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Variations in the Concentration of Air Pollutants due to the COVID-19 Lockdown in Istanbul, Turkey

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ABSTRACT

Countries have implemented partial or full quarantine practices to reduce the effects of the COVID-19 pandemic, which severely affects the whole world and controls the increase in cases and deaths. Studies have observed improvements in air pollution due to reducing emissions from traffic and industrial processes during lockdown periods. In this study, the effects of quarantine activities on air quality in the pre-COVID-19 period and during the COVID-19 pandemic, both in 2020 and 2021, were examined through the data obtained from the air quality monitoring stations located in the three districts with the highest traffic density in Istanbul, the most populated city of Turkey.

Based on the findings obtained from the study, it can be concluded that lockdown applications contributed to the reduction of air pollution in the examined regions. In addition, another finding is that there is a positive correlation between air quality parameters. It is expected that the results of the study will lead the decision-makers in the areas of dissemination of renewable energy systems instead of energy generation from coal-fired power plants and the widespread use of electric vehicles instead of diesel-fueled vehicles for many countries that have committed to net-zero carbon emissions within the scope of the Paris Agreement and the European Green Deal.

1. INTRODUCTION

It is well known that the SARS-CoV-2 virus, which was first recorded in Wuhan, China, in December 2019, quickly spread to other countries and was declared a pandemic by the World Health Organization (WHO) on March 11, 2020 [1-2].
Due to the rapidly peaking number of cases, many countries have started implementing restrictive measures such as curfew at certain time intervals to prevent the increase in the number of cases [1]. Globally, as of February 01, 2022, there have been 376.478.335 confirmed cases of COVID-19, including 5.666.064 deaths, reported to WHO. As of January 30, 2022, a total of 9.901.135.980 vaccine doses have been administered [3]. The first case in Turkey was recorded on March 11, 2020, and the first death occurred on March 17, 2020. By February 01, 2022, the total number of cases and deaths reached 10,808,770 and 85,600 [4]. Turkey began to take many measures to prevent the increase in confirmed cases. The first measure started with the suspension of all flights from China on February 05, 2020. After that, on March 16, 2020, face-to-face education was suspended in primary and secondary schools and universities, and online education was started. The first curfew was imposed on citizens over 65 years of age and those with chronic diseases on March 22, 2020. Between April 11 and April 19, 2020, a curfew was imposed in Zonguldak and 30 major cities on weekends. In addition, a wider curfew was introduced during the official holidays of April 23 and May 01, and 23-26 April and 01-03 May 2020 were declared as quarantine periods. In addition, a curfew was implemented in 15 provinces between 8-10 May and 15-19 May 2020, while a curfew was implemented in all provinces of Turkey on 22-26 May 2020. The lockdowns imposed in 2021 were as follows: A 2-week partial lockdown was implemented starting from 19.00 on April 14, 2021. A curfew was imposed between 19.00 and 05.00 on weekdays and covered the entire weekend. A full lockdown had been announced until 05:00 on May 17, effective from 19:00 on April 29, 2021 [5]. With the implementation of the curfew, it is possible to reduce emissions from traffic and industrial facilities.

Air pollution, which occurs depending on natural (i.e., volcanic eruptions) and anthropogenic drivers (i.e., greenhouse gases caused by traffic emissions, industrial activities, such as the burning of fossil fuels in power plants and during the production of cement), is of severe significance on public health as one of the most important environmental issues, regionally or globally. Air pollutants are classified as sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide

(NO_2), ozone (O_3), lead (Pb), and particulate matter (PM) by Environmental Protection Agency [6].

Studies in the literature focus on the effects of quarantine practices on air pollution. Most studies have revealed that lockdown applied partially or fully positively impacts declining air pollution [7-9]. Some studies examining the effects of quarantine measures on air quality are presented below.

