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Evaluation of the effects of Covid-19 lockdowns and strict restrictions on İstanbul's air quality

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Abstract
The Covid-19 pandemic, which started in Wuhan, China, led to several strict restrictions and lockdowns in Turkey, like many other countries. Although lockdowns have had a socially and economically negative impact, they have affected the air quality in a positive way. The aim of this study is to examine the spatial impact of lockdowns on air quality in İstanbul and to determine the correlation of polluting indicators. In line with the determined purpose, PM10, SO2, NO2, CO and NOx parameters were spatialized with ordinary kriging method in 5 different time intervals and the relativity levels between meteorology, transportation and particles that cause pollution were examined with the Pearson correlation method. As a result, lockdowns caused an increase on CO and SO2 by up to 28%, while other particles decreased by 2% to 23%. Compared to 2019, a decrease of up to 60% in all particles except CO and SO2 has shown that lockdowns have a positive effect on air quality. It was observed that the pollution, which was concentrated in urban areas before the pandemic, spread to rural areas with the precautions taken. Temperature, number of vehicles and traffic index were found to play an important role in the emission of particles, while wind speed and direction played an important role in the displacement of pollution. It has been observed that finding a positive correlation between pollutants and the factors that trigger pollution has rapidly changed the ecosystem of the city along with the policies affecting air quality.

Keywords
Air quality, Covid-19 Lockdowns, İstanbul, Urban pollution.

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1. Introduction

The Covid-19 pandemic, which started with the record of the first case in Wuhan, China on December 27, 2019 and affected the whole world, reminded again the importance of the relationship between public health and air quality. Pre-pandemic studies, which indicates that people who are exposed to long-term air pollution, especially in megacities, have a higher risk of chronic diseases, have been accepted by WHO (WHO, 2013). Studies conducted since the beginning of the COVID-19 outbreak have emphasized that there is a positive relationship between air pollution and the rate of spread of the virus (Comunian et al., 2020). Therefore, it is vital to define the effect of atmospheric particles in metropolitan cities with overpopulation during the epidemic period.

With the declaration of a pandemic by the WHO on March 11, 2020, many countries have tried to take measures with lockdowns or restrictions (WHO, 2021). Although the lockdown in the fight against the epidemic has caused a decrease on the global economic activities, it has helped to improve air quality on a large scale. It has been analyzed that air pollution has decreased significantly, especially in many countries that have become the center of the pandemic. A study conducted in Wuhan, China, analyzed significant decline in PM2.5, NO2 and O3 pollution types. It has also been emphasized that air quality tends to improve faster in regions with the highest population density (Lian et al., 2020). In a study conducted in Shanghai, China, a decrease of 31,3% to 77% was observed in PM2.5, PM10, SO2 and NO2 types in lockdowns compared to 2019 (Peterson & Filonchyk, 2020). In Barcelona and Madrid, Spain, NO2 concentrations decreased by up to 62% (Baldasano, 2020). Research in Gujarat, India, showed that PM2.5, PM10, SO2, CO, NO2 and O3 pollution types improved by up to 58% compared to 2019 (Selvam et al., 2020). In a study conducted by Chowdhuri et al. in Kolkata, India, it was observed that there was a 40% to 60% decrease in PM2.5, PM10, CO, O3 and SO2 parameters as a result of the lockdowns (Chowdhuri et al., 2021).

In a study using satellite data from 27 countries, it was analyzed that air pollution decreased by about 20% in the first two weeks of the lockdown (Venter et al, 2020). Apart from Antarctica, NO2, SO2, CO, O3, PM2.5 and PM10 particles were investigated in the 20 largest cities in the world, which were most affected by the epidemic. At the end of the study, SO2, NO2 and CO showed a significant decrease. While a significant decrease was also detected in PM2.5 and PM10 levels, it was observed that O3 increased in many cities (Fu et al., 2020). By using PM10, SO2 and NO2 parameters in Morocco Sale City, a different rate of reduction in pollutant determined was determined during the Covid-19 lockdowns (Otmani, 2020). Table 1 shows some of the studies examining the effect of Covid-19 lockdowns on air quality. When the studies are examined in detail, it is seen that restrictions and lockdowns have a positive effect on air quality in many countries, especially in

Table 1. *Previous studies examining the effect of Covid-19 lockdowns on air quality .*

Author(s)	Case Study City/Country	Air quality parameters	Outputs
Sharma et al, 2020	India	PM2.5, PM10, NO2, O3, SO2, CO	A decrease was observed in air quality values except for O3 parameter.
Zhu et al, 2020	China	PM2.5, PM10, NO2, O3, SO2, CO	It has been analyzed that lockdowns contribute to air quality in the short term.
Mahato et al, 2020	Delhi, India	PM2.5, PM10, NO2, O3, SO2, NH3, CO	There was a decrease in PM2.5, PM10, NO2, CO levels.
Fattorini et al, 2020	İtaly	PM2.5, PM10, NO2, O3	It has been determined that there is a positive relationship between Covid-19 cases and air quality parameters.
Dantas et al, 2020	Rio De Janeiro, Brazil	PM10, NO2, O3, CO	Except for the O3 type, a decrease was observed in other parameters.
Shrestha et al, 2020	40 Cities worldwide	PM10, PM2.5, O3, SO2, CO, NO2	While there was generally a decrease in PM10, PM2.5 and NO2 values, variable results were obtained in other parameters.
Donzelli et all, 2020	Florence, Pisa, and Lucca, Italy	NO2, PM10, PM2.5, O3	While there was a decrease in NO2 level, no change was observed in other pollutant types.
Xu et al, 2020	Central China	PM2.5, PM10, SO2, CO, NO2, O3	A significant decrease was recorded in the lockdown process in all parameters.
Freitas et al, 2020	Sao Paulo, Brazil	NO2, SO2, CO, O3, PM2.5, PM10, NOx,	Partial restrictions contributed to the improvement of air quality.
Kerimray et al, 2020	Almaty, Kazakhstan	NO2, SO2, CO, O3, PM2.5 and BTEX	Pollutant types have contributed significantly to the development of air quality as a result of the lockdowns.
Aydın et al, 2020	Turkey	PM2.5, O3	While PM2.5 decreased, an increase was observed in O3.
Çelik & Gül, 2021	İstanbul, Turkey	PM10, SO2, CO, NO2, NO, NOX, O3	While there was a decrease in PM10, NO2, NO, NOX values, the results of SO2 and CO pollutant types varied according to the different stations.

countries with the highest number of Covid-19 cases and death tolls.

