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Trends in Air Quality Index (AQI) in Tehran, Iran: A Comprehensive Analysis Before, During, and After COVID-19 Pandemic (2018–2024)

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ABSTRACT

Background: The largest capital of the Middle East, with 8000 Km^2 and a population of 13 million people, has about 40% of Iran's industrial units in its suburbs. The purpose of this study was to investigate the trend of air quality in Tehran between 2018 and 2024.

Methods: Daily air quality index (AQI) data were collected from 16 monitoring stations in Tehran province over three time periods: 2 years before, 2 years during, and 2 years after the COVID-19 pandemic. Descriptive statistics were calculated for each pollutant during these periods, and box plots were used to visualize AQI distributions. The Kruskal-Wallis test was applied to assess significant differences in AQI across the three time periods.

Results: $PM_{2.5}$ was the dominant pollutant across all seasons, peaking at 99.4% in autumn and remaining above 90% in winter. The AQI for $PM_{2.5}$ increased from 109 pre-pandemic to 143 post-pandemic. Seasonal trends revealed significant increases in pollutants such as O_3 and $PM_{2.5}$ in spring, summer, and autumn, while NO_2 levels fluctuated. The Kruskal-Wallis test indicated significant seasonal variations, with $PM_{2.5}$ showing the most substantial increase ($H = 262.43$, $p < 0.001$). O_3 and PM_{10} also showed significant post-pandemic growth, whereas SO_2 and NO_2 had smaller but significant fluctuations ($p < 0.05$).

Conclusion: The results show that reducing traffic and preventing the use of Mazut fuel in power plants have had significant effects on reducing air pollutants, and the sharp decrease in precipitation in recent years has increased the dispersion and emission of particles.

1. Introduction

Many cities face numerous environmental challenges, including air pollution, due to their urban development and surrounding polluting industries (Farahmandkia et al., 2017), which often expose their residents to adverse health effects (Farahmandkia et al., 2017). The World Health Organization has estimated that approximately seven million people worldwide, primarily children and young individuals, lose their lives annually due to diseases caused by air pollution (WHO, 2023). The International Agency for Research on Cancer (IARC, 2013) has classified air pollution as a Group 1 carcinogen for humans. In late 2020, the COVID-19 virus originated in Wuhan, China, and rapidly spread worldwide, leading to various restrictions in each country to prevent the spread of the disease (Hasnain et al., 2021). This deadly disease was reported in Iran in February 2020, and respiratory-related restrictions were imposed, including the closure of universities, schools, educational institutions, malls, shops, and all gathering places (Doost Mohammadi et

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al., 2021). The disease lasted for almost two years. Since urban air quality is influenced by traffic, industry, and other pollutants, minimizing the contribution of traffic during the pandemic can help understand its impact on urban air quality. Therefore, much research has been conducted, and the impact of restrictions on air quality has been shown in many cities around the world (Magazzino et al., 2020; Son et al., 2020). Among these cities, Tehran province, the capital of Iran, is one of the polluted areas requiring monitoring and control of air quality. Extensive research has been conducted on the short-term air quality in this city, and high levels of air pollution have been observed (Krzyzanowski et al., 2014; Naddafi et al., 2012). However, the effects of the pandemic restrictions and air quality in this metropolis after the pandemic have not been studied. Therefore, this research aims to investigate and compare the biannually air quality level of NO_2, SO_2, O_3, CO, $PM_{2.5}$, and PM_{10}, in Tehran Province using data from air quality monitoring stations belonging to the Iranian Department of Environment during the years 2018 to 2024, covering the pre-pandemic, pandemic, and post-pandemic periods.

2. Materials and Methods

2.1 The study area

Tehran Province spans over 8000 km^2, located between 34°53′ to 36°7′ north latitude and 50°20′ to 53°9′ east longitude. It is bordered by Mazandaran Province to the north, Semnan Province to the east, Qom Province to the southeast, Alborz Province to the west, and Markazi Province to the southwest. According to the latest population and housing census in October 2016, the population of Tehran province exceeded 13 million people, and almost 40% of the country's industrial units are located in this province. The development of these industries is concentrated predominantly along the main entry routes to Tehran, especially the Tehran-Karaj, Tehran-Saveh, Tehran-Qom, and Tehran-Semnan roads (Amar, 2018). Figure 1 demonstrates the map of Iran and Tehran Province. The province of Tehran includes a part of the Central Alborz Mountain Range and primarily extends in an east-west direction in the northern region of Tehran province. In the northeastern parts, these elevations extend with the Firouzkouh and Savadkouh mountain ranges to the Firouzkouh River valley. In the southern and eastern parts of Tehran, the Hasanabad, Bibi Shahr Banu, Alghadir, and Qasr Firouzeh mountains are located (Amar, 2018).