Ali Sahraei et al. (2021) [1] investigated the improvements in air quality in Turkey's Istanbul and Ankara provinces based on the limitation in public transportation usage. Due to lockdown measures from January to May 2020, the improvements were estimated at 9% and 47% for Ankara and Istanbul. Gao et al. (2021) [10] investigated the impact of changes in human activities on air quality during the COVID-19 pandemic by determining the relationships between air quality, traffic volume, and meteorological conditions based on lockdown activities, considering megacities of China, such as Wuhan, Beijing, Shanghai, and Guangzhou for the period January–May between 2016 and 2020. Following the results obtained from the present work, the change rates of $PM_{2.5}$, NO_2, and SO_2 before and during the lockdown in the four megacities showed diversities from −55.4% to 78.2% because of meteorological conditions of provinces. Gautam et al. (2021) [11] investigated the air quality index (AQI) of Delhi (DTU, Okhla and Patparganj), Haryana (Jind, Palwal and Hisar), and Uttar Pradesh (Agra, Kanpur and Greater Noida) from February 17, 2020, to May 4, 2020, including lockdown period started from April 25, 2020, by the Government of India. Results suggested that AQI has improved by up to 30–46.67% after lockdown. Goren et al. (2021) [12] investigated the impacts of lockdown on the air quality of 11 cities, looking at concentrations of air quality parameters containing $PM_{2.5}$, PM_{10}, SO_2, NO_2, NO, NO_x, O_3 and CO obtained from 51 air quality measurement stations (AQMS) from March – April period of 2020 compared with that of the previous year. While $PM_{2.5}$ and PM_{10} concentrations were not significantly affected, NO, NO_2 and NO_X concentrations were decreased, SO_2 did not show a significant change. Hu et al. (2021) [13] assessed air quality by looking at the variations in the concentration of air pollutants and air quality index in China (Wuhan), Japan (Tokyo), the Republic of Korea (Daegu), and India (Mumbai) during and after lockdowns. The results indicated that air pollution levels were positively correlated with reducing pollutant levels during and after lockdowns in these cities. Moreover, the lockdown policy generally reduced air pollution, which is more significant for regions with high air pollution levels. Sahoo et al. (2021) [14] investigated the changes in air quality, comparing the COVID-19 pandemic periods, including the lockdown and unlock period (post-lockdown) with pre-lockdown in the state of Maharashtra, the worst-hit state in India. Results demonstrated that atmospheric pollutants such as $PM_{2.5}$, PM_{10}, NO_x, and CO were substantially reduced during the lockdown and unlock phases, with the greatest reduction in cities having larger traffic volumes. Compared with the immediate pre-lockdown period, the average $PM_{2.5}$ and PM_{10} were reduced by 51% and 47%, respectively, during the lockdown periods, resulting in a 'satisfactory' air quality index level (AQI) a result of reduced vehicular traffic and industrial closing. Shakoor et al. (2020) [15] investigated the impacts of lockdown on the environmental pollutants (CO, NO_2, SO_2, $PM_{2.5}$ and PM_{10}) with (the year 2020) and without (the year 2019) the lockdown period in the majorly hit states and provinces of the USA and China, respectively. The results showed that the overall concentrations of CO, NO_2 and $PM_{2.5}$ were decreased by 19.28%, 36.7% and 1.10%, respectively, while PM_{10} and SO_2 were increased by 27.81% and 3.81%, respectively, in five selected states of the USA during the lockdown period. However, in the case of chosen provinces of China, overall, the concentrations of all selected pollutants, i.e., CO, NO_2, SO_2, $PM_{2.5}$ and PM_{10}, were reduced by 26.53%, 38.98%, 18.36%, 17.78% and 37.85%, respectively. Shehzad et al. (2020) [16] investigated the variation in the air pollution in India to demonstrate the impacts of COVID-19 lockdown from January 2020 to April 2020 using data from European Space Agency (ESA) and Central Pollution Control Board (CPCB) online portal. Results illustrated that the air quality of Indian territory improved significantly during COVID-19. NO_2 concentration showed a substantial decrease in Mumbai and Delhi, which are among the most populated cities in India.

Within the scope of this study, the changes in air quality parameters containing PM_{10}, SO_2, CO, NO_2 and O_3 based on full and partial lockdowns implemented in Istanbul in 2020 and 2021 were examined using data obtained from Air Quality Monitoring (AQM) stations installed in Aksaray, Beşiktaş and Kadıköy districts, where the traffic density is high almost every hour of the day in Istanbul, the most crowded city of Turkey, for April and July of 2019, 2020 and 2021. The difference of the present study from the previous works conducted for the province of Istanbul in the literature is that it covers the lockdown period imposed in 2021 and compares the quarantine process applied in two different periods (years 2020 and 2021).

2. METHODS

2.1. Description of the regions

The present work examined variations in the air quality of the Istanbul province of Turkey using data from AQM stations located in three different zones with different population densities. Locations of AQM stations examined in the present work are presented in Figure 1. Stations in Aksaray and Beşiktaş are located on the European side of Istanbul, and Kadıköy is located on the Asia continent. The general information about locations is presented in Table 1.

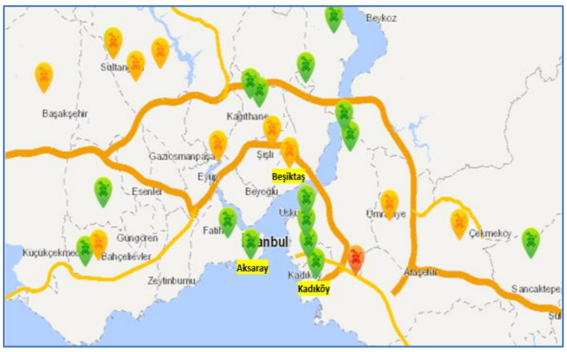

Figure 1. Locations of Air Quality Monitoring Stations (Adopted from National Air Quality Monitoring Network, Republic of Turkey, Ministry of Environment, Urbanization and Climate Change, NAQMN, 2022) [17].