With the first case seen in İstanbul, Turkey on March 11, 2020, gradual restrictions started to be implemented throughout the country. In a study including PM2.5 and O3 particulate matter in Turkey, a 34,5% decrease in PM2.5 pollutant type and an increase of up to 28% in O3 particle was observed by comparing the values with 2019 (Aydın et al., 2020). In the study examining PM10, PM2.5, O3, SO2, CO and NO2 parameters in 40 cities worldwide, high SO2 concentration but low values in other pollutants were observed in İstanbul in March 2020 compared to the same month of 2019 (Shrestha, 2020). In the study, which included 20 major cities worldwide, it was analyzed that there was a decrease in NO2 particle by up to 38% and O3 particle by up to 43,6% in İstanbul from 2017 to 2020, while there was an increase in SO2 by up to 29,3%. In addition, PM10, PM2.5 and CO were significantly reduced (Fu et al., 2020). In another study conducted by Çelik and Gül in İstanbul, the hourly values of PM10, SO2, CO, NO2, NO, NOX, O3 particles from 19 air monitoring stations (AMS) were taken into account. When the findings were examined, a significant decrease was observed in PM10, NO2, NO, NOX levels compared to 2019. However, while there was an inhomogeneous increase and decrease in SO2 and CO pollutant types compared according to the stations, there was a partial increase in O3 value (Çelik & Gül, 2021). In the air quality literature for Turkey and İstanbul, comparisons were generally made with the year of 2019. Findings clearly indicated that a significant decrease was observed in parameters other than O3, CO and SO2 values.

Lockdowns and strict restrictions in the fight against Covid-19 have had a positive effect on the improvement of air quality. However, there are very few studies examining the spatial distribution of polluting particles and the relationship of other polluting urban elements with these particles. The main purpose of this study is to analyze in detail the spatial distribution of PM10, SO2, NOX, NO2 and CO pollutant types in İstanbul in the global epidemic period, and to investigate the effects of meteorological conditions, particles and other pollutant urban elements affecting the air quality of the city on air quality.

Based on the determined purpose, this study provides methodological contributions to the literature. In addition to the methods in the literature, particles were spatialized with ordinary kriging, which is one of the geospatial methods. In addition, indicators that have an effect on air quality such as wind, humidity, temperature, number of vehicles, average traffic density, which are not commonly included in particle studies, are also included in the study. Thus, the addition of new indicators to the measurement of air quality and the analysis of the spatial distribution of particles contribute to the literature by strengthening the outputs of the study with a multiple methodological approach.

2. Materials and methods

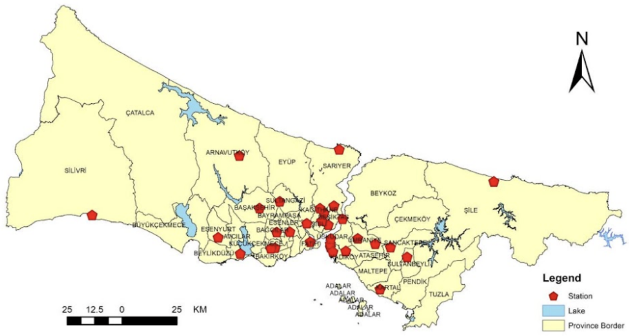
2.1. Study area

İstanbul is the fastest urbanized metropolitan city in Turkey. With 39 districts, İstanbul, where 18,49% of Turkey resides, is the most crowded city with a population of 15.462.452 and a population density of 2.975 people/km2 (TSI, 2021). However, it is the most important city developed in the services sector and industry of the country. İstanbul's rapid urbanization and intense urban mobility cause air pollution to increase. According to 2020 TurkStat (2021) data, the number of 4.388.118 road vehicles in İstanbul corresponds to the total population of 21 medium-sized cities in Turkey. In addition, İstanbul has been the city with the highest number of deaths due to air pollution in Turkey since 2017 (Karababa et al., 2020). According to the 2018 Air Pollution Report, 9 out of 10 people in İstanbul are directly exposed to air pollution (TMMOB, 2019). The first Covid-19 case in Turkey was also seen in İstanbul. According to the figures announced by the Ministry of Health of the Republic of Turkey (2021), İstanbul is one of the cities with the highest number of deaths and cases. However, it has been stated in the literature that the government has started to take measures against the pandemic with strict restrictions and lockdowns, and that it has contributed to the development of air quality, especially in a densely populated city such as İstanbul. For this reason, İstanbul was selected as a case to investigate the effect of lockdowns and lockdowns on the air quality of the city during the Covid-19 pandemic.

2.2. Data collection

The data set necessary to examine the impact of lockdowns and strict restrictions on air quality was obtained from the websites of two different public institutions with open access. First data on the measurement of air quality were obtained from https://www.havaizleme.gov.tr/ website. Hourly concentrations of PM10, SO2, NOX, NO2 and CO pollutant types were reached from the data set accessible by the Ministry of Environment, Urbanization and Climate Change. PM 2.5 and O3 parameters could not be included in the study because there was no information about them in some stations. There are a total of 38 air monitoring stations in İstanbul. Data were collected from 31 of these stations. As the 4 of these stations has been built very recently, data set could not be reached. In 3 stations, pollutant types were not included in the study area due to the inability to access data at certain intervals.