2.2 Air quality monitoring stations

In this research, data were collected from air quality monitoring stations belonging to the Iranian Department of Environment. The data, obtained daily, pertains to various regions including Tehran Central, Islamshahr, Pakdasht, Shahriar, Lavasanat, Varamin, Pardis, Robat Karim, Baharestan, Baqershahr, Shahr-e-Qods, Malard, Pishva, Gharchak, Damavand, and Baghestan. These reports are accessible through the website https://aqms.doe.ir/Home/AQI (in Persian). Furthermore, the geographical locations of these stations can also be observed on the website of the Tehran Department of Environment. The daily index of NO_2, SO_2, O_3, CO, $PM_{2.5}$, and PM_{10} is obtained by calculating the AQI from 11 a.m. to 11 a.m. the next day. The AQI is calculated using the following equation (Yousefi et al., 2019). The parameters used in the equation are taken from Table 1, which shows the AQI breakpoints.

$$I_p = \frac{I_{Hi} - I_{LO}}{BP_{Hi} - BP_{LO}}(C_P - BP_{LO}) + I_{LO}$$

Where I_p = the index for pollutant p
C_p = the truncated concentration of pollutant p
BP_{Hi} = the concentration breakpoint that is greater than or equal to C_p
BP_{Lo} = the concentration breakpoint that is less than or equal to C_p
I_{Hi} = the AQI value corresponding to BP_{Hi}
I_{Lo} = the AQI value corresponding to BP_{Lo}

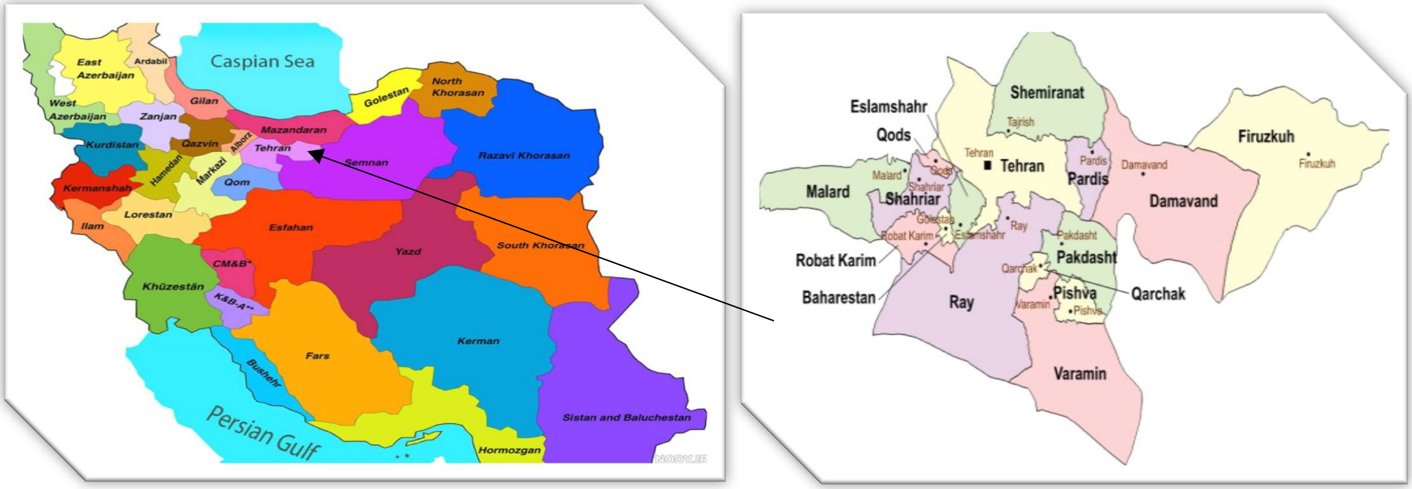

Figure 1. Map of Iran and Tehran Province, delineating the counties

Table 1. AQI Breakpoint in Iran

Air quality categories	AQI	Break point					
		CO (ppm)	O_3 (ppm)	NO_2 (ppb)	SO_2 (ppb)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)
Good	0-50	0-4.4	0-0.054	0-0.053	0-0.034	0-12	0-54
Moderate	51-100	4.5-9.4	0.055-0.07	0.054-0.1	0.035-0.144	13-35.4	54-154
Unhealthy for the sensitive group	101-150	9.5-12.4	0.071-0.085	0.101-0.360	0.145-0.224	35.5-55.4	155-254
Unhealthy	151-200	12.5-15.4	0.086-0.105	0.361-0.64	0.225-0.304	55.5-150.4	255-354
Very unhealthy	201-300	15.5-30.4	0.106-0.2	0.65-1.24	0.305-0.604	150.5-250.4	355-424
Hazardous	301-400	30.5-40.4	0.201-0.6	1.25-1.64	0.605-0.804	250.5350.4	425-504
	401-500	40.5-50.4		1.65-2.04	0.805-1.004	350.5500.4	505-604

