Thorac Res Pract. 2023; 24(5): 253-261 DOI: 10.5152/ThoracResPract.2023.22231

Original Article

Correlation Between Daily PM_{10}, Nitrogen Dioxide, and Ozone Measurements with the Stringency Index in 15 Different Districts of a Big Metropolis

Pınar Bostan[1], Cavit Işık Yavuz[2], Berker Öztürk[3], Sabri Serhan Olcay[4], Nilüfer Aykaç[5]

[1]Department of Nursing, İstanbul Bilgi University Faculty of Health Sciences, İstanbul, Turkey
[2]Department of Public Health, Hacettepe University Faculty of Medicine, Ankara, Turkey
[3]Department of Chest Diseases, Kırşehir Training and Research Hospital, Kırşehir, Turkey
[4]Department of Chest Diseases, Muğla Sıtkı Koçman University Faculty of Medicine, Muğla, Turkey
[5]Department of Chest Diseases, Acıbadem University Faculty of Medicine, İstanbul, Turkey

Cite this article as: Bostan P, Yavuz CI, Öztürk B, Olcay SS, Aykaç N. Correlation between daily PM_{10}, nitrogen dioxide, and ozone measurements with the stringency index in 15 different districts of a big metropolis. *Thorac Res Pract.* 2023;24(5):253-261.

Abstract

OBJECTIVE: Studies have investigated the effects of lockdowns on air quality around the world and found that fine particulate matter and nitrogen dioxide concentrations decreased due to reduced human activity, while ozone concentrations increased. In this study, we aimed to evaluate the correlation between daily stringency index values of our country and daily PM_{10}, nitrogen dioxide, and ozone measurements in different districts of Istanbul between March 1, 2020, and February 28, 2022.

MATERIAL AND METHODS: Ministry of Environment and Urbanization and National Air Quality Monitoring Network data on Istanbul air quality monitoring stations were used. The analysis included 15 stations that can monitor at least 75% of the days in a year. PM_{10}, nitrogen dioxide, and ozone were the main pollutants analyzed.

RESULTS: There was negative correlation between daily PM_{10} measurements and daily stringency index values in 3 stations; there was positive correlation in 6 stations. Between daily stringency index values and daily nitrogen dioxide measurements, there was a negative correlation in 3 stations and a positive correlation in 1 station. The daily measurements of 1 station showed a negative correlation with the daily values of stringency index for both PM_{10} and nitrogen dioxide. In 1 station, while PM_{10} measures were negatively correlated with stringency index, nitrogen dioxide measurements were positively correlated.

CONCLUSION: This study showed that pandemic limitations could not improve Istanbul's air quality everywhere. For adequate evaluation of impact of the limitations on air quality, it may be more relevant to study the socioeconomic infrastructure of each living area, the sociospatial inequality, industrial employment, the number of households, the density of employee class, and so on with all influencing factors that could have contributed to these various changes.

KEYWORDS: COVID-19, air pollution, stringency index, PM10, NO2, O3

Received: *December 9, 2022* ***Accepted:*** *June 19, 2023* ***Publication Date:*** *August 15, 2023*

INTRODUCTION

On December 31, 2019, the Central Hubei Province in China's Wuhan region verified the finding of a novel coronavirus.[1,2] The novel coronavirus was given the name severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) by the World Health Organization, and it was categorized as a new group within the family coronaviridae.[3] World Health Organization issued an official declaration on March 11, 2020, declaring the novel coronavirus [coronavirus disease 2019 (COVID-19)] outbreak a global pandemic.[4] This day coincided with the declaration by Turkey that it had identified its first case of COVID-19.

The lockdown measures implemented to prevent the spread of SARS-CoV-2 have significantly impacted human activities such as automobile use, public transportation, and economic activity.[5,6] In relation to this, the restrictions have improved air quality due to fewer human activities.[7,8] Since more than 55% of the global population lives in industrialized areas,[9] industrial air pollution is also a global threat in addition to transportation, heating, and other human activities.[5,10,11] Pollution-related illnesses caused approximately 9 million premature deaths, globally, in 2019, and 6.7 million of these deaths were related to outdoor and indoor air pollution.[12]

Air pollution is defined as "the contamination of the indoor or outdoor environment by any chemical, physical, or biological substance that alters the inherent qualities of the atmosphere. Particulate matter (PM), carbon monoxide, ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2) are the pollutants having the most evidence of endangering public health."[13,14] Particulate matter denotes inhalable particles made up of sulfate, nitrates, ammonium, sodium chloride, black carbon, mineral dust, or water. PM_{10} and $PM_{2.5}$ are related to well-known health hazards.[15] Both long-term and short-term exposures to PM are connected with cardiovascular and respiratory disease morbidity and mortality. Nitrogen dioxide

Corresponding author: Sabri Serhan Olcay, e-mail: serhanolcay@mu.edu.tr

is a key precursor of O_3, a pollutant closely associated with asthma and other respiratory problems. The primary source of NO_2 emissions into the atmosphere is the combustion of fuels for a variety of reasons, including but not limited to heating, transportation, and electricity generation.[13-15]

Many current studies have evaluated the effects of lockdown measures on air quality across the globe and showed that fine PM and NO_2 concentrations generally decreased during lockdowns.[16-18] The majority of studies found decreased background concentrations of pollutants and improved air quality indices during lockdowns, particularly for NO_2 because of its impact on reducing traffic movement.[16,18] In a study from our country, the effect of the lockdown on the air quality in Turkey from December 2019 to May 2020 was studied. $PM_{2.5}$ had a maximum reduction in most cities, while O_3 levels increased in most cities, including İstanbul.[19] The impact of COVID-19 measures on air pollutant concentrations measured in urban areas and traffic monitoring stations on both the European and Asian sides of İstanbul in March 2020 was analyzed in another study from our nation. Reductions of pollutants were estimated to range from 33% to 43% for PM_{10} and from 29% to 44% for NO_2. Nitrogen dioxide, which is mostly caused by vehicle emissions, decreased the greatest at the traffic monitoring sites.[20] Also, Aykaç et al[21] discovered that there were decreases of 33.4%, 59.6%, and 52.6% in the average concentrations of PM, NO_2, and O_3, respectively, in Istanbul during lockdowns between April 23 and 26, May 1 and 3, and May 23 and 26, in 2020; however, according to the findings of this study, there were significant variations in the rate of change of air quality among Istanbul districts. Aydın et al[19] found that O_3 levels were higher in April and May 2020 than 2019 in Istanbul. In this recent study, we tried to explore the correlations between pandemic restrictions and the change in air quality in accordance with the different areas of İstanbul in order to gain additional knowledge that would enable us to comment on these disparities.