The distribution of the stations included in the scope of the study by settlement types is shown in Figure 1. The figure shows that the stations in the city are mostly located in urban areas and the suburban and industrial areas developing around it. In addition, of the 7 stations that were not included in the study area, 4 were located in the urban area, 2 in the suburban area, and 1 in the industrial area. Figure 1 also shows the locations of the air monitoring stations in İstanbul. 12 of the stations on the European Side located to the west of the map are located in the city center. 3 are located in suburban areas, 3 in rural areas in the north and north-west regions of the city and 3 other stations are located in industrial areas. In the Anatolian side of the map, stations were distributed in different spatial use types; 6 in the city center, 3 in suburban, 1 in rural area and 1 in industrial area.



Placement types of stations	Number of stations	Spatial distributions of AMS	
		European Side	Anatolian Side
Urban areas	18	Yenibosna, Şirinevler MTHM, Bağcılar, Aksaray, Alibeyköy, Şişli MTHM, Mecidiyeköy MTHM, Beşiktaş,Sarıyer, Kağıthane, Kağıthane MTHM, Maslak	Ümraniye MTHM, Kandilli, Göztepe, Kadıköy, Selimiye, Üsküdar
Sub-urban areas	6	Esenyurt, Sultangazi, Silivri	Sultanbeyli, Sancaktepe, Kartal
Rural areas	3	Kumköy, Arnavutköy	Şile
Industrial areas	4	Esenler, Avcılar, Başakşehir	Ümraniye

Figure 1. *Spatial distribution of the air monitoring stations in istanbul.*

Secondly, data on urban and meteorological factors that have a direct effect on air quality were obtained from https://data.ibb.gov.tr/ website. At the urban scale, daily counts of 7 indicators, namely average temperature, humidity, average wind speed, wind direction, amount of precipitation, average traffic index and number of vehicles, which are accessible by İstanbul Metropolitan Municipality, have been reached. According to the Phases, the average values of the relevant indicators were calculated and compared with the year of 2019.

All datasets used in the study were collected between 9 and 15 January 2021 from the websites of relevant public establishments. Characteristics of the emissions were based on both primary pollutant types, which were directly emitted to the atmosphere, such as PM10, SOx, NOx, NO2, CO, and secondary pollutants ones, which formed in the atmosphere or emitted from a reaction between primary pollutants, such as temperature, humidity, traffic, and other artificial pollutants. The data source was the locations of air

Table 2. *Classification of lockdowns and strict restrictions for the COVID-19 pandemic in İstanbul (Source: It was created with the help of the announcements and news published by the Ministry of Health of the Republic of Turkey, the Ministry of Interior of the Republic of Turkey, the Governorship of İstanbul and the İstanbul Metropolitan Municipality).*

Phases	Time Interval	Lockdowns and Restrictions
Phase-I	February 16, 2020 March 15, 2020	• Pre-Covid-19 Pandemic Period
Phase-II	March 16, 2020 April 10, 2020	• Education was suspended on March 16. All schools switched to distance education. Many different activities in different sectors, from leisure activities such as theater, cinema, indoor playgrounds and restaurants to the activities of many industrial enterprises were suspended. • On March 21, a lockdown was imposed on people over the age of 65 and for people that have chronic conditions. Borders were closed to 16 countries. • On 27 March, intercity travel was subject to a governor's permit. All overseas flights were suspended. • All trains except Marmaray were stopped on 28 March. • On March 31, it was started to record those that were travelling in the entry and exit points of the cities. • On April 3, a lockdown was declared for citizens under the age of 20. • On April 6, it was decided that subway services in İstanbul would be in service until 21:30. • On 10 April, restrictions were imposed on IETT (İstanbul electric tramway and tunnel establishments) services.
Phase-III	April 11, 2020 May 3, 2020	• A lockdown was declared on 11-12 April. • On April 18-19, a lockdown was declared. • A lockdown was declared between 23-26 April. • A lockdown was declared between May 1 and 3.
Phase-IV	May 4, 2020 May 31, 2020	• On May 4, the gradual normalizing process was announced. • A lockdown was declared on 9-10 May. • On May 11, the activities of the shopping mall and some production facilities were allowed. • A lockdown was declared between May 16 and 19. • A lockdown was declared between May 23 and 26. • A lockdown was declared on 30-31 May.
Phase-V	June 1, 2020 June 30, 2020	• It was announced that the normalizing process began on June 1. • After Covid-19 Pandemic Period

monitoring stations, which measured primary and secondary pollutants at regular intervals. In order to get reliable information, spatial datasets were used partially spatial coverage by taking into account the distance of the station points to each other, as shown in Figure 1.

2.3. Lockdown and restrictions

When the lockdowns in Turkey are compared with other countries, no long-term lockdown has been declared. As shown in Table 3, lockdowns across the country were organized to cover official national holidays, religious holidays, and weekends. Apart from that, the measures taken were carried out in a way that would gradually restrict urban mobility. For this reason, threshold days were determined by considering lockdowns and restrictions, and the study was carried out in 5 different time intervals. Phase-I covered the period between February 16 and March 15, 2020. This period has been called the "pre-pandemic time" due to the lack of any restrictions. Phase-II includes the period from March 16 to April 10. On March 16, it was decided to close many businesses and educational institutions at all levels due to the pandemic. On 31 March, 3 and 10 April, restrictive decisions were taken regarding the use of urban public transportation for İstanbul. Since the decision taken on April 10 was the last measure restricting urban mobility in terms of transportation, phase-II covered the period until this time period. The time period between April 11th and May 3rd formed the Phase-III. This period was the first time that the most intense lockdowns were imposed due to the pandemic. Phase-III was declared a constant lockdown on weekends. On 4th of May flexing decisions were taken and the bans were removed completely on 1st of June, the 4th Phase was between 4 and 31 May. Although official and religious holidays were declared as lockdowns during this period, restrictions on some sectors were also lifted. Phase-IV was the longest period under lockdowns. As the restrictions were removed in between 1-30 June, it was examined as 5th Phase and called "post-pandemic period".