TABLE I
THE PROPERTIES OF AQM STATIONS

AQM Stations	Latitude	Longitude	Population
Aksaray	28.9547	41.0147	382.990
Beşiktaş	29.0100	41.0538	178.938
Kadıköy	29.0336	40.9919	485.233

2.2. Data collection

The present work examined variations in the air quality of Istanbul province of Turkey for pre-and during the COVID-19 pandemic period using data obtained from Air Quality Monitoring Stations under the Ministry of Environment, Urbanization and Climate Change [17].

2.3. Statistical Analysis

To evaluate the interactions of air quality parameters statistically, Pearson's rank correlation tests were used as empirical methodologies by the Statistics Software IBM SPSS® version 23. The value of 0.05 was considered the significance level.

3. RESULTS AND DISCUSSION

3.1. Variations in the concentration of air pollutants

Sources of air pollutants, such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), and particulate matter (PM), vary widely. In this context, burning fuels for road transport and electricity generation is particularly important. Pollutants directly released into the atmosphere are called primary pollutants, while some pollutants that are chemically reacted with other pollutants in the air are known as secondary pollutants. The major sources of SO_2 and CO are the combustion of fossil fuels containing sulfur and carbon, particularly from power stations burning coal and vehicles. The pathways for NOx formation are lightning, forest fires and microbial activities in the soil [18]. Vehicle emissions and gas stoves are the major sources of most outdoor and indoor NO_2. Moreover, the precursors of ozone are produced by vehicle emissions, industrial processes, chemical solvents, and natural sources [19]. Studies in the literature have depicted improvements in air pollution due to the reductions in the activities of sectors that contribute significantly to greenhouse gas emissions, such as roads and airlines, due to the restrictions during the pandemic. The results obtained differ according to countries, cities and even districts [20-21]. Ekici et al. (2021) [20] investigated the concentration values of air pollutants caused by commercial air transport in Turkey regarding quarantine applications of the COVID-19 pandemic period accepted from March to August 2020 compared with starting from January 2017. The monthly pollutant amount showed remarkable declines during the pandemic due to reducing domestic flights and international traffics. Ghahremanloo et al. (2021) [21] investigated the air pollution levels comparing pre-lockdown and lockdown periods (between February 2019 and February 2020) based on the COVID-19 outbreak in East Asia, including Beijing-Tianjin-Hebei (BTH), Wuhan, Seoul, and Tokyo regions using data from the Sentinel-5P and the Himawari-8 satellites to examine concentrations of NO_2, HCHO, SO_2, and CO, and the aerosol optical depth (AOD). Results showed that the greatest reductions in pollutants occurred in Wuhan, with a decrease of almost 83%, 11%, 71%, and 4% in the column densities of NO_2, HCHO, SO_2, and CO, respectively, and a decrease of about 62% in the AOD. With large reductions in the concentrations of NO_2 during lockdown situations, they suggested that significant increases in surface ozone in East China from February 2019 to February 2020 are likely the result of less reaction of NO and O_3 caused by significantly reduced NO_X concentrations and less NO_X saturation in East China during the daytime. Within the scope of this study, how the decrease in the use of public transportation, the reduction in the working load of industrial facilities and the decline in traffic density affect the air pollution due to partial and full-time lockdowns based on the COVID-19 outbreak were determined considering the year 2019 before the pandemic. Statistical values, including minimum, maximum and average concentration values of air pollutants, including PM_{10}, SO_2, CO, NO_2 and O_3 obtained from three AQM stations located in Istanbul for years between 2019 and 2021, including only three months (April 01 – July 01) showing the lockdown periods in 2020 and 2021 were presented in Table 2.