There are several difficulties when assessing the impact of pandemic restrictions on air quality. One of them is the evaluation framework of restrictions. Gkatzelis et al[22] and Schneider et al[23] utilized the stringency index (SI) to examine the relationships between restrictive measures and air pollution. The SI is an indicator that identifies the stringency of government policies, considering the restrictive measures of the pandemic. They discovered substantial negative associations between the SI and variations in pollutant concentration, particularly that of NO_2. In this study, we aimed to evaluate the correlation between daily SI values of our country and daily PM_{10}, NO_2, and O_3 measurements at different stations in different districts of Istanbul between March 1, 2020, and February 28, 2022.

MAIN POINTS

- Many studies have examined the effects of the pandemic on air quality and demonstrated that particulate matter (PM) and nitrogen dioxide (NO2) concentrations generally decrease during the pandemic, but we found in this study that there was no negative correlation between Stringency Index values and daily PM10 and NO2 measurements in some districts of İstanbul.
- Pandemic restrictions would not be able to achieve the same levels of success in reducing air pollution across all of the districts in a big metropol (like İstanbul).
- For adequate evaluation of impact of the limitations on air quality it may be more relevant to study the socioeconomic infrastructure of each living area, socio-spatial inequality, industrial employment, the number of households, the density of employee class etc. with all influencing factors that could have contributed to these various changes.
- Only 15 of İstanbul's 39 stations met the criteria necessary to be declared genuine for this study. This is due to the fact that not all the stations could measure air pollution in accordance with the qualification definition of the European Environment Agency (the minimum percentage of days in a year that each station may monitor should be 75%).
- Studies monitoring pollutant concentrations with an increasing number of stations that are representative of the population everywhere need to be carried out.

MATERIAL AND METHODS

Study Area

İstanbul is the most populated metropolitan in Turkey and serves as the center of the country's economy as well as its culture and history. Over 15 million people call the city home, making up 19% of Turkey's total population. With a total land area of 5712 km^2, the city is located on both the European and Asian sides of the Bosporus Strait. İstanbul has the highest population of any city in Europe and is the 15th largest metropolis in the world.[24]

The metropolis, which connects Europe and Asia and has a 647-km coastline, is the most commercially and consequential city in Turkey, with 2 airports, 1796 historical sites, 712 hotels, 57 universities, and 36 libraries. İstanbul, the main city in terms of trade, business, investment, banking, and tourism in Turkey, is home to 20.3% of the country's workforce, 50.6% of exports, and 54.6% of imports.[25]

There are 39 districts (962 neighborhoods) in Istanbul, and they each have their own unique demographic characteristics. Esenyurt, Küçükçekmece, and Bağcılar are the 3 districts in İstanbul that have the highest populations. The population of Esenyurt increased between 2017 and 2018, making it the district with the biggest population growth. The districts of Istanbul are shown in Figure 1, and the districts that have been dyed red are those that had the air quality station included in the study.

Air Pollution Data

In this cross-sectional study, publicly available data from the Ministry of Environment and Urbanization and the National Air Quality Monitoring Network[26] on air quality monitoring stations in the province of İstanbul were utilized. In accordance with the qualification definition of the European Environment Agency, the study included only those Istanbul stations whose percentage of the number of days they can monitor in a year was at least 75%. During the study period, 15 stations with this feature were included in the study. Each was assigned a number for this study. Two stations numbered

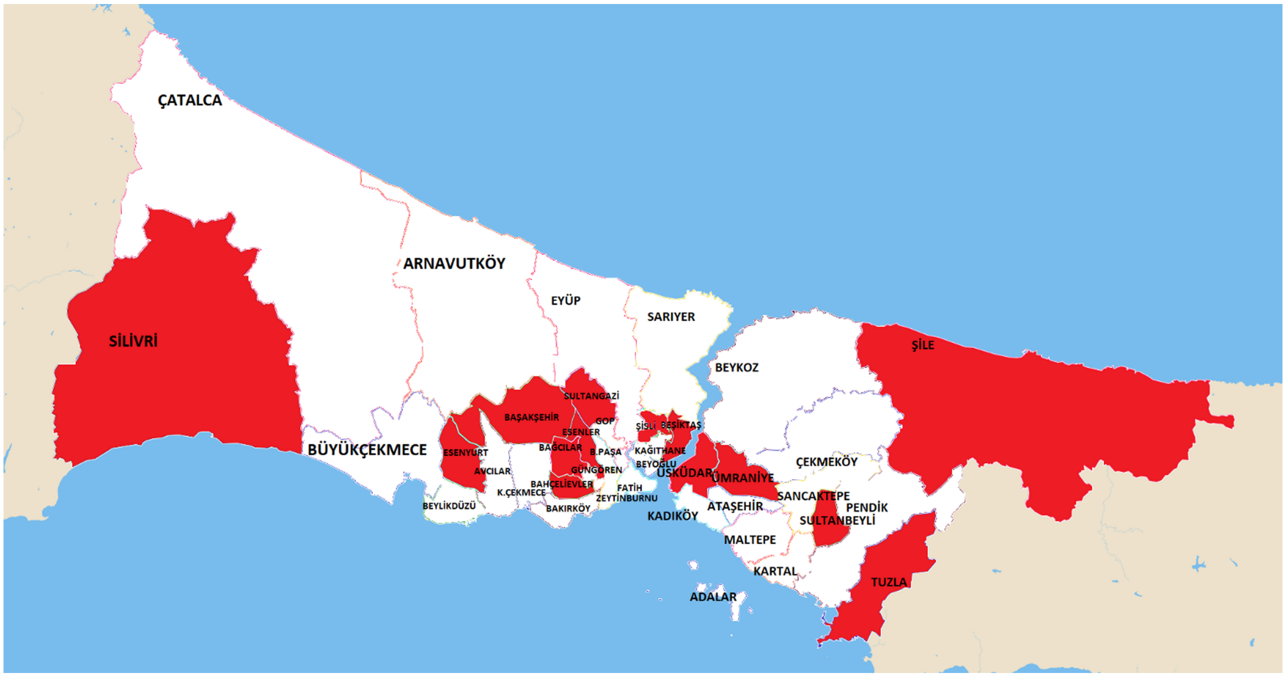

Figure 1. The districts of İstanbul (areas that have been dyed red are those that had air quality station included in the study).