2.3 Statistical analyses

The mean values reported by 16 air quality monitoring stations were gathered in Excel 2016 and, following data verification and cleaning, imported into SPSS for analysis. Descriptive statistics, including the mean, standard deviation (SD), median, and interquartile range (IQR), were calculated for each pollutant during the three time periods. Box plots were used to visualize the distribution of AQI values across different time periods for each pollutant. The Kruskal-Wallis test, a non-parametric method for comparing more than two independent groups, was applied to determine whether significant differences existed among AQI values across the three time periods. Next, the test statistic (H), mean rank, and *p-values* were computed for each pollutant across the years. A significance threshold of $p < 0.05$ was used to determine statistically significant differences. All statistical analyses were performed using IBM SPSS Statistics (version 27) and R (version 4.2.1).

3. Results and Discussion

The descriptive analysis showed that $PM_{2.5}$ was the dominant pollutant in all seasons, peaking at 99.4% in Autumn and remaining above 90% in Winter. Totally, before, during, and after COVID-19, $PM_{2.5}$ remained the dominant pollutant, with its AQI increasing from 109 pre-pandemic to 127 during and 143 post-pandemic. Additionally, the analysis of AQI variations across the three study periods (before, during, and after COVID-19) revealed distinct seasonal trends for different pollutants (Table 2, Figure 2, and Figure 3). As shown in Table 2 and Figure 2, in Spring, pollutants such as O_3, $PM_{2.5}$, and PM_{10} exhibited an increasing trend, with their AQI values rising after the pandemic. For instance, the mean AQI for $PM_{2.5}$ increased from 89 before the pandemic to 131 post-pandemic. In contrast, NO_2 showed a decreasing trend, dropping from 101 during COVID-19 to 81 after COVID-19.

During Summer, a similar trend was observed, where O_3, $PM_{2.5}$, and PM_{10} increased after the pandemic. As an example, the mean AQI for O_3 rose from 132 before COVID-19 to 186 after COVID-19. Meanwhile, NO_2, which showed a temporary rise during COVID-19 (mean AQI = 103), was not reported after the pandemic, suggesting a decline.

In Autumn, O_3, $PM_{2.5}$, and PM_{10} once again demonstrated increasing trends post-pandemic, while NO_2 showed a slight decline. The mean AQI for O_3 increased from 173 during COVID-19 to 215 after COVID-19, while $PM_{2.5}$ rose from 1401 during COVID-19 to 154 post-pandemic. Meanwhile, NO_2 levels declined gradually, dropping from 98 before COVID-19 to 90 during COVID-19 and further to 89 after the pandemic. In Winter, unlike other seasons, O_3 exhibited a decreasing trend, while $PM_{2.5}$ and NO_2 increased after COVID-19. The mean AQI for O_3 declined from 130 during the COVID-19 period to 122 in the post-pandemic period. Conversely, $PM_{2.5}$ levels rose from 117 before COVID-19 to 143 during the pandemic and remained elevated at 141 after COVID-19. Additionally, NO_2 increased from 82 before COVID-19 to 92 after the pandemic. Finally, as shown in Table 3, the Kruskal-Wallis test results indicate significant seasonal variations in AQI levels across the three time periods, particularly for O_3 and $PM_{2.5}$. In Spring, both O_3 (H = 49.44, $p < 0.001$) and $PM_{2.5}$ (H = 96.27, $p < 0.001$) showed substantial increases post-pandemic, while NO_2, PM_{10}, and SO_2 did not exhibit significant changes. In Summer, significant differences were observed for O_3 (H = 62.29, $p < 0.001$), $PM_{2.5}$ (H = 96.08, $p < 0.001$), PM_{10} (H = 9.13, $p = 0.002$), and NO_2 (H = 6.51, $p = 0.007$). In Autumn, only $PM_{2.5}$ exhibited significant differences (H = 102.56, $p < 0.001$), indicating worsening pollution, while other pollutants remained stable. In Winter, $PM_{2.5}$ (H = 68.05, $p < 0.001$) was the only pollutant showing a significant rise post-pandemic, while NO_2, O_3, and SO_2 did not exhibit meaningful variations. The Kruskal-Wallis test for total AQI levels showed significant differences across the three periods (before, during, and after COVID-19) for most pollutants. $PM_{2.5}$ exhibited the most substantial increase (H = 262.43, $p < 0.001$). Similarly, O_3 (H = 108.24, $p < 0.001$) and PM_{10} (H = 20.27, $p < 0.001$) showed significant post-pandemic growth. NO_2 also displayed statistical significance (H = 9.33, $p < 0.05$), although with smaller fluctuations, while SO_2 levels increased notably (H = 7.17, $p < 0.05$).