TABLE II

STATISTICAL VALUES OF AIR POLLUTANTS BETWEEN APRIL 01 AND JULY 01, 2019-2021 IN AQM STATIONS

Period		Air Quality Monitoring Stations								
		Aksaray			Beşiktaş			Kadıköy		
April – July 2019		Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Air Quality Parameters (μgm^{-3})	PM_{10}	22.6	101	46.7±16.2	14.1	82.7	36.3±13.1	11.9	81.6	33.7±14.1
	SO_2	0.89	14.3	3.68±2.67	1.09	16.5	4.12±3.18	1.07	12.6	3.41±2.35
	CO	2.74	947	440±142	145	905	433±118	119	954	470±130
	NO_2	71.0	158	112±18.8	41.9	127	74.5±21.9	26.2	87.5	49.5±13.8
	O_3	7.04	65.7	25.8±15.1	8.90	63.9	30.4±13.5	8.20	52.7	29.3±10.8
April – July 2020										
Air Quality Parameters (μgm^{-3})	PM_{10}	16.5	83.9	36.4±12.9	11.7	55.9	27.0±9.81	6.19	86.3	29.2±17.8
	SO_2	0.83	5.25	2.42±0.93	0.93	12.3	3.77±2.27	2.04	9.14	4.52±1.45
	CO	133	876	409±160	78.5	1066	297±168	187	983	564±191
	NO_2	24.0	150	88.2±30.9	8.96	105	53.2±24.1	42.0	199	83.9±23.1
	O_3	9.73	66.9	35.9±15.0	7.22	53	24.7±12.1	6.40	40.6	18.4±7.46
April – July 2021										
Air Quality Parameters (μgm^{-3})	PM_{10}	14.1	100	36.6±15.8	10.1	70.5	27.5±11.6	7.87	80.1	26.7±13.9
	SO_2	1.39	12.1	4.67±1.89	0.67	15.2	4.94±2.84	0.82	8.62	2.99±1.28
	CO	58.4	1016	454±160	235	899	517±109	37.9	659	219±181
	NO_2	31.7	299	186±61.6	10.1	62.3	32.0±11.0	24.5	97.3	56.5±17.8
	O_3	2.28	40.6	16.6±9.19	1.23	46.8	11.4±10.1	6.54	32.4	23.1±5.18

Although Istanbul's Aksaray, Beşiktaş, and Kadıköy districts differ in terms of air quality, it can be expressed by looking at the decrease in the average concentrations of CO, NO_2 and O_3 pollutants that the quarantine practices covering the year 2020 contributed to the improvement of the air quality, especially in Beşiktaş. According to Table 1, it can be concluded that the district with a more effective improvement in air quality in 2021 is Kadıköy. Normalized concentrations of air pollutants based on pre-COVID-19 and COVID-19 periods for AQM stations examined in the present work are demonstrated in Figure 2.

To better understand the impact of lockdown applications on air quality improvements, variations in the concentration of air pollutants were also presented in Table 3. When Figure 2 and Table 3 are evaluated together, a decrease was observed in the concentrations of all pollutants except for the O_3 parameter for the Aksaray district with the lockdown effect applied in 2020, while there was a decrease in only the O_3 concentration in 2021.

For the Beşiktaş district, it is seen that the quarantine implemented in 2020 improved the air quality in all parameters, and there was a decrease in NO_2 and O_3 concentrations in 2021. As for the district of Kadıköy, it is noticed that quarantine practices in 2020 caused a decline in PM_{10} and O_3 concentration, and in 2021, lockdown had a better influence on air pollution.