11 and 15 were located in the same district (Bahçelievler). Table 1, shown in the "Results" section, displays the districts where the stations were located. Among the pollutants available from the database, PM_{10}, NO_2, and O_3 compounds were studied as the main pollutants. The daily data for these 2 compounds for the period between March 1, 2020, and February 28, 2022, were included in the correlation analysis.

Restriction Data

To analyze the correlation between the sociopolitical efforts taken to prevent pandemic transmission and the changes in air quality in Istanbul, the SI was utilized to reflect the change in preventative measures. It is crucial to note that this index just gauges the rigor of government regulations. It neither quantifies nor suggests the sufficiency or effectiveness of a nation's response. A higher score does not imply that a country's response is superior to the response of those with lower scores. The Oxford COVID-19 Government Response Tracker (OxCGRT) project computes the SI as "a weighted average of nine response criteria: school closures, workplace closures, cancellation of public events, restrictions on public gatherings, closures of public transportation, stay-at-home requirements, public information campaigns, internal movement restrictions, and international travel controls."[27,28]

The index is calculated on any given day as the mean score of 9 measures, each of which has a value between 0 and 100. A higher grade indicates stricter regulations. This implies that the value of the SI system increases when more measures are added. Stringency index is shared publicly on the website.[27,28] Stringency index values for Turkey between March 1, 2020, and February 28, 2022, were included in the correlation analysis as daily data.

Other Data

Population, surface area (km^2), and population density data of each district were reported besides SI and air pollution data. Also, the neighborhoods where the stations were located were categorized as trafficked areas, industrial areas, urban residential areas, and urban background areas. The stations in urban background areas monitor background concentrations of air polluting chemicals in a region for particularly long-term changes in atmospheric composition.[29] All these data were obtained from İstanbul Metropolitan Municipality, Governorship of İstanbul, and Turkish Statistical Institute websites.[30]

Statistical Analysis

Using IBM Statistical Package for the Social Sciences 28.0's (IBM Corp.; Armonk, NY, USA) Spearman correlation analysis, the correlation between daily SI data and daily pollutant (PM_{10}, NO_2, and O_3) measurements in different areas of Istanbul was analyzed. Any score from 0 to −1 indicates a negative correlation, which means that as one variable increases, the other decreases proportionally, and any score from 0 to +1 indicates a positive correlation, which means that they both increase at the same time, while the P was <.05.

Ethical Consideration

There was no need to get approval from an ethics committee for this study because it used publicly available data from the National Weather Monitoring Network run by the Ministry of Environment and Urbanization, and no special precautions were taken to protect individuals or communities that might be vulnerable.

RESULTS

There are 39 stations in İstanbul that measure the pollutants in the air. However, only 15 of those stations may be considered valid for this study because the percentage of days they can monitor in a year is at least 75%. Therefore, these findings are representative of 38.4% of the stations in İstanbul. Comparing the population of İstanbul to that of the districts in which the stations involved in this research were located, we find that the relevant population accounts for 42.4% of the

Table 1. The Characteristics and Demographical Properties of the Districts and Neighborhoods Where the Valid Stations for the Study Were Located

Number Assigned to the Stations for the Study	Name of the District Where the Station Is Placed	Area of the District (km²)	Population of the District	Name of Neighborhood of the Station	Characteristics of the Neighborhood*	Population of the Neighborhood Where the Station Is Located	The area of the Neighborhood Where the Station Is Located (km²)
1	Bağcılar	22.27	777 561	Kirazlı	Trafficked area	41 823	0.941
2	Başakşehir	104.49	481 900	Başakşehir	Urban residential area and industrial area	71 609	8.129
3	Beşiktaş	17.83	170 894	Yıldız	Urban background area	6552	1.119
4	Esenler	18.42	476 568	Yavuz Selim	Trafficked area	5482	0.241
5	Esenyurt	43.13	983 557	Mehterçeşme	Urban residential area	37 848	0.609
6	Şişli	10.72	261 595	Merkez	Trafficked area	13 738	1.131
7	Silivri	869.37	175 431	Alibey	Urban residential area	18 175	0.642
8	Sultanbeyli	29.10	361 702	Battalgazi	Urban residential area	36 341	3.131
9	Sultangazi	35.71	570 868	Uğur Mumcu	Trafficked area, urban residential area	41 937	1.433
10	Şile	781.72	37 290	Meşrutiyet	Urban background area	1909	3.243
11	Bahçelievler	16.59	596 374	Zafer	Trafficked area	86 758	1.085
12	Tuzla	124.51	269 798	Evliya Çelebi	Urban residential area	13 487	3.250
13	Ümraniye	45.38	711 395	Yukarı Dudullu	Trafficked area	21 532	1.786
14	Üsküdar	35.33	515 363	Selami Ali	Urban background area	13 286	0.447
15	Bahçelievler	16.59	596 374	Çobançeşme	Trafficked area	34 117	1.269
		Total = 2171.16	Total = 6 986 670			Total = 444 594	Total = 28.456

*Characteristics of the districts and neighborhoods were grouped as trafficked area, urban residential area, industrial area, and urban background area.

city's total population. The neighborhood population where the station was located accounted for 7% of the total population of the districts included in the study. The total area of the neighborhoods where the valid stations for the study were located accounted for 1.3% of the total area of the districts included in the study (Table 1).

Figure 2 depicts the trend of the SI for Turkey from January 2020 to March 2022, as a component of the OxCGRT project. Stringency index values for Turkey between March 1, 2020, and February 28, 2022, were included in the correlation analysis as daily data.

