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ORIGINAL ARTICLE / ORİJİNAL MAKALE

The effect of measures taken during the COVID-19 pandemic on air pollution: A East Mediterranean example from Turkey

COVID-19 pandemisi döneminde alınan önlemlerin hava kirliliğine etkisi Türkiye/Doğu Akdeniz örneği

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ABSTRACT

Objective: Air pollution is both an environmental and a social problem, as it leads to a multitude of adverse effects on human health, ecosystems, the built environment and the climate. Air pollutants are emitted from anthropogenic and natural sources. This study aimed to examine the effects of the measures taken during the COVID-19 pandemic on air pollution in the province of Adana in Turkey. **Methods:** The data related to the measurements of air pollution parameters were obtained from the Mediterranean Station of the National Air Quality Monitoring Network provided by the Ministry of Environment and Urbanization. The parameters were recorded on a daily basis between March 1st and May 1st in 2019 and 2020. The effects of measures that limited human movements like curfews, travel bans, etc. due to the COVID-19 pandemic on air pollution parameters were examined. **Results:** A significant decrease was found in the parameters of SO_2, CO, NOx, NO, NO_2 and O_3, except PM10, in 2020 when compared to 2019. The measures taken due to the COVID-19 pandemic were observed to result in a decrease of 0.35% in PM10, 23.6% in SO_2, 84% in CO, 46.5% in NOx, 34.5% in NO, 63.1% in NO_2 and 68.4% in O_3 concentrations. It was found that a significant part of the emissions that caused air pollution had originated from human activities. **Conclusion:** It was observed that the measures that reduced human movements had a significant effect on air pollution.

Keywords: Air pollution, particulate matter, COVID-19, pandemics, carbon monoxide

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ÖZ

Amaç: Hava kirliliği, insan sağlığı, ekosistemler, çevre ve iklim üzerinde çok sayıda olumsuz etkiye yol açtığı için hem çevresel hem de sosyal bir sorundur. Hava kirleticileri, antropojenik ve doğal nedenlerden kaynaklanır. Bu çalışmada; COVID-19 pandemisi nedeni ile alınan önlemlerin hava kirliliğine etkisinin incelenmesi amaçlanmıştır. **Yöntem:** Hava kirliliği parametreleri ölçüm sonuçları Çevre ve Şehircilik Bakanlığı Ulusal Hava Kalitesi İzleme Ağı, Akdeniz İstasyonu verilerinden alınmıştır. 1.Mart-1.Mayıs 2019-2020 arası hava kirliliği parametreleri günlük olarak alınmıştır. COVID-19 pandemisi nedeni ile insan hareketlerini azaltan (sokağa çıkma yasağı, seyahat yasakları vb.) önlemlerin hava kirliliği parametrelerine etkisine bakılmıştır. **Bulgular:** 1 Mart - 1 Mayıs 2020 arasında 2019 yılının aynı dönemine göre; PM10 hariç SO_2, CO, NOx, NO, NO_2 ve O_3 parametrelerinde önemli bir azalma tespit edilmiştir. COVID-19 nedeni ile alınan önlemlerden dolayı PM10, SO_2, CO, NOx, NO, NO_2, O_3 konsantrasyonlarında sırasıyla % 0.35, % 23.6, % 84, % 46.5, % 34.5, % 63.1 ve % 68.4 oranında azalma olmuştur. Hava kirliliğine neden olan emisyonların önemli bir kısmının insan faaliyetlerinden kaynaklandığı görülmektedir. **Sonuç:** İnsan hareketlerini azaltan önlemlerin hava kirliliği parametreleri üzerindeki etkisinin büyük boyutta olduğu görülmektedir.

Anahtar kelimeler: Hava kirliliği, partiküler madde, COVID-19, pandemi, karbonmonoksit

Introduction

Air is a fundamental requirement for the survival and development of all living organisms on the Earth. Air pollution affects health and the development of the economy. At the present time the increase in the number of private vehicles and the use of fossil fuels as a result of the industrialisation, the air quality is gradually decreasing followed by the increase in air pollution. Air pollution is caused by harmful amounts of gases and particles released into the atmosphere due to natural or human activities. There are many pollutants in the atmosphere such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon dioxide (CO_2), nitric oxide (NO), carbon monoxide (CO), nitrogen oxides (NOx), particulate matters smaller than 2.5 μm ($PM_{2.5}$), and those smaller than 10 μm (PM_{10}). Air pollution occurs when these substances in the atmosphere exceed a certain concentration, when they begin to damage the ecological system and the normal conditions of human existence and development.[1] Sources of air pollutants are categorised as natural and anthropogenic pollutants. Anthropogenic sources, which constitute the largest amount of pollutants causing air pollution, include the use of fossil fuels, emissions from industrial production processes and transportation. The large-scale use of fossil fuels for energy production worldwide has led to a number of environmental problems that have detrimental effects on human health and the environment.[2-4] With the increase in the world population and the developing of the world economy, the demand for energy has increased dramatically. After the start of the COVID-19 pandemic, various measures limiting human activities were taken like curfews, intercity travel bans (by bus or plane), changes in working hours and days, closure of schools, etc., aiming to reduce the transmission of the virus and to prevent its national and international spread. All these measures are expected to reduce transportation activities and decrease fossil fuel and energy consumption. This study aimed to investigate the effect of the measures, which reduce human movement, taken within the context of COVID-19 pandemics in Adana, Turkey on air pollution parameters.