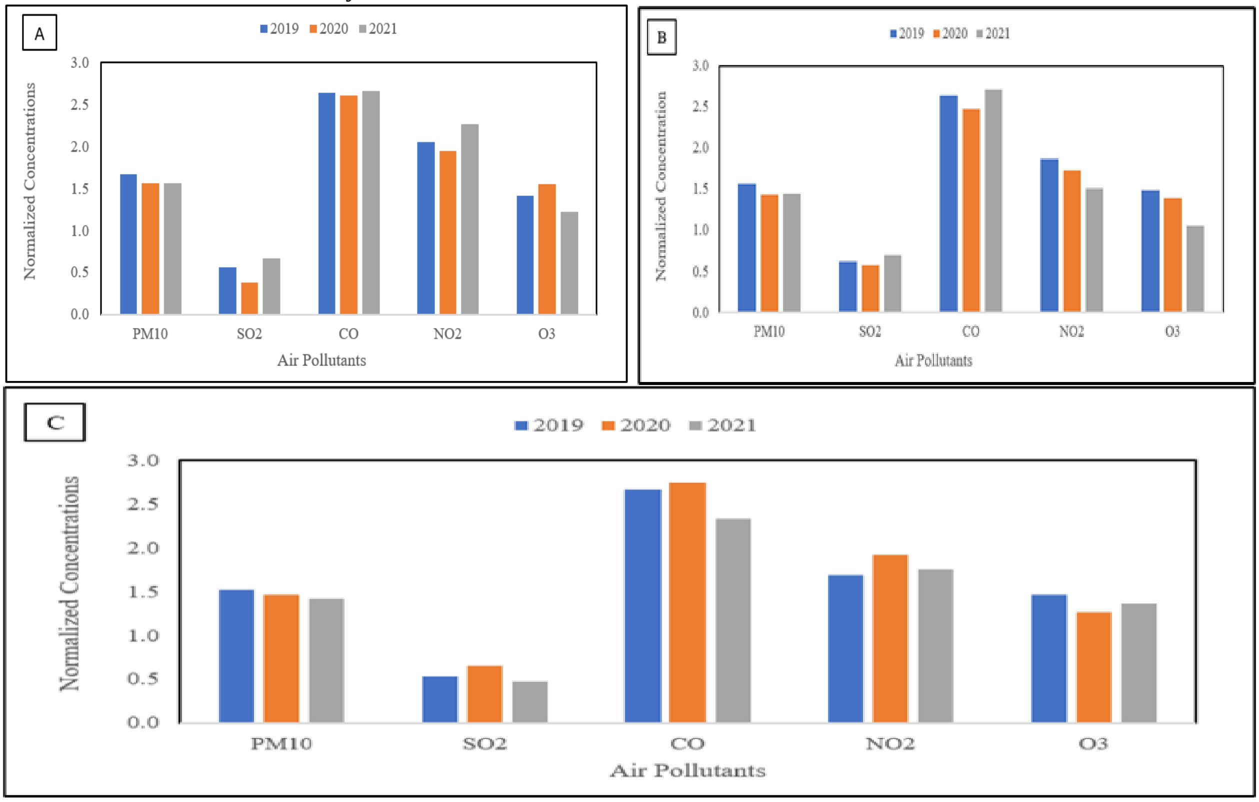

Figure 2. Normalized Concentrations of Air Pollutants based on pre-COVID-19 and COVID-19 Period for Three AQM Stations, in which A stands for Aksaray, B is Beşiktaş and C represents Kadıköy. The pre-COVID-19 period stands for 2019, and the COVID-19 period represents 2020 and 2021.

TABLE III

VARIATIONS IN THE CONCENTRATION OF AIR POLLUTANTS BETWEEN PRE-COVID-19 AND COVID-19 PERIOD

Pollutants	Variations (μg/m³)								
	Aksaray			Beşiktaş			Kadıköy		
	2019-2020	2020-2021	2019-2021	2019-2020	2020-2021	2019-2021	2019-2020	2020-2021	2019-2021
PM_{10}	-10.3	0.20	-10.1	-9.30	0.50	-8.80	-4.50	-2.50	-7.00
SO_2	-1.26	2.25	0.99	-0.35	1.17	0.82	1.10	-1.53	-0.42
CO	-31.0	45.0	14.0	-136	220	84.0	94.0	-345	-251
NO_2	-23.8	97.8	74.0	-21.3	-21.2	-42.5	34.4	-27.4	7.00
O_3	10.1	-19.3	-9.20	-5.70	-13.3	-19.0	-10.9	13.2	-24.1

It can be said that the results of the present study are consistent with those of previous studies. Baysan et al. (2021) [5] compared average values of air quality parameters, including particulate matter (PM_{10}), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), and ozone (O_3) values in March, April, and May between 2017 and 2020 and their activity data in the same months of 2020 when Turkey applied the strict measures to prevent the fast increase in the confirmed cases of 31 cities consisting of 30 metropolitan cities and Zonguldak. Results showed that during the lockdown period, the PM_{10} and NO_2 levels decreased from 47.6 $\mu g/m^3$ to 38.1 $\mu g/m^3$ and from 54.8 $\mu g/m^3$ to 25.7 $\mu g/m^3$, respectively, compared with the 3-month average parameters of the previous 3 years. Celik- Gul (2021) [22] investigated how the concentration values of the air quality parameters consisting of particulate matter (PM_{10}), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), nitrogen oxide (NO), nitrogen oxides (NO_x), and ozone (O_3) concentrations obtained from 19 air monitoring stations (AMSs) in Istanbul, the most affected city with more than half of Turkey's cases change with lockdown applications. Results indicated a clear decline in

PM_{10}, NO_2, NO, and NOx concentration levels during the pandemic compared to the normal times in Istanbul.

Ozbay and Koc (2021) [23] investigated the variations in air pollution during the COVID-19 pandemic lockdown period (March–June 2020) for an industrialized city of Turkey, Izmit using data from four different air quality monitoring stations. Results showed that the lockdown period reduced pollution levels in urban, industrialized, and rural areas.

The current study presents the variations as percentages in the air pollutants between 2019 and 2021 in Figure 3. When compared to the 3-month average values of the previous year, in 2020 in the Aksaray district, the pollutant SO_2 showed a maximum decrease with a decrease from 3.68 μg/m^3 to 2.42 μg/m^3. According to the quarantine process implemented in 2021, when the concentration values are compared with the previous two years, the maximum decrease was observed in O_3, which decreased from 25.8 μg/m^3 to 16.6 μg/m^3 in a ratio of 55.4%.

In Beşiktaş, when the concentration of pollutants during the first lockdown applications of the COVID-19 was compared to the 3-month average values of the previous year, it was observed that the concentrations of CO, NO_2, PM_{10}, O_3 and SO_2 pollutants decreased by 46, 40, 34, 23 and 9 %, respectively. In 2021, the highest reduction in the concentration of pollutants was observed in O_3 (62.5 %), followed by NO_2 (57%) and PM_{10} (32%). As for the Kadıköy district, only O_3(59 %) and PM_{10} (15%) showed a decrease in their concentration in 2020 compared to the previous year.