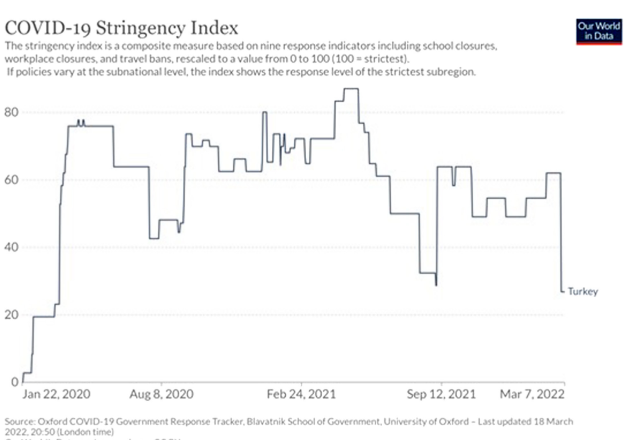

Figure 2. The trend of the stringency index (SI) for Turkey from January 2020 to March 2022, as a component of the Oxford COVID-19 Government Response Tracker (OxCGRT) project.

Table 2 displays averages of daily PM_{10}, NO_2, and O_3 measurements for 15 stations in Istanbul for the study period (March 1, 2020-February 28, 2022) and also during the first and second years of the pandemic separately; it also displays the data for PM_{10}, NO_2, and O_3 levels between March 1, 2018, and 29 February 2020, as a historical reference.

The result of the correlation analysis between daily SI values and daily PM_{10} and NO_2 measurements of these 15 stations in Istanbul between March 1, 2020, and February 28, 2022, is shown in Table 3. While there was a negative correlation between daily PM_{10} measurements and daily SI values in 3 of 15 stations (station numbers: 3, 5, and 9), there was a positive correlation between daily PM_{10} measurements and SI measurements in 6 stations (station numbers: 1, 7, 10, 12, 14, and 15). Evaluating the correlation between daily SI values and daily NO_2 measurements of stations, again for 3 stations but 2 different stations this time (station numbers: 2, 5, and 13), there was a negative correlation. But in 1 station (station number: 9), there was a positive correlation. The daily measurements of only 1 station (station number: 5) showed a negative correlation with the daily values of SI for both PM_{10} and NO_2. In 1 station

Table 2. Averages of Daily PM_{10}, NO_2, and Ozone Measurements for 15 Stations in Istanbul for the Study Period (March 1, 2020-February 28, 2022) and Also During the First and Second Years of the Pandemic

		Historical Reference March 1, 2018-29 February, 2020			During the First Year of the Pandemic *March 1, 2020-February 28, 2021			During the Second Year of the Pandemic **March 1, 2021-February 28, 2022			During the study period ***March 1, 2020-February 28, 2022		
Number Assigned to the Stations for the Study	Name of Districts Where the Stations Were Located	PM_{10} Median (Minimum–Maximum) (µg/m³)	NO_2 Median (Minimum–Maximum) (µg/m³)	Ozone Median (Minimum–Maximum) (µg/m³)	PM_{10} Median (Minimum–Maximum) (µg/m³)	NO_2 Median (Minimum–Maximum) (µg/m³)	Ozone Median (Minimum–Maximum) (µg/m³)	PM_{10} Median (Minimum–Maximum) (µg/m³)	NO_2 Median (Minimum–Maximum) (µg/m³)	Ozone Median (Minimum–Maximum) (µg/m³)	PM_{10} Median (Minimum–Maximum) (µg/m³)	NO_2 Median (Minimum–Maximum) (µg/m³)	Ozone Median (Minimum–Maximum) (µg/m³)
1	Bağcilar	—	—	—	34.1 (10.1-157.7)	35.8 (6-125)	38.2 (4.2-88.9)	30.8 (8.2-119.7)	42.0 (10-111)	37.6 (8.4-72.8)	32.5 (8.2-157.7)	39.3 (6-125)	37.7 (4.3-88.9)
2	Başakşehir	47.6 (7.2-204.2)	25 (4.1-110.4)	57.5 (3.14-110.6)	34.9 (6-163)	6.5 (1-58)	72.1 (16.7-119.8)	37.4 (8.6-127.5)	28.5 (8-90)	71.3 (12.8-129.9)	36.3 (6-163)	16.5 (1-90)	71.8 (12.8-129.8)
3	Beşiktaş	—	—	—	23.3 (4-82)	54.3 (9-137)	19.0 (1.2-146.9)	29.7 (8-86)	35.2 (10-62)	6.3 (1-108)	26.7 (4-86)	40.8 (9-137)	12.6 (1-146.4)
4	Esenler	—	—	—	28.8 (4.9-313.7)	53.3 (10-178)	—	28.7 (6.8-125.2)	49.5 (11-114)	—	28.8 (4.9-313.7)	51.7 (10-178)	—
5	Esenyurt	61.8 (18.2-228.5)	27.8 (7.3-78.3)	30.4 (1.5)-97.6	45.4 (20.6-174.2)	11.3 (2-33)	22.6 (5.2-52.8)	54.3 (21.5-161.1)	23.7 (1-70)	32.9 (3.6-100.3)	49.0 (20.6-174.2)	14.0 (1-70)	27.6 (3.6-100.3)
6	Mecidiyeköy	60.5 (17.9-178)	65.4 (24.5-131.9)	—	46.2 (10-184)	46.0 (15.1-106.8)	—	47.9 (20-128)	47.5 (13.1-113.6)	—	47.1 (10-184)	46.8 (13.1-113.6)	—
7	Silivri	29.4 (4.8-124.6)	22.1 (5.1-62.9)	61.7 (7.1-133.2)	23.8 (5.8-154.7)	14.3 (3.8-53.3)	66.5 (10.6-108.3)	29.2 (6.6-88.1)	16.2 (2.6-42.8)	55.2 (9.5-106.5)	26.8 (5.8-154.7)	15.3 (2.6-53.3)	61.7 (9.5-125.7)
8	Sultanbeyli	—	12.4 (1.3-60.26)	59.1 (6.7-121.6)	26.0 (5.1-130.7)	19.1 (1-176)	59.0 (3.3-106.4)	27.3 (7.5-138.7)	19.3 (2-65)	57.9 (9-106.5)	26.8 (5.1-138.7)	19.2 (1-176)	58.2 (3.3.-106.5)
9	Sultangazi	—	35.3 (8.1-100.7)	38.6 (0.5-98.5)	70.7 (8.1-162.3)	43.9 (16.9-275.8)	31.2 (7.6-103.6)	49.4 (11.3-105.2)	29.2 (9.3-98.4)	49.6 (8.4-120.5)	49.7 (8.1-162.3)	38.2 (9.3-275.8)	39.4 (7.6-120.5)
10	Şile	24.7 (6.1-116.4)	4.2 (0.1-31.6)	75.5 (18.6-129.2)	23.3 (7.7-90.3)	2.0 (0.1-20.9)	75.8 (22.3-118.2)	23.9 (9.6-86.6)	3.5 (0.6-24.7)	66.8 (19.8-97.7)	23.6 (7.7-90.3)	2.8 (0.1-24.7)	71.2 (19.8-118.3)
11	Şirinevler	46 (14.8-171.8)	67.5 (20.1-184.8)	—	38.2 (15.4-130.4)	46.4 (12.3-142.4)	—	37.2 (16.2-99.6)	46.4 (12.6-109.7)	—	37.6 (15.4-130.4)	46.4 (12.3-142.4)	—
12	Tuzla	—	—	—	33.9 (10-162)	36.9 (14-110)	25.9 (3-71)	34.5 (7-107)	45.2 (15-91)	33.4 (2.28-69.1)	34.1 (7-162)	41.7 (14-110)	31.2 (2.3-71.0)
13	Ümraniye	—	—	—	30.1 (6.5-127.9)	41.6 (14-86)	11.8 (8-62.8)	38.7 (12.3-126.3)	59.7 (15-104)	25.5 (3.8-80.1)	34.6 (6.5-127.9)	46.7 (14-104)	20.9 (3.8-80.1)
14	Üsküdar	—	—	—	25.0 (6.5-115.4)	31.9 (6-104)	—	22.9 (6.5-79.4)	40.0 (9-89)	—	23.9 (6.5-115.4)	37.2 (6-104)	—
15	Yenibosna	—	—	—	30.9 (2-173)	38.4 (9.2-132.4)	—	27.8 (3-129)	46.8 (8.0-134.9	—	29.1 (2-173)	43.5 (8.0-134.9)	—