The comparison of the biannual mean quality indexes revealed that the CO and O_3 were 30 and 37, respectively, before the pandemic. These indices remained relatively constant during the pandemic (30 and 36) but increased to 34 and 39 after the pandemic. At the beginning of the pandemic, Tehran Province had over 2,200,000 students and more than 693,000 individuals attending universities in the province (Amar, 2018), and with the implementation of travel restrictions, their educational activities changed to remote learning. Additionally, with the implementation of six periods of restrictions on the activities of government employees, as well as many other occupations, and the prohibition of commuting and gathering, the closure of malls and shopping centers, the traffic generated by their movements decreased. This reduction was observed to affect the quality indexes of CO and O_3. After the end of the pandemic and the return to the initial conditions, the quality indexes of these two pollutants increased.

Table 2. Seasonal Descriptive Statistics of AQI by Pollutant: A Comparative Analysis Before, During, and After COVID-19

Season	Pollutant	Before COVID			During COVID			After COVID		
		N (%)	Mean (SD)	Median (IQR)	N (%)	Mean (SD)	Median (IQR)	N (%)	Mean (SD)	Median (IQR)
Spring	CO	1.00 (0.50)	53.00 (--)	53.00 (--)	----	----	----	----	----	----
	NO_2	4.00 (2.20)	73.50 (20.31)	70.50 (37.00)	2.00 (1.10)	101.00 (2.83)	101.00 (--)	1.00 (0.50)	81.00 (--)	81.00 (--)
	O_3	77.00 (41.40)	104.29 (35.28)	109.00 (47.50)	37.00 (19.90)	129.35 (36.01)	121.00 (57.50)	56.00 (30.1)	158.27 (37.46)	159.50 (44.30)
	PM_{10}	1.00 (0.50)	46.00 (--)	46.00 (--)	----	----	----	12.00 (6.50)	242.67 (148.69)	183.00 (260.50)
	$PM_{2.5}$	100.00 (53.80)	88.95 (23.51)	89.50 (34.00)	147.00 (79.00)	102.67 (23.31)	99.00 (33.00)	116.00 (62.40)	131.10 (33.15)	132.50 (47.50)
	SO_2	3.00 (1.60)	31.33 (0.58)	31.00 (--)	----	----	----	1.00 (0.50)	137.00 (--)	137.00 (--)
Summer	CO	----	----	----	----	----	----	1.00 (0.50)	124.00 (--)	124.00 (--)
	NO_2	13.00 (7.00)	80.00 (15.84)	81.00 (22.00)	4.00 (2.20)	102.75 (8.84)	104.00 (16.80)	----	----	----
	O_3	40.00 (21.50)	132.17 (26.13)	130.50 (26.30)	82.00 (44.10)	137.98 (26.64)	138.00 (43.30)	86.00 (46.20)	186.13 (55.05)	178.00 (55.00)
	PM_{10}	9.00 (4.80)	86.11 (41.34)	75.00 (50.50)	----	----	----	10.00 (5.40)	192.80 (104.07)	169.00 (46.50)
	$PM_{2.5}$	124.00 (66.70)	100.22 (19.69)	99.00 (31.50)	99.00 (53.20)	114.36 (25.62)	111.00 (25.00)	89.00 (47.80)	139.48 (34.70)	136.00 (37.00)
	SO_2	----	----	----	1.00 (0.50)	97.00 (--)	97.00 (--)	----	----	----
Autumn	CO	----	----	----	----	----	----	3.00 (1.70)	184.33 (45.57)	200.00 (--)
	NO_2	1.00 (0.60)	98.00 (--)	98.00 (--)	4.00 (2.20)	90.50 (7.33)	92.50 (13.00)	1.00 (0.60)	89.00 (--)	89.00 (--)
	O_3	----	----	----	6.00 (3.30)	173.00 (57.40)	174.00 (71.50)	5.00 (2.80)	214.80 (50.44)	206.00 (84.00)
	PM_{10}	----	----	----	2.00 (1.10)	205.00 (128.69)	205.00 (--)	2.00 (1.10)	258.00 (82.02)	258.00 (--)
	$PM_{2.5}$	179.00 (99.40)	119.92 (28.87)	120.00 (37.00)	167.00 (92.80)	140.74 (28.68)	152.00 (43.00)	169.00 (93.90)	154.10 (26.83)	156.00 (32.50)
	SO_2	----	----	----	1.00 (0.60)	95.00 (--)	95.00 (--)	----	----	----
Winter	CO	----	----	----	----	----	----	----	----	----
	NO_2	6.00 (3.40)	81.50 (17.40)	80.50 (29.00)	11.00 (6.20)	90.91 (12.39)	93.00 (20.00)	2.00 (1.10)	92.50 (16.26)	92.50 (--)
	O_3	----	----	----	5.00 (2.80)	129.80 (27.11)	131.00 (51.00)	11.00 (6.20)	121.82 (24.48)	110.00 (43.00)
	PM_{10}	3.00 (1.70)	72.67 (21.08)	61.00 (--)	----	----	----	----	----	----
	$PM_{2.5}$	169.00 (94.90)	117.09 (31.19)	115.00 (47.50)	160.00 (89.90)	143.41 (30.01)	154.00 (44.00)	161.00 (90.40)	141.23 (30.19)	152.00 (47.00)
	SO_2	----	----	----	2.00 (1.10)	115.00 (8.48)	115.00 (--)	3.00 (1.70)	117.33 (18.56)	119.00 (--)
Total	CO	1.00 (0.10)	53.00 (--)	53.00 (--)	----	----	----	4.00 (0.50)	169.25 (47.90)	166.50 (88.80)
	NO_2	24.00 (3.30)	80.04 (16.51)	81.00 (23.80)	21.00 (2.90)	94.05 (11.17)	95.00 (17.00)	4.00 (0.50)	88.75 (10.84)	85.00 (19.30)
	O_3	117.00 (16.00)	113.82 (34.95)	118.00 (51.00)	130.00 (17.80)	136.82 (32.21)	131.50 (48.30)	158.00 (21.60)	172.68 (51.44)	164.50 (57.50)
	PM_{10}	13.00 (1.80)	79.92 (36.76)	67.00 (41.00)	2.00 (0.30)	205.00 (128.69)	205.00 (--)	24.00 (3.30)	223.17 (125.73)	175.00 (74.00)
	$PM_{2.5}$	572.00 (78.40)	109.40 (29.48)	107.00 (40.00)	573.00 (78.50)	127.16 (32.41)	124.00 (55.50)	535.00 (73.30)	142.81 (31.74)	150.00 (43.00)
	SO_2	3.00 (0.40)	31.33 (0.58)	31.00 (--)	4.00 (0.50)	105.50 (12.04)	103.00 (--)	4.00 (0.50)	122.25 (18.06)	127.00 (33.30)