Considering the comparison of values between 2019 and 2021, the maximum decline was observed in O_3 (82 %), similar to Beşiktaş province, followed by CO (53 %), PM_{10} (26 %) and SO_2 (14 %). As a result, the pollutant, which was observed with the highest reduction in its concentration during the first lockdown implementation compared to the pre-COVID-19 period, was determined as O_3 with a ratio of 59 %; similarly, in 2021, O_3 showed the maximum reduction in its concentration compared with others. Moreover, results obtained from the current study pointed out that Aksaray, Beşiktaş and Kadıköy demonstrated the highest decline in SO_2, CO and O_3, respectively, during the first period of lockdown applications.

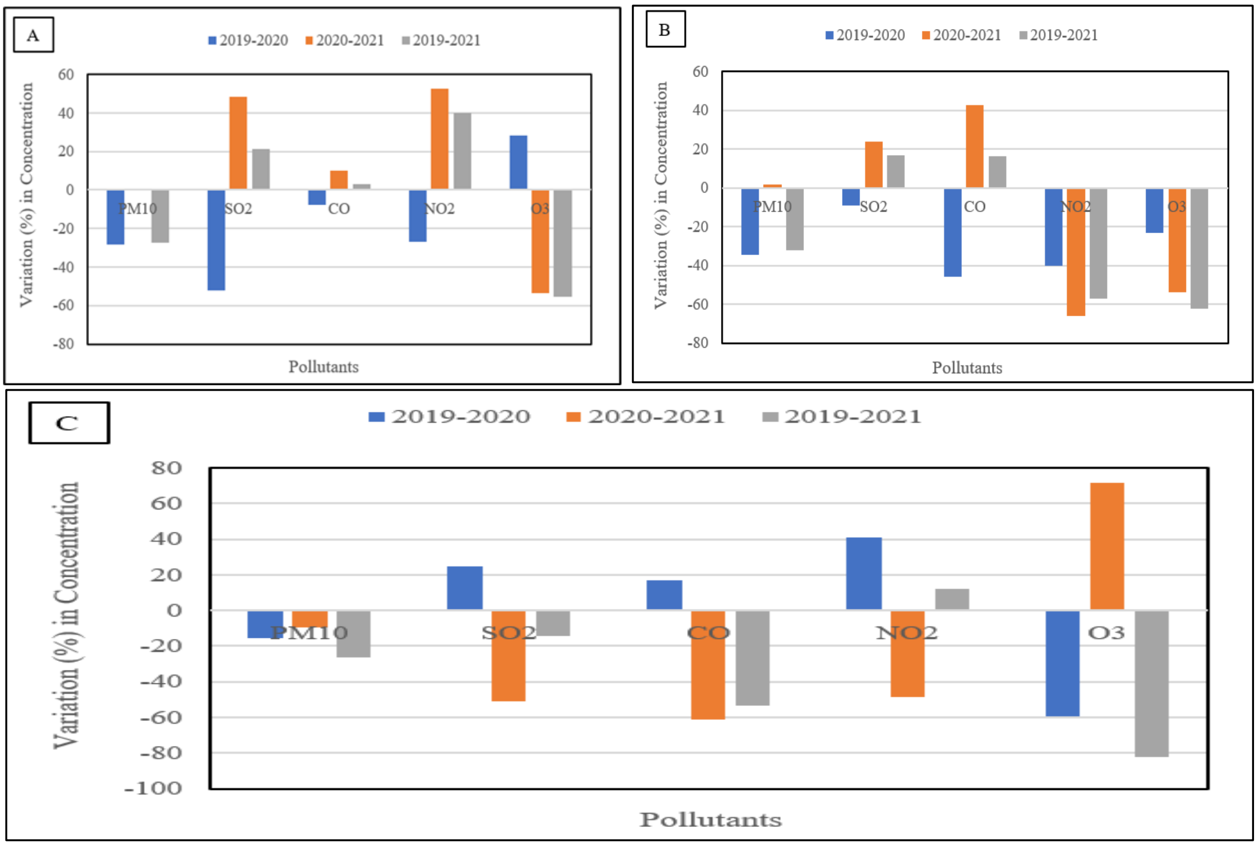

Figure 3. Variations of Air Pollutants as Percentage based on pre-COVID-19 and COVID-19 Period for Three AQM Stations, in which A stands for Aksaray, B is Beşiktaş, and C represents Kadıköy.