NO_2, nitrogen dioxide; O_3, ozone; PM, particulate matter.

Table 3. The Result of the Correlation Analysis Between Daily PM_{10} and NO_2 Measurements and Daily Stringency Index Values of the Selected Stations in Istanbul Between March 1, 2020, and February 28, 2022

Number of Stations	Name of Districts Where the Stations Were Located	PM_{10} Correlation *r*	NO_2 Correlation *r*	O_3 Correlation *r*
1	Bağcılar	0.09*	−0.02	−0.16*
2	Başakşehir	0.06	−0.09*	0.007
3	Beşiktaş	−0.08*	0.003	0.27*
4	Esenler	−0.009	−0.03	—
5	Esenyurt	−0.09*	−0.5*	−0.31*
6	Mecidiyeköy	0.04	−0.02	—
7	Silivri	0.13*	0.01	0.08*
8	Sultanbeyli	0.02	−0.43	0.008
9	Sultangazi	−0.10*	0.35*	0.29*
10	Şile	0.11*	0.008	0.17*
11	Şirinevler	0.03	0.03	—
12	Tuzla	0.12*	0.002	−0.01
13	Ümraniye	−0.2	−0.49*	−0.18*
14	Üsküdar	0.15*	0.03	—
15	Yenibosna	0.15*	−0.06	—

PM, particulate matter; NO_2, nitrogen dioxide.
*Spearman correlation analysis $P < .05$.

(station number: 9), while the daily measurements of PM_{10} were correlated negatively with the daily values of SI, the daily measurements of NO_2 were correlated positively with the daily values of SI.

Evaluating the correlation between daily SI values and daily O_3 measurements of stations, for 3 stations (station numbers: 1, 5, and 13) there was a negative correlation, while for 4 stations (station numbers: 3, 7, 9, and 10) there was a positive correlation.

DISCUSSION

It is evident that the COVID-19-related lockdown has led to a significant drop in pollution levels, hence improving air quality across the majority of the world. Although many studies have examined the effects of the pandemic on air quality and demonstrated that PM and NO_2 concentrations generally decrease during the pandemic, we found in this study that there was no negative correlation between SI values and daily PM_{10} and NO_2 measurements in some districts of Istanbul. In addition, despite the pandemic restrictions, there was a positive correlation in some districts, indicating the increase of these pollutants. There may be several potential explanations for the results despite the lack of a proper approach to analyzing the causes in this study.

When a policy is enacted, the compliance of citizens is crucial, and there can be significant variation in its implementation. As the reason for our results differed according to the districts of Istanbul, implementation of pandemic restrictions may vary within Istanbul districts. El-Sayed et al[31] interpreted in their study that the stay-home orders were stricter in Miami as opposed to Orlando, hence the stronger reductions in levels of pollutants observed in Miami. In addition, the timing of restrictions, the method in which restrictions are applied, meteorological circumstances, and especially the physical characteristics of the districts, all may influence the effectiveness of air quality improvement. Lu et al[32] observed that the short-term emission control effect of lockdown ranged between 53.0% and 98.3% for all cities included in their study; however, the effect is much greater in southern cities than in northern cities ($P < .01$), while small and medium cities have a similar influence on NO_2 and SO_2 as megacities but a greater effect on $PM_{2.5}$ and PM_{10}. In a study from Myanmar, the researchers showed that during the COVID-19 pandemic, while restricting measures were in effect, the city's PM-related air quality improved from "unhealthy" to "good." However, the percent changes in PM concentrations varied among the 3 study sites, with the highest percent reduction in a semicommercial crowded area (84.8% for $PM_{2.5}$ and 88.6% for PM_{10}) and the lowest percent reduction in a residential quiet area (15.6% for $PM_{2.5}$ and 12.0% for PM_{10}). The percent reductions also varied among the different times during the COVID-19 pandemic that measurements were made.[33] In our study, the varying directions (positive or negative) of correlation between SI and daily measurements of PM_{10} and NO_2 in various districts were interpreted particularly as a result of district/neighborhood characteristics and variations in the enforcement of restrictions.