2.4. Statistical and spatial analysis

There are many methods for studying the relationship between public health and particles, as well as methods for analyzing the spatial distribution of pollution. The literature provides good examples of techniques such as geospatial interpolation, regression models, and dispersion models that combine time and space data (Haworth, 2020). This study has been formed as three stages based on the latest statistical methods frequently used in the literature.

In the first stage, the mean PM10, SO2, NOX, NO2 and CO values of the specified time intervals for all stations were calculated and spatialized by kriging method. There are many kriging methods such as simple, ordinary, universal, block, etc. In this study, ordinary kriging method was chosen. The ordinary kriging method, which provides the opportunity to interpolate the measured values and the spatial relations of the values, was preferred in this study because it makes it possible to determine the weights according to the condition that the estimation error is minimum and to evaluate the magnitude of the error term (Isaak & Srivastava, 1989). The most basic feature that distinguishes the Ordinary kriging method from the others is that it allows to estimate an unmeasured value in the location by calculating the weighted sum of the observations with the assumption that the variables are stable, and the mean is fixed in determining unknown values. Journel and Huijbregts (1978), Isaaks & Srivastava (1989), Cressie (1993), Skøien et al. As it was proven by the studies of (2006), Archfield and Vogel (2010) and many other studies, the ordinary kriging method offers more accurate and reliable results. The Ordinary Kriging Formula is as follows (Tyagi & Singh, 2013):

$$Z_{(s0)} = \sum_{i=1}^{N} \lambda_i Z_{(si)}$$

Where:
$Z_{(si)}$= the measured value at the ith location
λ_i= an unknown weight for the measured value at the ith location
$(s0)$ = the prediction location
N = the number of measured values

In the second stage, meteorological conditions, transportation indicators and levels of pollutant parameters, which had an effect on the increase in pollution, were compared with the average data of 2019 at the same time intervals. Thus, the effects of lockdowns and strict restrictions on pollutants and pollutant elements, which are the main purpose of the study, were examined in detail.

In the third stage, the Pearson correlation coefficient, which is one of the statistical methods used to define the relationship between all pollutant types (PM10, SO2, NOX, NO2, temperature, humidity, wind speed, wind direction, amount of precipitation, number of vehicles, traffic index) affecting air quality, was used. This method helps to measure the quantitative dimension of the relationship between all pollutant types. In the method that creates values between +1 and –1, a value close to +1 means a strong correlation and strong relationality between the two pollutant types, while a value close to -1 indicates a weak relationship or a negative relationship between the variables. A value of 0 indicates that there is no relationship between the two particles.

$$r = \frac{n(\sum(xy)) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}}$$

Where,
r = Pearson Coefficient
n = sample size
$\sum(xy)$ = sum of the paired variables
$\sum x$= sum of the x valiable
$\sum y$ = sum of the y valiable
$\sum x^2$= sum of the squared x valiable
$\sum y^2$= sum of the squared y valiable

3. Results

3.1. Carbon monoxide

CO concentration occupies an important place among the air quality parameters. CO, a harmful gas type in the atmosphere, negatively affects human health and environmental quality due to its ability to remain in the air for 2 to 4 months. As it is the type of pollutant that usually occurs in cities due to reasons such as domestic heating, industrial fuels and traffic, its levels can be quite high in densely populated cities.

When the hourly CO concentration in İstanbul was examined during the pandemic period, it was observed that there was an increase of 53,29% between Phase-I and Phase-II. The CO level tended to increase substantially compared to the period before the measures restricting urban mobility were taken. CO showed an 8,25% reduction between Phase-II and Phase-III. Thus, it means that lockdowns imposed in Phase-III phase positively affect the CO level. In Phase III-Phase IV stages, CO decreased by 5,57% and in Phase IV-Phase V, it increased by 12,13%. Despite the decrease in domestic fuel consumption during these time intervals, the tendency of the pollutant types to increase is based on the removal of restrictions. When the overall change in CO level was eval-

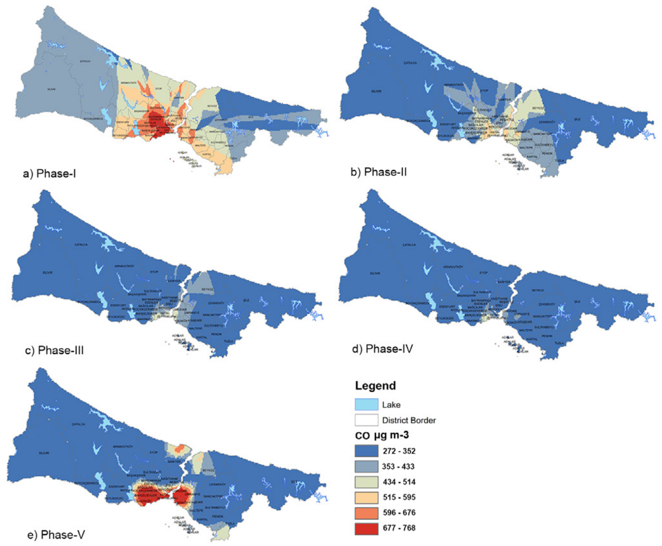


Figure 2. *Spatial distribution of CO emission.*

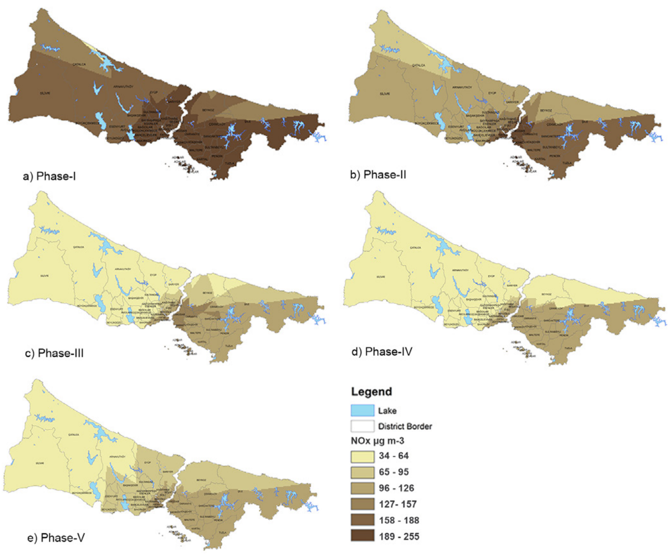


Figure 3. *Spatial distribution of NOx.*

uated, it was found that there was an increase of 66,49%. Therefore, it is seen that the biggest reason for the spread of CO level in İstanbul is based on vehicle emission.