Note: Certain data points lacked a reported index, resulting in the presence of empty cells

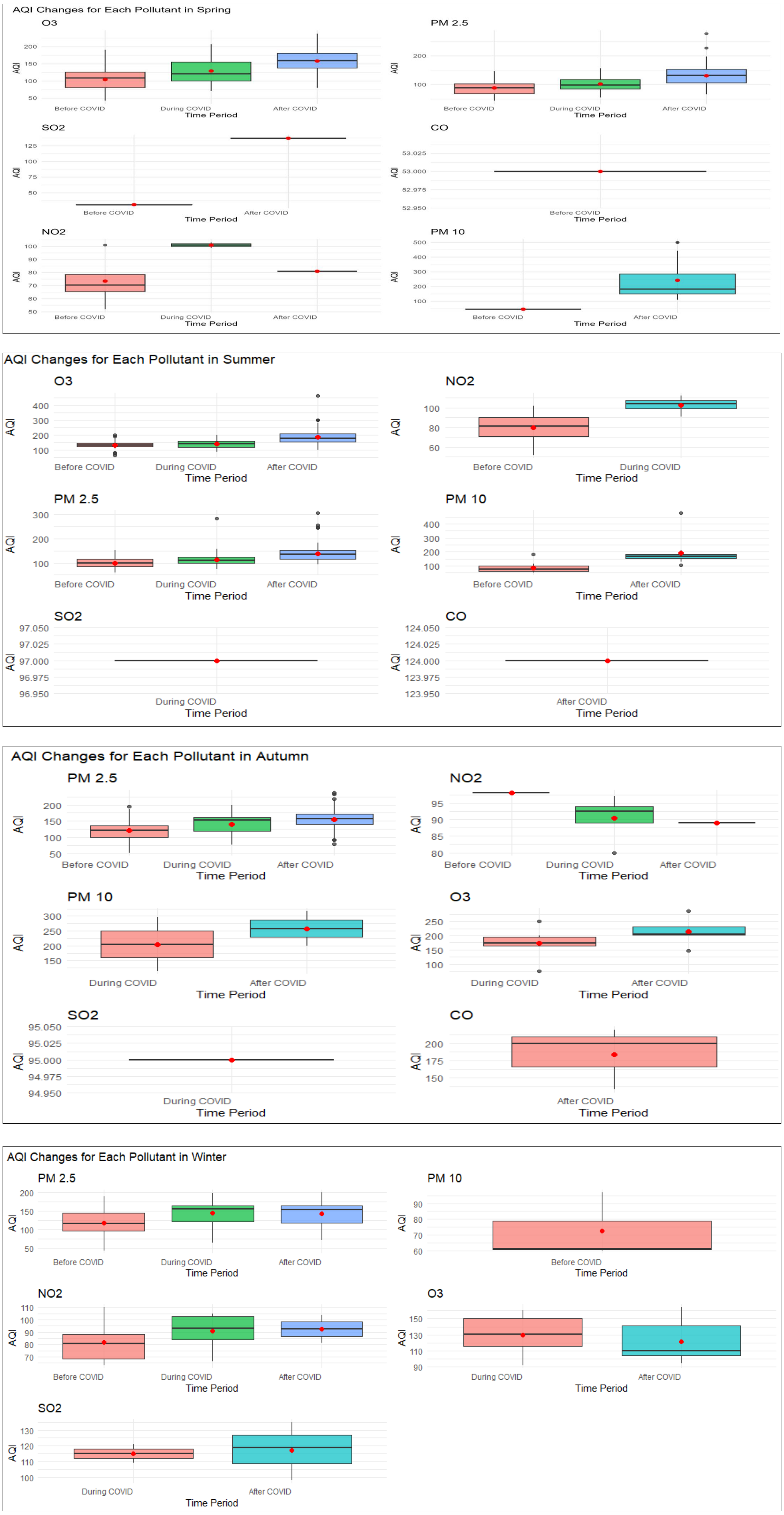

Figure 2. Box Plot of Seasonal Air Quality Index (AQI) by Pollutant Type

Table 3. Seasonal Analysis of AQI by Pollutant Type: A Kruskal-Wallis Comparison Before, During, and After COVID-19

Season	Pollutant	H (Chi-square statistic)	Mean Rank			*p-value*
			Before COVID	During COVID	After COVID	
Spring	CO	----	----	----	----	----
	NO_2	2.57	4.00	2.00	1.00	0.276
	O_3	49.44	77.00	37.00	56.00	<0.001
	PM_{10}	2.58	1.00	---	12.00	0.108
	$PM_{2.5}$	96.27	100.00	147.00	116.00	<0.001
	SO_2	2.00	3.00	----	1.00	0.157
Summer	CO	----	----	----	----	----
	NO_2	6.51	7.27	14.63	----	0.007
	O_3	62.29	70.00	80.46	143.47	<0.001
	PM_{10}	9.13	5.89	----	13.70	0.002
	$PM_{2.5}$	96.08	105.91	154.94	228.71	<0.001