When describing the changes in PM concentrations during the COVID-19 pandemic, some studies have additionally accounted for seasonal variations. In the study described by Hashim et al,[5] the researchers compared the average PM concentrations in Baghdad, Iraq, throughout 5 time periods: the first period prior to the implementation of a lockdown and the remaining 4 periods during a partial or complete lockdown. The concentrations of $PM_{2.5}$ and PM_{10} were found to be the lowest during the initial partial and total lockdowns compared to the other 4 periods. They hypothesized the following possible explanations for this result: the citizens' compliance with the lockdown measures during the first lockdown period contributed to the large decline of PM concentrations during that period, and the dry, hot climate during the summer led to the relative increase of PM concentrations in the subsequent lockdown periods. Chen et al[34] noted that other meteorological factors, such as the ambient temperature, relative humidity, wind speeds, precipitation, radiation, and ambient pressure, could also exert an influence on the ambient PM concentrations. We lacked data regarding meteorological parameters and seasonal variations, which was one of the limitations of our study. In actuality, the entire 2-year pandemic period was included in the evaluation of the correlation analysis for the study, as we hypothesized that this may reduce the shadowing effects of short-term factors such as seasonal and meteorological differences and the restriction and liberalization periods and permit evaluation over a longer period.

Lange et al[35] conducted a study in Pittsburgh, which, because of its industrial heritage and current sources of PM, provides a unique setting for assessing changes in air pollution during COVID-19 lockdowns. This study evaluated the premise that air pollution in Pittsburgh reduced during the lockdown—specifically, that NO_2 decreased greatly due to the decrease in traffic, whereas $PM_{2.5}$ did not fall or decreased very little due to the assumed continuation of industrial activity. Their study indicates that industrial sources contribute more PM to the atmosphere. In our study, there was a negative correlation between daily PM_{10} measurements and daily SI values in 3 of 15 stations (station numbers: 1, 5, and 9) located in 3 neighborhoods that were grouped as urban residential or urban background areas. Only 1 station's daily measurements (in the district of Esenyurt) demonstrated a negative correlation with the daily values of SI for both PM_{10} and NO_2. The Esenyurt district has a land area of 43.13 km^2 and a population of 983 557 people, and the station is located in the district's second most populous section. The pandemic limitations appear to have been useful in this area for improving air quality. On the other side, there was a positive correlation between daily PM_{10} measurements and SI measurements at 6 stations (station numbers: 1, 7, 10, 12, 14 and 15) located in the urban residential or urban background neighborhoods. Despite the restrictions, the increase in PM_{10} was a significant issue that required discussion with other affecting factors, such as the continuing industrial activity and others. The range of dates that we analyzed in our study (March 1, 2020-February 28, 2022) is extensive, and during this entire time period, the restrictions in Istanbul did not always include all aspects of society. In the study of Aykaç and Elbek,[36] it has been shown that especially at the beginning of the pandemic, the lockdown did not cover blue-collar workers. Continual population mobility and density during the pandemic in industrially populated districts such as Bağcılar, Bahçelievler, Esenler, Esenyurt, Sultangazi, and Tuzla have the potential to generate air pollution.[37] It may be possible to fully evaluate the impact of the SI reported for Turkey on the air quality in different living areas by assessing the socioeconomic infrastructure of each living area, the sociospatial inequality, industrial employment, the number of households, the employee class, and so on.

In some periods of pandemic, blue-collar workers were ordered to keep working. Their travel to the industrial zone from their residences made it harder to manage the pandemic and this contributed to the air pollution in these places. Consequently, examining districtional disparities and revealing the SI for each district could provide a more comprehensive view of the changes in air quality due to the pandemic restrictions.

Li et al[38] showed that the COVID-19 containment and closure policies did not significantly reduce NO_2 tropospheric NO_2 vertical column density (TVCD) in the mild or moderate clusters, but they did so in the poor cluster. They utilized the SI for monitoring pandemic restrictions like in our study and demonstrated that specifically, a rise of 1 SD (23.58) in the SI is associated with a drop of 3.2% NO_2 TVCD in the poor cluster (coefficient = −0.033, $P < .05$). In other words, these estimations imply that the most strict containment and closure policies (index score of 100) would reduce NO_2 TVCD by a maximum of 13.1%.[38] In the study of El-Sayed et al,[31] they found that differences observed in NO_2 between cities were likely due to the population differences among cities, leading to differences in mobile emissions. Dobson and Semple[39] showed that during the 2020 lockdown period, due to the effect of decreasing car journeys in Scotland, NO_2 values were considerably lower than those in the preceding 3 years. In Chen et al[40] study, they investigated the changes in private vehicle restriction policies and their impact on air pollution before and after the outbreak of COVID-19 using daily data from August 1, 2019, to February 7, 2020. They discovered that private car restrictions are a viable strategy for improving air quality. However, its impact is contingent on the city's economic development features. Various categories of the restriction (restrictions for private cars on traffic, distant working, distant education and total lockdown periods, etc.) may have different effects. Likewise, Gkatzelis et al[22] stated in a worldwide analysis that NO_2 level decreases were due to the stringency of lockdown measures. In our analysis, 3 stations (station numbers: 2, 5, and 13) exhibited a negative correlation between SI daily values and NO_2 levels. In particular, station number 13 was located in a densely trafficked area, and it appeared that the pandemic period improved NO_2 air quality in this region.