When the spatial distribution of the CO particle is examined, Phase-I and Phase-V are a time period in which there are no restrictions and economic activities take place intensively. In these intervals, İstanbul's urban areas, industrial zones and sub-urban areas are the places where CO concentration is most intense. Although the manufacturing industry is not active in Phase II, CO emissions are concentrated in urban areas. CO distribution in Phases III and IV had a positive effect on air quality thanks to lockdowns and restrictions. However, with the removal of the measures, it was observed that the CO value was highly concentrated in urban areas compared to the pre-pandemic period.

3.2. NOx

The main source of NOx increases due to high vehicle emissions in large metropolitan areas such as İstanbul. The hourly NOx level in İstanbul decreased by 65,42% with the measures taken in Phase I-II. Restriction measures in Phase-II have greatly contributed to the improvement of air quality. It showed a 22,52% decrease in Phase II-III and 1,38% decrease in Phase III-IV. An increase of 7,97% was observed in the Phase IV-V range. However, in general, NOx contributes very positively to air quality with a 71,47% decrease.

The spatial change of NOx concentration in İstanbul generated unexpected results. While NOx spreads in urban areas and sub-urban areas around it before the pandemic, it is seen in Figure 3 that it is highly concentrated especially on the eastern side of the city with the restrictions and lockdowns. This situation has been associated with the intense traffic flow that occurs during service circulation between other cities of Turkey and İstanbul.

3.3. NO2

The main reason for the spread of NO2 is based on the fact that the heat generated as a result of burning fossil fuels such as coal, oil and natural gas increases the average temperature. While the NO2 value in İstanbul decreased by 60,21% in Phase I-II and 14,81% in Phase II-III, it increased by 4,89% in Phase III-IV and 24,12% between Phase IV-V. Within the time period included in the study, there was a 59,98% decrease in NO2 change.

When the spatial distribution of the pollutant particle was examined, the period when the pollution spread the least was Phase-III. This period constitutes the first time period when lockdowns and restrictions are most intense. The general distribution of NO2 was analyzed to spread from urban areas to sub-urban areas.

3.4. PM10

PM10, which caused a significant decrease in the quality of life in cities, showed a significant decrease in İstanbul with the lockdowns. Particulate matter diffusion decreased by 37,69% in Phase I-II, 1,93% in Phase II-III and 8,87% in Phase III-IV. Between Phase IV and V, an increase up to 13,31% was seen. However, when the overall change was evaluated, the PM10 value decreased by 36,90%.

When the spatial distribution of the PM10 concentration in İstanbul is analyzed, it is observed that the spatial spread of the parameter decreased compared to the pre-pandemic period. It has been analyzed that the relevant particle is more concentrated in urban, suburban and rural areas on the western side of the city in general. Also noteworthy is the decrease in the spread of pollution, especially on rural areas, during lockdowns and strict restriction periods.

3.5. SO2

SO2 is as important as other parameters in determining air quality. The gas produced as a result of vehicle emissions and burning of fossil fuels has direct negative effects on human health. According to the Greenpeace 2018 report, Turkey ranks 7th among the top 10 countries with the highest SO2 parameter. (Greenpeace, 2021). However, it has been determined that 3000 premature deaths in the same year in the country have a positive relationship with SO2 emission (TUİK (Turkish Statistical Institute), 2021).

When the SO2 change in İstanbul during the pandemic period was examined in detail, an increase of 30,86% was observed in Phase I-II and 4,76% in Phase II-III. It was analyzed that it decreased by 3,79% in Phase III-IV and by 2,99% in Phase IV-V. When the rate of change was examined in general, an increase of 27,96 was observed. SO2 increased during the periods of lockdowns and precautions. The reason of it is based on weather conditions, domestic heating and vehicle emissions.

Figure 6 shows the spatial distribution of the SO2 parameter in İstanbul and supports that the emission spread

