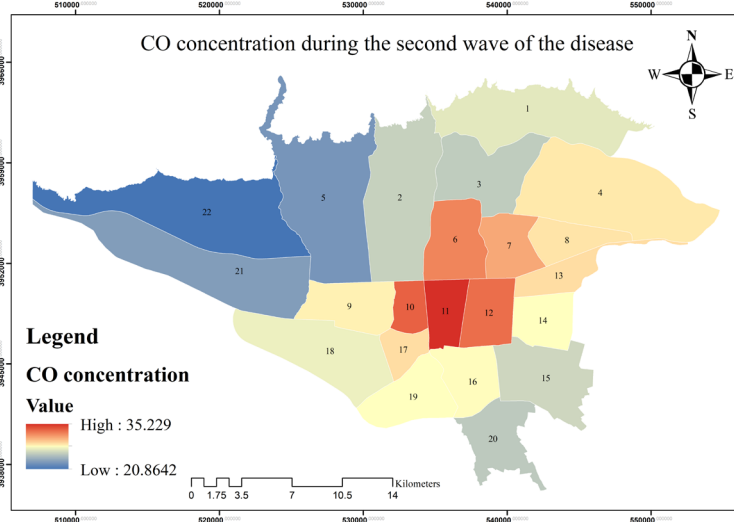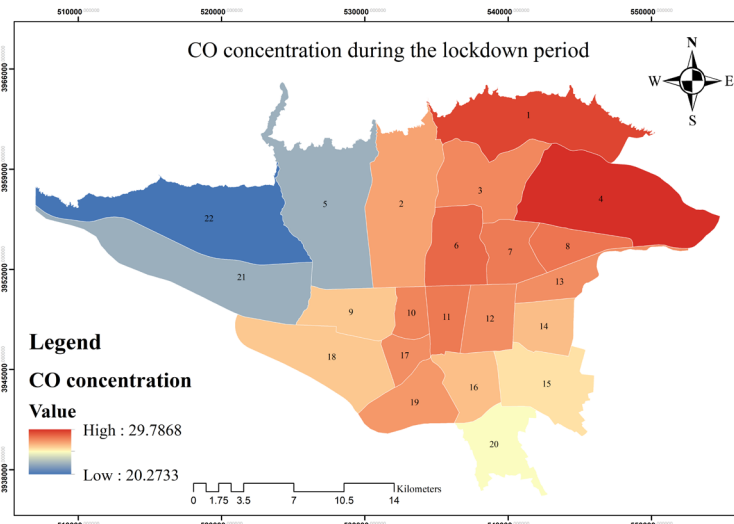| Station	Zone 15	Cheshmeh	Salamat	Atisaz	Geophysics	Shahre Rey	Shahid Beheshti University	Tehran University
Lockdown period	25.47	16.78	27.92	33.4	28.75	24.45	25.61	28.87
Second wave	25.06	17.72	27.5	29.8	29.1	24.55	22.56	40.9
Changes (%)	-2	+5	-1.5	-11	+1	+0.4	-12	+41

Fig. 4. Changes in NO$_2$ concentration (ppb) in the first and second waves of the disease (data source: Table 4)

NO2 concentration during the lockdown period

NO2 concentration during the second wave of the disease

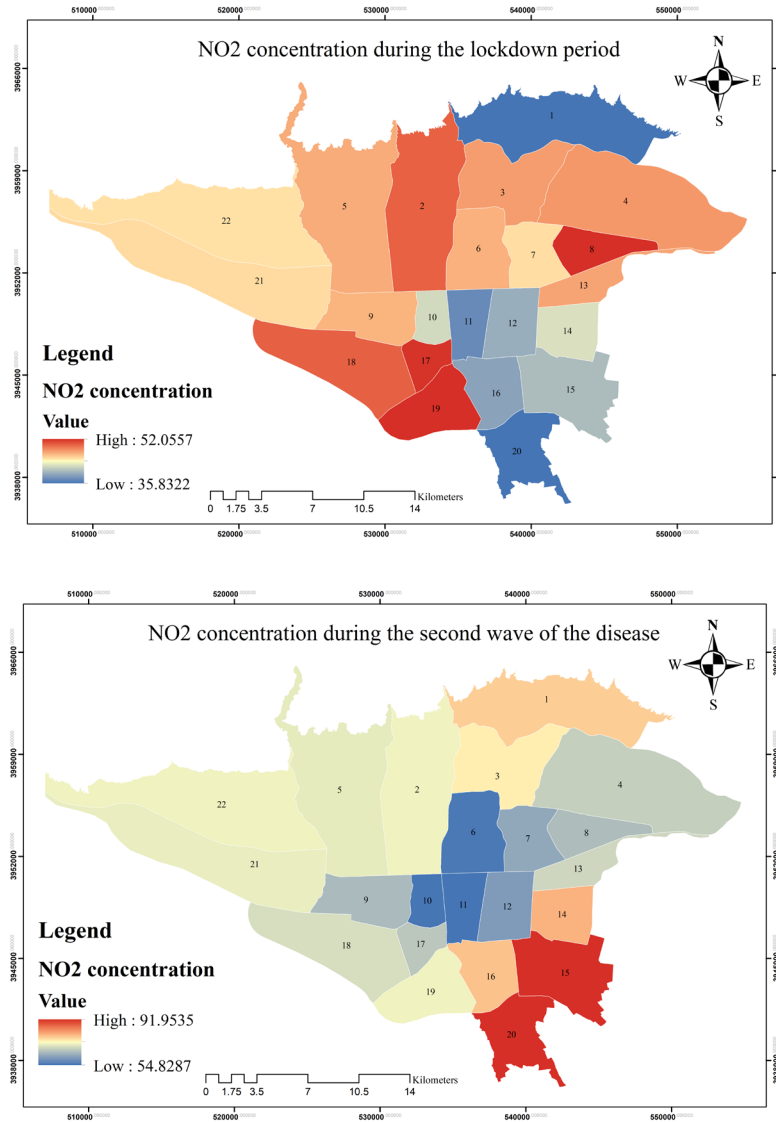**Fig. 5. Changes in CO concentration (µg/m³) in the first and second waves of the disease, (data source: Table 5)**

plants, and this situation can cause severe economic damage.

Overall, the information on the reduction of total air pollutants (CO, O_3 NO_2, SO_2, $PM_{2.5}$, PM_{10}) in Tehran shows that their emission during the lockdown period has decreased by an average of 5%, but the average level of total pollutants in the second wave compared to the first wave shows an increase of 60%. The reason could be the reduction of industrial activities during the shutdown period and the resumption of activities in the second wave. The average total concentra-

tions of pollutants from 2017-2019 were calculated as 45.96, 45.76, and 37.18, respectively. The average for the lockdown period was 40.84. The average concentration of contaminants in the second wave of the disease shows that air pollution has increased by lifting transport restrictions. The average for second wave period was 65.44. The second wave of the disease occurred while there was no quarantine and no restrictions.

Almost all environmental scientists and researchers believe that more renewable energy sources such as solar, wind, nuclear, and biomass should

be used to reduce air pollution. Coronavirus has allowed policymakers and government officials to focus more on plans to reduce oil and fossil fuel consumption.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical considerations

Ethical issues (Including plagiarism, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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