	SO_2	----	----	----	----	----
Autumn	CO	----	----	----	----	----
	NO_2	2.50	6.00	3.25	2.00	0.287
	O_3	1.63		4.83	7.40	0.201
	PM_{10}	0.60		2.00	3.00	0.439
	$PM_{2.5}$	102.56	173.13	273.41	332.66	<0.001
	SO_2	----	----	----	----	----
Winter	CO	----	----	----	----	----
	NO_2	1.42	7.75	10.95	11.50	0.492
	O_3	0.32	----	9.50	8.05	0.571
	PM_{10}	----	2.00	----	----	----
	$PM_{2.5}$	68.05	173.01	288.87	278.49	<0.001
	SO_2	0.00	----	3.00	3.00	1.00
Total	CO	2.00	1.00	----	3.50	0.400
	NO_2	9.33	18.85	31.88	25.75	0.009
	O_3	108.24	126.94	186.56	272.85	<0.001
	PM_{10}	20.27	8.38	24.50	25.92	<0.001
	$PM_{2.5}$	262.43	603.68	857.64	1075.34	<0.001
	SO_2	7.17	2.00	6.25	8.75	0.001

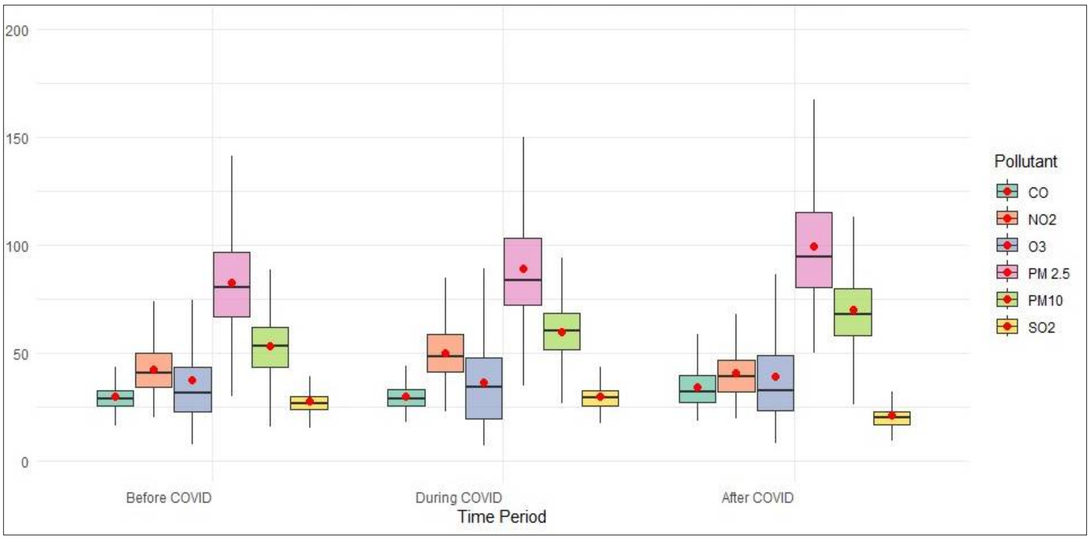

Figure 3. Box Plot of Air Quality Index (AQI) by Pollutant Type Before, During, and After COVID-19