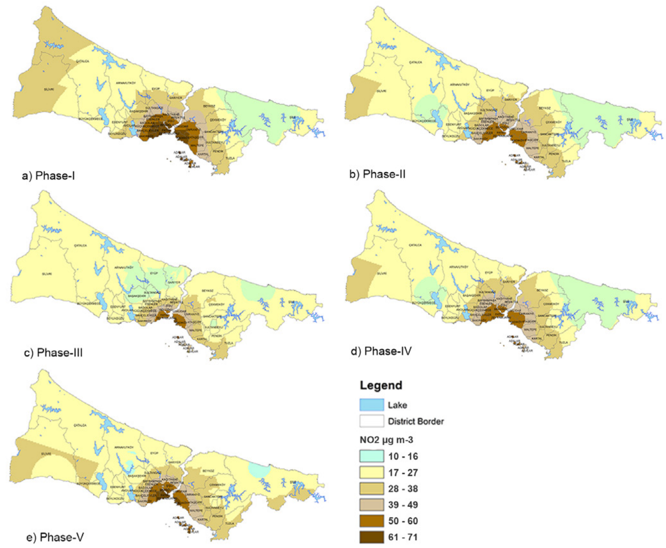


Figure 4. *Spatial distribution of NO2.*

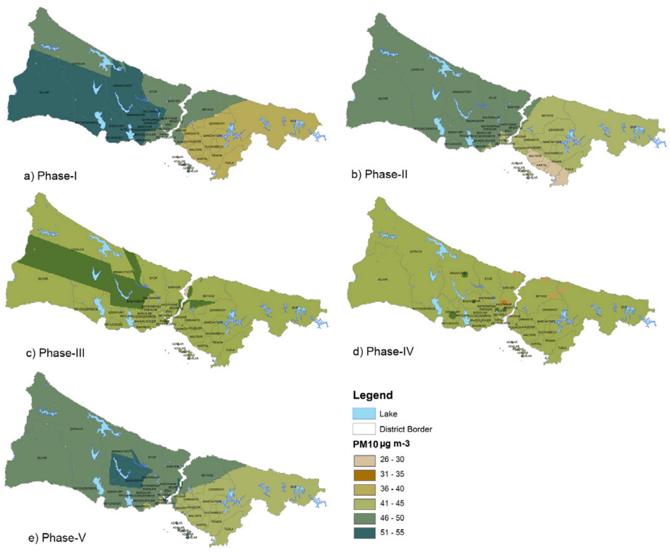


Figure 5. *Spatial distribution of PM10.*

is dependent on domestic heating. Because while the SO2 parameter was intense in urban and industrial areas in Phase I, it changed direction towards sub-urban areas with the restrictions. The continuity of the increase in SO2 levels as a result of the increase in vehicle mobility after the removal of restrictions is shown in Phase V.

3.6. Comparison of indicators affecting air quality

In evaluating the effects of Covid-19 lockdowns on air quality, it is not enough to examine only the particles. Factors such as meteorological conditions, traffic density, and the number of motor vehicles that play a

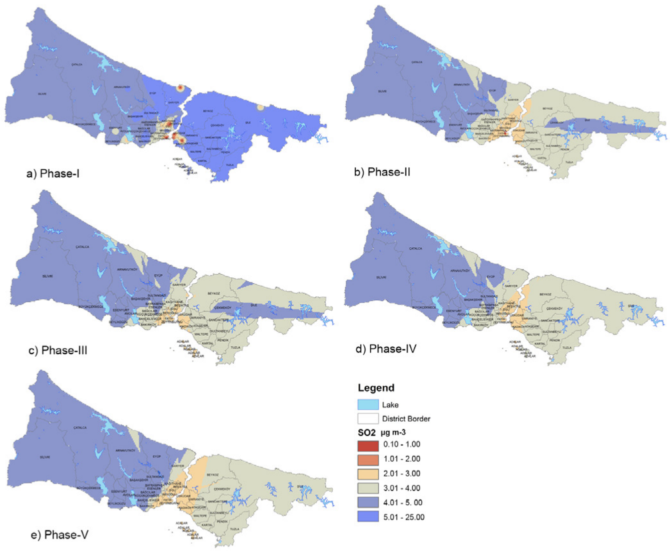


Figure 6. *Spatial distribution of SO2.*

role in the change of emission values on air quality also have a significant impact. Table 3 compares the change rates of the indicators affecting air quality compared to 2019.

Average temperature values have an important place in air pollution. When the air temperature drops below 18 C degrees due to the season, it causes the domestic fuel consumption to start. The amount of fuel burned during the season directly affects pollution (TÜCAUM, 2021). When we look at the average temperature values and the changes of pollutant types in Table 3, we see that CO and SO2 increased up to 71% in the Phase-II and Phase-III periods when the temperature decreased, while pollution decreased up to 35% in the phases in which the temperature increased. With the effect of temperature, the humidity rate also had the highest rate of change with 9,97%, especially in Phase-IV. The change in humidity rate has been one of the indicators contributing to the reduction of SO2 release by up to 15% compared to 2019.

Average wind speed and wind direction are another factor to consider in terms of carrying pollutant particles. In İstanbul, the dominant wind direction blows from the north to the south-west. In Table 3, while wind helps disperse light gases such as NOx, PM10 and NO2, it causes condensation and displacement of gases that remain in the air for a long time such as CO and SO2. Based on this assumption, when we look at the Table 3, we see that the de-

Table 3. *Comparison of indicators affecting air quality for 2019 and 2020.*

Years	Indicators	Phase-I	Phase-II	Phase-III	Phase-IV	Phase-V
2019	Average Temperature (°C)	11,36	9,01	14,98	16,01	20,8
2020		11,74	7,98	13,47	15,87	21,81
Change (%)		3,35	-11,43	-10,08	-0,87	4,86
2019	Average Humidity (%)	78,09	80,03	64,65	83,63	74,26
2020		76,28	79,39	65,20	75,29	73,13
Change (%)		-2,32	-0,80	0,85	-9,97	-1,52
2019	Average Wind Speed (m/sec)	2,50	3,90	2,50	0,99	2,56
2020		2,43	3,50	2,69	0,81	4,12
Change (%)		-2,80	-10,26	7,60	-18,18	60,94
2019	Direction of Wind	155,32	115,04	130,36	165,0	148,36
2020		156,02	112,13	140,79	155,30	152,68
Change (%)		0,45	-2,53	8,0	-5,88	60,94
2019	Precipitation (mm/hr)	0,96	0,65	0,89	1,35	1,0
2020		0,88	0,67	1,06	1,52	1,07
Change (%)		-8,33	3,08	19,10	12,59	7,0
2019	Average Traffic Index	26,53	25,27	27,13	23,62	26,03
2020		30,66	13,07	10,69	26,85	30,43
Change (%)		15,57	-48,28	-60,60	13,67	16,90
2019	Number of vehicle	76.653	84.441	80.100	86.528	94.818
2020		97.999	63.691	51.249	59.336	87.758
Change (%)		27,85	-24.57	-36,02	-31,43	-7.45
2019	CO	541,830	517,09	451,26	499,90	479,64
2020		388,59	595,69	546,54	576,97	646,987
Change (%)		**-28,28**	**15,20**	**21,11**	**15,42**	**34,89**
2019	**SO2**	5,81	2,5	3,79	5,10	3,58
2020		3,27	4,28	4,49	4,32	4,19
Change (%)		**-43,72**	**71,20**	**18,47**	**-15,29**	**17,04**
2019	NO2	35,84	47,14	48,90	49,87	36,10
2020		101,83	40,52	34,52	32,83	40,75
Change (%)		**184,12**	**-14,04**	**-29,41**	**-34,17**	**12,88**
2019	NOx	158,19	100,46	95,19	92,11	62,30
2020		287,88	99,55	77,13	76,07	82,14
Change (%)		**81,98**	**-0,91**	**-18,97**	**-17,41**	**31,85**
2019	**PM10**	44,06	44,76	38,57	45,53	36,94
2020		54,61	34,03	33,37	30,41	34,46
Change (%)		**23,94**	**-23,97**	**-13,48**	**-33,21**	**-6,71**