Although some criteria pollutants,[41] such as PM and NOx, decreased during closure periods, O_3 levels increased. In this respect, O_3 may be viewed as an exceptional pollutant in terms of COVID-19 measures and the relationship between air pollution and COVID-19. In our study, O_3 levels were measured at 10 of 15 stations, and in 4 of those stations, daily O_3 levels were positively correlated with SI values, whereas in 3 stations, the correlation coefficient was negative. Ozone has a complex structure and is a secondary pollutant. The levels of its precursors NOx and volatile organic compounds (VOCs) are crucial for O_3 formation. Due to the dependence of O_3 levels on these precursors and photochemical reaction, levels of NOx and VCs and sunlight are O_3 level drivers.[19]

As an important matter, recent studies on COVID-19 in different countries have examined that improving air quality has been a component of reducing the risk of COVID-19 infection,[42] and geographical patterns of COVID-19 transmission and mortality among countries are linked with local levels of pollutants.[43-45] In their research, Baniasad et al[46] aimed to shed light on the COVID-19 pandemic and determine the relationship between the COVID-19 transmission rate, environmental factors (air pollution, weather, and mobility), and sociopolitical variables [government stringency index (GSI)]. In Russia, the United Arab Emirates, India, and the Philippines, it was observed that a higher SI was associated with a reduced incidence of COVID-19 cases. In spite of this, an increasing number of COVID-19 cases with greater GSI have been observed in a few nations. This increasing trend seen in Iran, Turkey, and Saudi Arabia suggests that the government has been slow to implement countermeasures against the COVID-19 pandemic.

There were some limitations to this study. First of all, only 15 among 39 stations in Istanbul were considered valid for this study because the percentage of days they can monitor in a year is at least 75%. Therefore, these findings are representative of 38.4% of the stations in Istanbul. Also, the total area of the neighborhoods where the valid stations for the study were located accounted for 1.3% of the total area of the districts included in the study. It has to have a greater number of valid stations monitoring the air quality in İstanbul in order to ensure that it is more representative. On the other hand, SI simply demonstrates the existence of restrictions but not their effectiveness. Adaptation of the population to the measures and seasonal and activity density variations during the study period may therefore influence the results. However, it should also be considered that these elements may not be similar among districts. The use of country-based values of the SI and the lack of data on the district-level specifics of the measures and their implementation may be significant limitations of our study. To analyze the effects of pandemic measures on air pollution levels in more detail, it would be advantageous to have access to pandemic data as well as environmental and sociopolitical variables.

In conclusion, the recent study looking at the correlation between SI and change in air quality in the districts of Istanbul determined that pandemic restrictions could not achieve the same improvements in air pollution in every district of İstanbul. We need to perform studies monitoring pollutant concentrations with an increasing representative number of stations while investigating all the influencing mechanisms and/or factors (e.g., meteorological conditions, changes in the behavior of population displacement, pollutant transportation, and implementation of government policies) that could have contributed to these changes in pollutant levels.

Ethics Committee Approval: There was no need to get approval from an ethics committee for this study because it used publicly available data from the National Weather Monitoring Network run by the Ministry of Environment and Urbanization, and no special precautions were taken to protect individuals or communities that might be vulnerable.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – P.B., C.I.Y., B.Ö., S.S.O., N.A.; Design – P.B., C.I.Y., B.Ö., S.S.O., N.A.; Supervision – C.I.Y.; Resources – P.B., N.A.; Materials – P.B., P.B.; Data Collection and/or Processing – B.Ö., S.S.O., N.A.; Analysis and/or Interpretation – P.B.; Literature Search – P.B., B.Ö.; Writing – P.B., C.I.Y., S.S.O.; Critical Review – P.B., C.I.Y.

Declaration of Interests: The authors have no conflict of interest to declare.

Funding: This study received no funding.

REFERENCES

1. Shi H, Han X, Jiang N, et al. Radiological findings from 81 patients with COVID-19 pneumonia in Wuhan, China: a descriptive study. *Lancet Infect Dis*. 2020;20(4):425-434. [CrossRef]
2. Xu B, Gutierrez B, Mekaru S, et al. Epidemiological data from the COVID-19 outbreak, real-time case information. *Sci Data*. 2020;7(1):106. [CrossRef]
3. Zhou P, Yang XL, Wang XG, et al. A pneumonia outbreak associated with a new coronavirus of probable bat origin. *Nature*. 2020;579(7798):270-273. [CrossRef]
4. World Health Organization (WHO). *WHO Director-General's opening remarks at the media briefing on COVID-19. 11 March 2020.* https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-on-covid-19---11-march-2020. Accessed: 23 August 2022.
5. Hashim BM, Al-Naseri SK, Al-Maliki A, Al-Ansari N. Impact of COVID-19 lockdown on NO2, O3, PM2.5 and PM10 concentrations and assessing air quality changes in Baghdad, Iraq. *Sci Total Environ*. 2021;754:141978. [CrossRef]
6. Gautam S, Trivedi U. Global implications of bio-aerosol in pandemic. *Environ Dev Sustain*. 2020;22(5):3861-3865. [CrossRef]
7. Wu Z, McGoogan JM. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: Summary of a report of 72 314 cases from the Chinese Center for Disease Control and Prevention. *JAMA*. 2020;323(13):1239-1242. [CrossRef]
8. He G, Pan Y, Tanaka T. The short-term impacts of COVID-19 lockdown on urban air pollution in China. *Nat Sustain*. 2020;3(12):1005-1011. [CrossRef]
9. United Nations World Urbanization Prospects 2018 – highlights. *Dep Econ Soc Aff Popul Div (ST/ESA/SERA/421)*. Available at: WUP2018-Highlights.pdf (un.org).
10. Begum BA, Hopke PK, Markwitz A. Air pollution by fine particulate matter in Bangladesh. *Atmos Pollut Res*. 2013;4(1):75-86. [CrossRef]
11. Lelieveld J, Evans JS, Fnais M, Giannadaki D, Pozzer A. The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*. 2015;525(7569):367-371. [CrossRef]
12. Fuller R, Landrigan PJ, Balakrishnan K, et al. Pollution and Health; a progress update. *Lancet Planet Health*. 2022;6(6):e535-e547. [CrossRef]
13. U.S. Environmental Protection Agency (EPA) nitrogen dioxide (NO2) pollution. Basic information about NO2. *US EPA*, Accessed 23 August 2022.
14. U.S. Environmental Protection Agency (EPA) particulate matter (PM) pollution. Available at: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#PM. Accessed August 23, 2022.