During the COVID-19 pandemic, traffic decreased due to the closure of commercial, educational, and service sectors. With the decrease in traffic, volatile substances that play an effective role in the formation of ozone in the air also decreased, resulting in a decrease in ozone during this period. Carbon monoxide, which is one of the main sources of its emission in the combustion environment of fossil fuels in vehicles, has also decreased during this period (Jaffe, 1968). The quality indexes of NO_2 and SO_2 were 42 and 27before the pandemic, increased to 50 and 30 during the pandemic, and then decreased to 40 and 21 after the pandemic. The similar trend of continuous increase and decrease of these two pollutants during the three periods under investigation indicated that they may have a common source. The industries surrounding this province, which account for over 40% of the country's industrial units and utilize sulfur-containing fossil fuels, have significantly contributed to the concentrations of these pollutants.

The consumption of fossil fuels in industries and vehicles is the main source of nitrogen dioxide and sulfur emissions in the air. In previous years, Mazut (heavy fuel oil) was used as fuel in power plants. Towards the end of 2021-2022, following the announcement by the Environmental Protection Organization of Iran, the use of Mazut was forbidden in all power plants, industrial units, and mines, resulting in a decrease in the concentrations of these two pollutants during 2022-2023 and 2023-2024 (Iran News Paper, 2021).

By comparing the quality indexes of $PM_{2.5}$ and PM_{10}, it was observed that before the pandemic, their indexes were

82 and 53, respectively. These indexes increased during the pandemic to 89 and 60 and continued to rise after the pandemic, with quality indexes of 100 and 72.

One of the sources of airborne particles is the resuspension and dispersion of particles from the soil due to wind. The lower the amount of atmospheric precipitation, the drier the land surface and the greater the possibility of particle dispersion. In recent years, the amount of precipitation in Tehran has decreased significantly, with amounts of 220, 265, 263, 128, 173, and 99 mm recorded from 2018 to 2023, respectively.

3.1 Comparison of the mean AQI in the Biannual periods before, during, and after the pandemic

The daily AQI is determined by the highest quality index among CO, O_3, SO_2, NO_2, $PM_{2.5}$, and PM_{10} (Li et al., 2018). Across the three periods-before, during, and after the coronavirus pandemic-$PM_{2.5}$ particles were the index pollutant on 78%, 78% and 73% of days, respectively, with mean values of 106, 125, and 141. O_3 served as the index pollutant on 16%, 18% and 21% days during the same periods, which had a mean of 118, 134, and 172, respectively, during the three periods before, during, and after the coronavirus. As can be seen, during the three periods under study, the concentration of $PM_{2.5}$ particles has increased significantly, and also the O_3 pollutant, which was not in unacceptable conditions on any day until 2011, has been introduced as an index pollutant on more days and in higher concentrations (Taghizadeh et al., 2019).

The prevailing winds in Tehran province are western, and the presence of the Alborz Mountain range significantly diverts the western winds towards Shahriar. Undoubtedly, many industrial units that operate in the west of Tehran can have a significant impact on increasing the concentration of suspended particles entering the city and take pollutants from the west of Tehran into the city (Delfanazari et al., 2017; Rahimi et al., 2021). After the western wind, the most important wind in the summer comes from the south, which originates from the desert and blows towards Tehran. When blowing, it takes dust particles to the province. Therefore, it seems that Tehran province is more affected by suspended particles from the western and southern regions (Jafari Hombari & Pazhoh, 2022). In general, the AQI in Tehran's air is on an upward trend. The main causes of this phenomenon are the increase in population, the development of industries, the deterioration of pollutant control equipment in industries and vehicles, the sharp decrease in rainfall, and the use of diesel fuel in power plants (Amar, 2018). The air quality index during the three study periods is shown in Figure 4.