creasing average wind speed in Phase II and Phase IV has played a significant role in the dispersion and reduction of light gases such as PM10, NO2 and NOx. Since the average amount of precipitation can absorb pollutants in the air more easily, it is an effective factor in cleaning the air. The increase in the amount of precipitation during the time intervals when the precautions were taken helped nitrogen oxides especially to dissolve with rain. Thus, a decrease of up to 34% in NO2 and NOx values was observed.

Traffic density is one of the important factors that increase vehicle emission according to the type of vehicle used. Increased emission causes an increase in the amount of particles in the air (TÜCAUM, 2021). Compared to 2019, the average traffic density in Phase-I increased by 15,57% and the number of vehicles by 27,85%. With the beginning of the restrictions, the average traffic index and the number of vehicles in Phase-II decreased significantly, while the average traffic index and the number of vehicles decreased by 60,60% and 31,43%, respectively, in Phase-III, in which lockdowns were announced. In Phase-IV and Phase-V periods, with the removal of lockdowns and steps taken towards normalization, the increase in traffic density compared to 2019 was analyzed, while the number of vehicles in the city decreased rapidly.

When the distribution of the particles examined within the scope of the study was reviewed according to 2019, positive effects were observed between 1% and 35% in PM10, NO2, NOx values in the phases in which measures were taken, while air quality was negatively affected between 12% and 185% in the phases in which measures were not taken. Although the SO2 and CO parameters decreased by up to 44% compared to 2019 before the pandemic, they increased between 15% and 71% with the measures taken. Despite the decrease in traffic density and the number of vehicles during the lockdowns, the reason for the increase in CO and SO2 is based on the fact that the values vary according to the type of motor vehicles in traffic and the type of fuel. However, changes in temperature, humidity, wind, and precipitation have a direct effect on the increase and distribution of pollutant particles.

3.7. Co-relationship between air quality parameters

The correlation between different pollutant parameters in İstanbul during the study period covering 16 February 2020 to 30 June 2020 is shown in Figure 7. It has been determined that there is a strong and moderate positive correlation relationship between hourly average NO2 value and NOx, PM10, Number of Vehicles and Traffic index values at 0.996, 0.990, 0.784 and 0.483 values, respectively, and a negative correlation relationship with

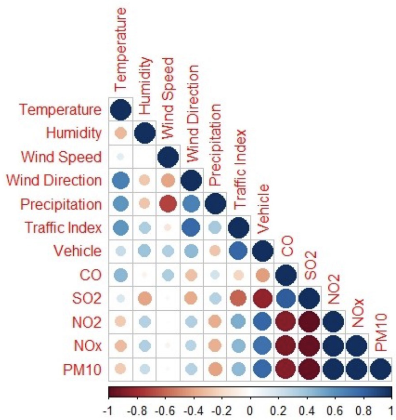


Figure 7. *Co-relation between pollutant types affecting air quality.*

CO and SO2 at 0.877 and 0.756 values, respectively. There is a moderate positive correlation between SO2 and CO with a value of 0.824, and between CO and temperature with a value of 0.446. There is a moderate positive correlation between the wind direction and the temperature with a value of 0.671, the precipitation and the traffic index with a value of 0.574. A positive correlation was observed between wind direction, precipitation, (0.666), traffic index (0.770) and the number of vehicles (0.432). No non-relational parameters were observed except for the low positive correlation between wind speed, number of vehicles and CO. However, the strong negative correlation of SO2 and CO particles with NO2, NOx and PM10 was analyzed.

4. Discussion

This study not only examined the effect of lockdowns on air quality through many different indicators, but also estimated the locations where pollutant particles are concentrated. For this purpose, PM10, SO2, NOX, NO2 and CO concentrations, meteorological factors (such as average temperature, precipitation, humidity, wind speed) and transportation indicators (traffic index, number of vehicles) were examined in 5 different time periods from mid-February 2020 to the end of June 2020, when measures were taken due to the pandemic in Turkey. Phase I and V were a time period when measures were not present or removed, Phase II was a time period when pandemic measures were taken, and Phase III and IV were a time period when lockdowns and measures were intensified. However, the study was completed by obtaining meteorology and transportation data from 31 air monitoring stations and from İstanbul Metropolitan Municipality from the website of the Ministry of Environment, Urbanization and Climate Change within the scope of the study.