Similar results showing the decline in the concentration of air pollutants depending on lockdown measures were also reported in the previous works [7,24-25]. Dabbour et al. (2021) [7] compared concentration levels of air pollutants containing PM_{10}, CO, NO_2 and SO_2 pollution in the three largest cities of Jordan, including Amman, Irbid and Zarqa, over the period from March 15 to June 30 during the years from 2016 to 2020 using a paired sample t-test to determine the impacts of the reduced traffic due to mandated business closures during the pandemic period. Results indicated that Zarqa had the highest decline in SO_2 and NO_2 concentration during the lockdown period. The maximum reductions in Irbid city were in CO and PM_{10} concentrations. Kumari et al. (2020) [24] investigated the impact of lockdown on air pollutants levels in 39 different cities of India (including 10 Indian cities considered among the world's 20 most polluted cities), comparing the pollutants levels from 24th March-31st May in 2020 with the same period in 2019. After implementing lockdown measures, air pollution decreased. The most significant reduction was observed for nitrogen dioxide (NO_2) (3– 79%) and carbon monoxide (CO) (2–61%). The maximum reduction observed in PM_{10} and $PM_{2.5}$ was 58 and 57%, respectively, during the lockdown period in 2020 compared to the previous year. Orak and Ozdemir (2021)

[25] investigated the impact of lockdown measures on air quality parameters, including PM_{10} and SO_2, in 81 cities in Turkey. They found that PM_{10} and SO_2 concentrations were lower in 67% and 59% of the cities, respectively, in April 2020 compared to the previous five years (2015–2019).

3.2. Correlations between air pollutants

When Table 4 is examined, it can be said that there is a positive relationship between parameters in all districts. Therefore, it can be thought that an increase in the concentration of one of the parameters increases the concentration of the other parameter, or vice versa, that a decrease in the concentration of one parameter causes a reduction in the concentration of the other parameter.

TABLE IIII
CORRELATIONS BETWEEN AIR POLLUTANTS FROM DIFFERENT AQM STATIONS

AQM Stations	Correlated Parameters	Pearson's Correlation Coefficient	P-value
Aksaray	PM_{10}-SO_2	0.086	0.94
	PM_{10}-CO	0.23	0.85
	PM_{10}-NO_2	0.27	0.83
	PM_{10}-O_3	0.04	0.97
	SO_2-CO	0.98	0.09
	SO_2-NO_2	0.94	0.23
	SO_2-O_3	0.99	0.02
	CO-NO_2	0.88	0.32
	CO-O_3	0.98	0.12
	NO_2-O_3	0.95	0.20
Beşiktaş	PM_{10}-SO_2	0.18	0.89
	PM_{10}-CO	0.18	0.88
	PM_{10}-NO_2	0.84	0.36
	PM_{10}-O_3	0.70	0.51
	SO_2-CO	0.93	0.23
	SO_2-NO_2	0.68	0.52
	SO_2-O_3	0.83	0.38
	CO-NO_2	0.38	0.75
	CO-O_3	0.58	0.61
	NO_2-O_3	0.97	0.15
Kadıköy	PM_{10}-SO_2	0.11	0.93
	PM_{10}-CO	0.58	0.61
	PM_{10}-NO_2	0.35	0.77
	PM_{10}-O_3	0.69	0.51
	SO_2-CO	0.87	0.33
	SO_2-NO_2	0.89	0.29
	SO_2-O_3	0.64	0.55
	CO-NO_2	0.56	0.62
	CO-O_3	0.19	0.88
	NO_2-O_3	0.92	0.26

In the Aksaray district, the degree of the strongest relations between the parameters can be listed as follows: SO_2-O_3 > SO_2-CO = CO-NO_2 > NO_2-O_3 > SO_2-NO_2. In Beşiktaş, this order is as follows: NO_2-O_3 > SO_2-CO > PM_{10}-NO_2 > SO_2-O_3. In Kadıköy, the strongest correlation between parameters was observed between NO_2-O_3, followed by SO_2-NO_2 and SO_2-CO parameters. When the statistical significance of the relations between the parameters for these three districts is evaluated, it can be said that there is a statistically significant positive and very strong association between only SO_2-O_3 in the Aksaray district.

As a result, it can be expressed that the restrictions during the quarantine period made a positive contribution to the fight against air pollution in Istanbul, similar to the previous studies for different countries and regions. El Kenawy et al. (2021) [9] investigated the percentage changes in the concentration of air

The associations between the parameters resulting from the decrease or increase in air pollution are vital to evaluate variations in the concentration of pollutants. In this regard, the Pearson correlation test was used to determine how the interaction of air pollutants affects air pollution. The results from correlations between the concentration of air pollutants taken from AQM stations located in three different districts of Istanbul are presented in Table 4.
pollutants during the COVID-19 lockdown period in 21 metropolitan areas in the Middle East. The results indicated considerable reductions in the levels of atmospheric pollutants, particularly NO_2, SO_2, and CO. Air quality improved significantly during the middle phases of the lockdown (April and May), especially in small metropolitan cities like Amman, Beirut, and Jeddah, while it was less significant in megacities like Cairo, Tehran, and Istanbul. Fu et al. (2020) [26] investigated the effects of the COVID-19 pandemic lockdown on the air quality of 20 major cities on six continents, evaluating Air Quality Index (AQI) to estimate the change in air quality. The results showed that AQI in NO_2, SO_2, CO, $PM_{2.5}$ and PM_{10} in most cities was significantly reduced because of decreasing transportation, industry and commercial activities during the lockdown.