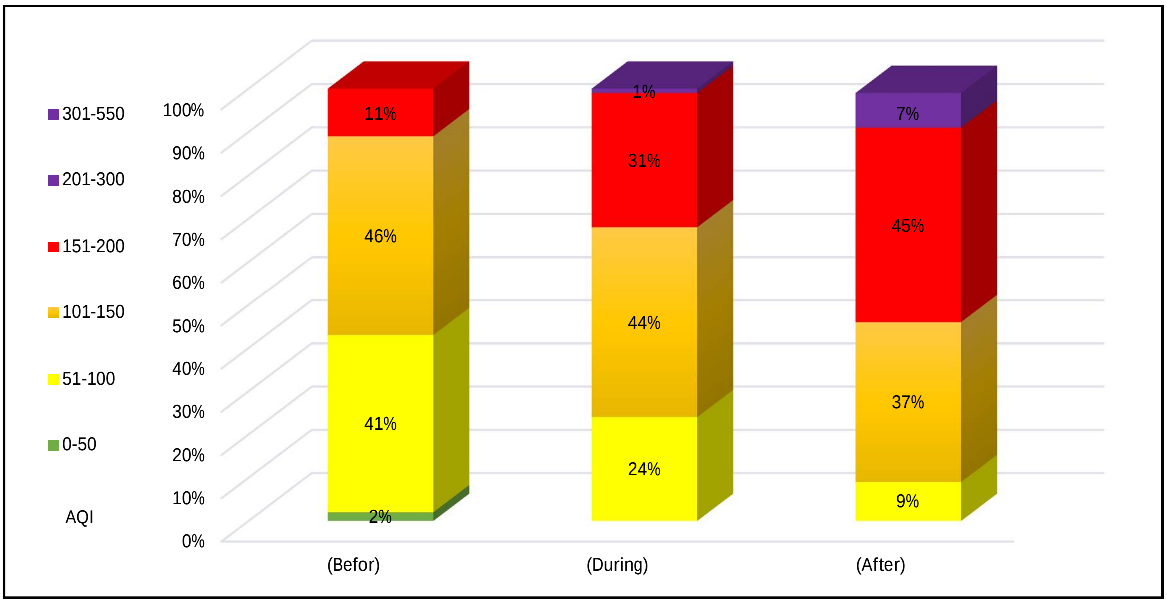

Figure 4. AQI status in percentage of days during the six years studied

A study in South Korea claimed that $PM_{2.5}$, PM_{10}, NO_2, and CO, particularly associated with industrial activities and traffic, decreased during the pandemic period compared to the mean levels of the previous year in all cities (Ju et al., 2021). However, $PM_{2.5}$ and PM_{10} in Tehran consistently showed an increasing trend during the periods under investigation, while NO_2 and SO_2 pollutants decreased after the pandemic period compared to the pandemic period. Additionally, air pollution in Barcelona, Spain, attributed to PM_{10}, NO_2, and SO_2, decreased during the pandemic, while O_3 levels increased (Tobías et al., 2020). Similarly, an increase in O_3 concentration was observed in Tehran during the investigated periods. In the US, during the pandemic, $PM_{2.5}$, O_3, CO, and PM_{10} levels did not fall below the expected limits in any state, and for NO_2, only Arizona had lower levels than expected throughout the quarantine weeks (Bekbulat et al., 2021). These findings are consistent with the present study, which did not indicate a reduction in the mean concentration of any pollutants during the pandemic. In Rio de Janeiro, Brazil, the concentrations of PM, CO, NO_2, and O_3 during the quarantine period showed significant differences compared to the values obtained during the same period of the previous year and the weeks before the pandemic. CO levels exhibited the highest reduction, followed by a decrease in NO_2 emissions (Dantas et al., 2020). Results from research conducted in 20 major cities worldwide demonstrated that the extent and compliance of quarantine measures implemented by countries had an impact on the changes in air pollution levels during the pandemic, compared to the pre-pandemic period (Fu et al., 2020).

4. Conclusion

Comparing the air quality indexes during three two-year periods before, during, and after the pandemic in the megacity of Tehran showed an increase in the $PM_{2.5}$ particles, which included 78%, 78% and 73% of the days, respectively, and on these days, it had a mean of 106, 125, and 141, respectively, during the three periods. Also, O_3 was the index pollutant in calculating the AQI on 16%, 18% and 21% of the days in these periods, which had a mean of 118, 134 and 172, respectively, in addition, the quality indexes of SO_2 and NO_2 pollutants increased during the pandemic compared to the pre period, but decreased after period with the announcement of Mazut fuel ban in industries around big cities. The results show that reducing traffic and preventing the use of Mazut fuel in power plants have had significant effects on reducing air pollutants, and the sharp decrease in precipitation in recent years has increased the dispersion and emission of particles.

Authors' Contributions

Zohre Farahmandkia: Data curation; Writing-original draft. **Koorosh Kamali, Fatemeh Masaebi:** Formal analysis; Data curation.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Ethical considerations

This study was approved by the Ethics Committee of Zanjan University of Medical Science. (IR.ZUMS.BLC.1403.154).

Using Artificial Intelligence

Artificial intelligence was not used in this research.

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