Inclusion of other pollutant factors as well as airborne particles in the study area and examination in 5 phases were consciously preferred. Thus, many factors selected played an important role in explaining the decrease in pollution. In İstanbul, air pollution has decreased the most in lockdowns. When the lockdown periods were compared with the pre-pandemic (Phase-I) period, a decrease of up to 73% in other particles except SO2 and CO, 65% in the average traffic index and 48% in the number of vehicles was observed. Thus, while the decrease in urban circulation greatly reduces the release of particles, it has been observed that wind direction and wind speed accelerate the spatial distribution of pollution. SO2 and CO increased up to 40% in phase III and IV, in which air quality improved positively. These particles also had a strong positive correlation with average temperature. While the relevant pollutants had the highest values in the time intervals when the temperature decreased, they showed a decrease in the times when the temperature increased. When the data set is compared with 2019, air pollution increased by up to 184% in terms of other polluting particles, traffic index and the number of vehicles for pre-pandemic period except for SO2 and CO, while it decreased by up to 60% in lockdowns. In SO2 and CO, just the opposite occurred. It caused SO2 and CO to increase up to 21% due to the increase in domestic fuel consumption and traffic density with the decrease in average temperature. Thus, in the examinations made on the change in air quality, it has been revealed that it is essential to examine transportation and meteorological indicators as well as pollutant particles.

It is just as important to determine the urban distribution of polluting types in İstanbul by stations as to examine the short-term development of air quality with various indicators. For this purpose, the city is divided into 4 different types according to the locations of the weather observation stations. These are urban areas, sub-urban areas, industrial areas and rural areas. Prior to the pandemic (Phase-I), the highest levels of all pollutants except PM10 were observed in Aksaray, Alibeyköy, Şişli MTHM (Marmara Fresh Air Directorate) , Mecidiyeköy MTHM, Beşiktaş, Kağıthane MTHM and Maslak stations on the west side of the city (European Side). When the data in the relevant stations in the urban area were compared with 2019, an increase of 112% to 215% was observed. In the same period, the stations where all pollutants on the eastern side of the city (Anatolian Side) increased were Ümraniye MTHM, Göztepe, Kadıköy and Üsküdar. Pollution levels in the relevant stations in the urban area increased by 70% to 119% compared to 2019. These results show that pollution spread rapidly in the city within a year if there was no pandemic, but also emphasize that pollution spreads mostly in urban areas. In this period, similar results were obtained in many particles in order of minimum from the places where pollution was observed the most. It has been observed that the distribution of pollution level is especially in urban areas, sub-urban areas, industrial areas and finally in rural areas, respectively.

During the pandemic (Phase-II, Phase-III, Phase-IV), a decrease in particles other than CO and SO2 was observed in all stations. Pollution in these phases decreased in stations in urban areas mostly. The stations where pollution intensified were urban areas such as Kadıköy, Kandilli, Üsküdar and Selimiye on the Anatolian Side and suburban areas such as Sultanbeyli and Kartal. Compared to 2019, PM10, NO2, NOx parameters in these stations decreased between 48% and 73%, and CO and SO2 increased up to 21%. During the pandemic process, regions where pollution was spatially concentrated started to change as well as decreases in the release of pollution. In particular, it was observed that CO and SO_2, which increased during this process, increased by up to 61% in the rural areas of the city compared to 2019. The fact that such heavy gases, which can remain in the air for up to 4 months, increase in rural areas reveals the possibility of long-term ecological imbalances. It has been observed that the distribution of pollution level is especially in urban areas, sub-urban areas, industrial areas and finally in rural areas, respectively.

Although particulate emission was mostly seen in urban areas after the pandemic, the pollution spreading to rural areas during the pandemic period (especially on the European Side) continued to show its effect during this period. The stations where pollution was most intense were Yenibosna, Şirinevler MTHM, Bağcılar, Aksaray, Alibeyköy, Kağıthane, Maslak, Ümraniye MTHM, Göztepe and Kandilli. Pollution recorded at these stations, excluding SO_2, increased by 8% to 14% compared to 2019. The stations with the least spread of pollution were Sultanbeyli, Kartal, Sancaktepe and Kumköy and an improvement of up to 49% was observed in particles other than SO_2. SO_2 was concentrated in Silivri, Arnavutköy and Kumköy and increased up to 21%. In this period, pollutant density is listed as urban areas, sub-urban areas, industrial areas and finally rural areas, respectively.

As a general assessment, pollution in the city is concentrated mainly in urban areas and suburban areas. Although measures and lockdowns reduced the emission of pollution at all stations, the most intense pollution has again been seen in highly populated urban and suburban areas. The interruption of economic activities in industrial areas has reduced the level of pollution in the stations in these regions and has had a positive effect on air quality. In addition, the increase in release of SO_2 particles in rural areas started with lockdowns and strict restrictions, and their distribution in rural areas continued after the pandemic due to the particle structure.

This study comprehensively discussed the effect of Covid-19 lockdowns on air quality. The findings contributed to the development of air quality in many other countries and cities examined in the literature, as well as in İstanbul. However, the rapid differentiation of the spatial distribution of pollution in a short time causes the ecosystem to change and the air circulation to be negatively affected in the long term. Our research includes many factors related to air pollution and it both reveals the causes of pollution in more detail and is useful in determining the types of places where pollution spreads and intensifies.

5. Conclusion

The Covid-19 pandemic has restricted economic and social activities in İstanbul as well as almost anywhere else in the world. Pollution from industrial and urban mobility has greatly decreased in this period. While the largest decrease was 71% in NO_x, 60% in NO_2 and 28%in PM_{10}, the largest increase was 67% in CO and 28% in SO_2, respectively. Even if improvement in air quality to a large extent is analyzed, the spatial change of particles in a short time poses a long-term threat to İstanbul's rural settlements and green areas. The study also found that the decrease in average temperature led to increases in the level of heavy gases such as SO_2 and CO. In addition, it has been shown that wind speed plays an accelerating role in the spatial change of particles, and NO_2, NO_x and PM_{10}, the traffic index and the number of vehicles, are among the factors that cause the increase in pollution in metropolitan İstanbul. If pollution continues to spread uncontrollably in the coming years, it will cause the regional climate to change rapidly and negatively affect the quality of life of urban residents. Therefore, decision-makers should raise awareness of air pollution among urban residents and take new long-term measures to reduce air pollution. In our future studies, we will focus on the relationship between the measures and policies taken against pollution in İstanbul so far and the change rates and spatial effects of pollution, and examine the deficiencies in policies and practices.

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