15. World Health Organization Health Topics. *Air Pollution Air Quality and Health (who.int)*. Accessed August 23, 2022.
16. Dutheil F, Baker JS, Navel V. COVID-19 as a factor influencing air pollution? *Environ Pollut*. 2020;263(A):114466. [CrossRef]
17. Bhatt AS, Moscone A, McElrath EE, et al. Fewer hospitalizations for acute cardiovascular conditions during the COVID-19 pandemic. *J Am Coll Cardiol*. 2020;76(3):280-288. [CrossRef]
18. Naqvi HR, Datta M, Mutreja G, Siddiqui MA, Naqvi DF, Naqvi AR. Improved air quality and associated mortalities in India under COVID-19 lockdown. *Environ Pollut*. 2021;268(A):115691. [CrossRef]
19. Aydın S, Nakiyingi BA, Esmen C, Güneysu S, Ejjada M. Environmental impact of coronavirus (COVID-19) from Turkish perceptive. *Environ Dev Sustain*. 2021;23(5):7573-7580. [CrossRef]
20. Şahin ÜA. The effects of COVID-19 measures on air pollutant concentrations at urban and traffic sites in Istanbul. *Aerosol Air Qual Res*. 2020;20(9):1874-1885. [CrossRef]
21. Aykaç N, Pazarlı Bostan P, Olcay SS, Öztürk B. Five-year analysis of air pollution in Istanbul including also the impact of the COVID-19 pandemic. *İzmir Göğüs Hastanesi Derg*. 2021;35(3):113-124. [CrossRef]
22. Gkatzelis GI, Gilman JB, Brown SS, et al. The global impacts of COVID-19 lockdowns on urban air pollution. *Elem Sci Anth*. 2021;9(1):1-46. [CrossRef]
23. Schneider R, Masselot P, Vicedo-Cabrera AM, et al. Differential impact of government lockdown policies on reducing air pollution levels and related mortality in Europe. *Sci Rep*. 2022;12(1):726. [CrossRef]
24. Republic of Turkey, Governorship of Istanbul T.C. İstanbul Valiliği. Available at: istanbul.gov.tr. Accessed August 23, 2022.
25. Republic of Turkey, Governorship of Istanbul Universities of Istanbul. Available at: http://en.istanbul.gov.tr/the-city-of-universities-istanbul. Accessed August 23, 2022.
26. Republic of Turkey Ministry of Environment, Urbanization and Climate Change 2022. https://www.havaizleme.gov.tr/. Accessed August 23, 2022.
27. Our world in data, COVID-19 Stringency index. Available at: https://ourworldindata.org/grapher/covid-stringency-index. Accessed August 23, 2022.
28. Hale T, Angrist N, Goldszmidt R, et al. A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker). *Nat Hum Behav*. 2021;5(4):529-538. [CrossRef]
29. European Environment Agency Glossary. Available at: https://www.eea.europa.eu/help/glossary/eea-glossary/background-station-air-monitoring. Accessed August 23, 2022.
30. Istanbul Metropolitan Municipality (IMM). IMM Open Data Portal. Available at: https://data.ibb.gov.tr/en/. Accessed August 23, 2022.
31. El-Sayed MMH, Elshorbany YF, Koehler K. On the impact of the COVID-19 pandemic on air quality in Florida. *Environ Pollut*. 2021;285(285):117451. [CrossRef]
32. Lu D, Zhang J, Xue C, et al. COVID-19-induced lockdowns indicate the short-term control effect of air pollutant emission in 174 cities in China. *Environ Sci Technol*. 2021;55(7):4094-4102. [CrossRef]
33. Aung WY, Paw-Min-Thein-Oo, Thein ZL et al. Effect of COVID-19-restrictive measures on ambient particulate matter pollution in Yangon, Myanmar. *Environ Health Prev Med*. 2021;26:92.
34. Chen Z, Chen D, Zhao C, et al. Influence of meteorological conditions on PM2.5 concentrations across China: a review of methodology and mechanism. *Environ Int*. 2020;139:105558. [CrossRef]
35. Lange CL, Smith VA, Kahler DM. Pittsburgh air pollution changes during the COVID-19 lockdown. *Environ Adv*. 2022;7:100149.
36. Aykaç N, Elbek O. COVID-19 outbreak in İstanbul. *Turk Thorac J*. 2022;23(1):63-69. [CrossRef]
37. Turkish Medical Association. *TTB COVID-19 Pandemic 6th Month Evaluation Report*; 2020. Available at: https://www.ttb.org.tr/kutuphane/covid19-rapor_6/covid19-rapor_6_Part60.pdf. Accessed August 23, 2022.
38. Li Y, Li Moming, Rice M, Yang Chaowei. Impact of COVID-19 containment and closure policies on tropospheric nitrogen dioxide: a global perspective. *Environ Int*. 2022;158:106887. [CrossRef]
39. Dobson R, Semple S. Changes in outdoor air pollution due to COVID-19 lockdowns differ by pollutant: evidence from Scotland. *Occup Environ Med*. 2020;77(11):798-800. [CrossRef]
40. Chen Z, Hao X, Zhang X, Chen F. Have traffic restrictions improved air quality? A shock from COVID-19. *J Cleaner Prod*. 2021;279:123622. [CrossRef]
41. U.S. Environmental Protection Agency (EPA) Criteria Air Pollutants. Available at: https://www.epa.gov/criteria-air-pollutants. Accessed August 23, 2022.
42. Han Cao H, Li B, Gu T, Liu X, Meng K, Zhang L. Associations of ambient air pollutants and meteorological factors with COVID-19Transmission in 31 Chinese provinces: a time series study. *J of Health Care Org*. 2021;58:1-11.
43. Conticini E, Frediani B, Caro D. Can atmospheric pollution be considered a co- factor in extremely high level of SARS-CoV-2 lethality in Northern Italy? *Environ Pollut*. 2020;261:114465. [CrossRef]
44. Frontera A, Cianfanelli L, Vlachos K, Landoni G, Cremona G. Severe air pollution links to higher mortality in COVID-19 patients: the "double-hit" hypothesis. *J Infect*. 2020;81(2):255-259. [CrossRef]
45. Singh M, Singh M, Singh BB, et al. Quantifying COVID-19 enforced global changes in atmospheric pollutants using cloud computing based remote sensing. *Remote Sensing App Soc Environ Soc Environ*. 2021;22:100489.
46. Baniasad M, Mofrad MG, Bahmanabadi B, Jamshidi S. COVID-19 in Asia: transmission factors, re-opening policies, and vaccination simulation. *Environ Res*. 2021;202:111657. [CrossRef]