By contrast, the changes of AQI in ground-level O_3 were not significant in most cities, as meteorological variability and ratio of VOC/NO_x are key factors in ground-level O_3 formation. Dursun et al. (2021) [8] investigated the impacts of COVID-19 measures on the improvements of air quality in Turkey, evaluating daily means of air pollutants including PM_{10}, $PM_{2.5}$, NO_2, CO, O_3, and SO_2 in 29 metropolitan cities and the province of Zonguldak for two periods: a period before the COVID-19 measures between January 1 and March 15, 2020, and the period in which the measures were in force between March 16 and April 15. Results suggested that the measures taken during the pandemic period significantly improved the air quality of provinces.

Alharbi et al. (2022) [27] investigated the changes in the concentrations of air pollutants (NO, NO_2, NO_x, SO_2, CO, O_3, PM_{10}, and $PM_{2.5}$) at three sites with different traffic loads (work, residential, and traffic sites) before, during, and after the COVID-19 lockdown applied in Riyadh City which is the capital of Saudi Arabia. Results indicated that the average concentrations of NO, NO_2, NO_x and CO decreased during the lockdown period by 73%, 44%, 53%, and 32% at the work site; 222%, 85%, 100%, and 60% at the residential site; and 133%, 60%, 101%, and 103% at the traffic site relative to the pre-lockdown period, respectively. The average concentration of O_3 increased by 6% at the worksite, whereas the concentration of SO2 increased by 27% at the residential site and decreased by 6.5% at the worksite.

Bhatti et al. (2022) [28] investigated the change in air pollution by analyzing AQI, six ambient air pollutants, including NO_2, O_3, SO_2, CO, PM_{10} and $PM_{2.5}$ for three periods: pre-COVID (from January 1 to May 30, 2019), active COVID (from January 1 to May 30, 2020) and post-COVID (from January 1 to May 30, 2021) in the Jiangsu province of China. Results exhibited that the mean change $PM_{2.5}$ from pre-COVID to active COVID decreased by 18%; post-COVID, it has only decreased by 2%. PM_{10} decreased by 19% from pre-COVID to active COVID, but post-COVID pollutant concentration has seen a 23% increase.

4. CONCLUSION

It is a well-known fact that vehicle emissions and industrial processes are the major sources of air pollutants. During the lockdown period of COVID-19, greenhouse gas emissions caused by traffic and industrial plants demonstrated a declining trend as expected. In this respect, the values of air pollutant concentrations obtained from the air quality monitoring stations in the regions with the highest workload and traffic density in Istanbul, the most populated city in Turkey, were compared with the values of the previous year in the quarantine periods, and the statistical changes in the concentrations were tried to be explained within the scope of this study.

According to the study results, the pollutant that showed the highest decrease in its concentration in 2020 compared to the previous year was observed in Ozone concentration in Kadıköy. According to the evaluations based on districts, the pollutants showing the maximum decrease in 2020 compared to 2019 were SO_2 in Aksaray district, CO in Beşiktaş district and O_3, as stated before in Kadıköy. When this comparison is made for the period between April 01 and July 01 in 2020 and 2021, when quarantine applications are made, O_3 was the pollutant with the maximum decrease in both Aksaray and Beşiktaş districts, while CO showed the maximum reduction in Kadıköy. Finally, when 2019, which was the pre-pandemic period, as compared with 2021, which did not exist in previous studies and which revealed the novelty of this study, and between April 01 and July 01, which includes quarantine practices, the pollutant showing the maximum decrease did not change in all districts and became O_3. Another result obtained from the study is that the interaction of the parameters directly affects their concentrations. According to the correlation results, it was determined that there was a statistically positive relationship between only SO_2 and O_3 parameters in the Aksaray district.

As can be understood from the results of this study, the reduction of traffic-related emissions and the reduction of greenhouse gases originating from industrial facilities are of great importance in air pollution control. In particular, supporting users by governments with initiatives such as tax reductions in the usage of electric vehicles instead of diesel-fueled those, expanding the use of renewable energy instead of electricity generation from coal-fired thermal power plants, giving importance to energy efficiency in buildings and workplaces, and providing thermal insulation in buildings should be considered and implemented by decision-makers as measures to cope with increasing air pollution in the cities.

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BIOGRAPHIES

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