Methods

The study was conducted in in 2020 in Adana province (Turkey), which is the sixth most populated province, with a population of 2,245,400 in 2020 on an area of sqm 13,844. The province is one of the six leading agricultural, commercial and cultural centres in the country. Air pollution parameters evaluated included PM_{10}, SO_2, CO, NO_2, NOx, NO, ozone (O_3) and temperature (°C). They were obtained from the Mediterranean Station of the National Air Quality Monitoring Network provided by the Ministry of Environment and Urbanisation. The parameters were recorded on a daily basis between March 1st and May 1st in 2019 and 2020.

Ethical approval was provided by the Ethical Committee of Çukurova University(Decree mno:100).

The National Air Quality Monitoring Network of the Ministry of Environment and Urbanisation in Turkey provides daily values of SO_2, NO_2, CO_2, NO, CO, NOx, $PM_{2.5}$ and PM_{10} for each province. $PM_{2.5}$ values were not included in the study as they were available since 2021. These parameters were used to evaluate the extent of air pollution in the study. Temperature data were also examined in the same period. The air pollution parameter measurements were obtained from four stations as Adana City Governorship, Çatalan, Doğankent and Meteorological Air Quality stations.[5]

Social activities and human movements were gradually restricted starting in March 11th, 2020 in Turkey when the first COVID-19 case was detected in the country. A series of additional measures were taken as follows: schools closed in March 12th, 2020, public events restricted in March 13th, extensive travel and transportation restricted and places where people are mostly gathered temporary closed in March 15th, Friday and diurnal ritual prayer activities performed in congregation suspended and medical elective surgeries and dental practices postponed in March 16th, flights directed to 20 countries cancelled in March 17th, sportive leagues postponed and number of countries closed to flight rose to 68 and restaurants limited to take-away only activities in March 19th, flexible working in the public sector introduced in March 22nd, public transportation capacity reduced to 50% per vehicle in March 24th, shopping in markets limited to indispensable needs in March 27th, intercity travel by bus or plane permitted, but flights abroad stopped in March 28th, curfew declared for citizens under the age of 20, and entry and exit banned in 30 metropolitan cities and Zonguldak province in April 4th, total closure for two days between April 11th and 12th, and for four days between April 23rd and 26th applied.

Statistical analyses

The data were analysed using SPSS 22 program. Mann-Whitney U test and Student's t test were used in the comparison of daily measurement values between 2019 and 2020 covering the period between March 1st and May 1st (61 days) in both years. The significance was set to $p < 0.05$. Cohen's d values were determined using effect size calculator, with $d>1$ interpreted as "very large", $1 \geq d > 0.8$ as "large", $0.8 \geq d > 0.5$ as "medium", $0.5 \geq d > 0.2$ as "small" effect.

Results

PM_{10}, SO_2, CO, NO_2, NOx, NO, O_3 gas and temperature measurement values with their comparison between two years (2019 vs 2020) were presented in table 1.

A significant decrease was observed in SO_2, CO, NOx, NO, NO_2 and O_3 values except PM_{10} in the period between March 1st and May 1st when 2019 and 2020 measurements were compared. It was found that the measures taken within the scope of combat with COVID-19 had a large-sized effect on the reduction of CO, NOx and O_3 gas, while SO_2 had an effect on the reduction of small-medium size. The average temperature for the same period in 2020 was found to be significantly higher compared to 2019. In figure 1, the average emission results for 2019-2020 and the differences between the two years are given.

When the same periods measurements were compared between 2019 and 2020,

Table 1. Comparison of air pollution parameters by years

Year		PM_{10}	SO_2	CO	NO_2	NO_X	NO	O_3	C^0
2019	**Mean (µg/m³)**	45.01	20.07	453.14	20.00	23.48	22.33	73.47	20.10
	S.D.	19.34	4.58	230.02	4.04	4.75	5.35	17.70	2.13
	Median	41.60	19.60	410.35	20.50	24.10	21.40	72.80	19.55
	Minimum	15.90	14.10	120.30	9.90	12.30	11.20	46.50	15.00
	Maximum	124.70	38.50	1338.10	26.70	31.60	46.10	142.70	25.40
	Range	108.80	24.40	1217.80	16.80	19.30	34.90	96.20	10.40
2020	**Mean (µg/m³)**	44.85	15.32	70.18	10.67	15.36	8.19	23.60	20.85
	S.D.	20.59	17.62	37.95	7.04	8.18	4.80	3.17	2.00
	Median	43.10	7.10	62.55	7.85	12.00	7.05	23.35	20.95
	Minimum	14.90	3.80	17.50	3.10	6.40	3.10	15.10	15.60
	Maximum	127.40	97.40	18.40	28.00	36.00	25.40	32.60	24.30
	Range	112.50	93.60	162.90	24.90	29.60	22.30	17.50	8.70
	Difference (%)	-0.35	-23.66	-84	-46.65	-34.5	-63.1	-68.4	+0.37
	p	**0.994**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.011**
	Cohen's d	0.008	0.36	2.32	1.62	1.21	2.78	3.92	8.34

Mann-Whitney U test, Student's t test

the measures taken due to the COVID-19 pandemic appeared to result in a decrease of 0.35% in PM_{10}, 23.6% in SO_2, 84% in CO, 46.5% in NO_x, 34.5% in NO, 63.1% in NO_2 and 68.4% in O_3 concentrations. Daily values of these parameters were presented in the graphs (Figure 2-5).

When the daily values of CO, NOx, SO_2 and O_3 gas measurements were compared between 2019 and 2020, it was found that the emissions were generally lower in 2020 compared to 2019. It was observed that there was an intense human activity and increases in emissions during curfew-free days.

Discussion

Today, environmental problems are increasing and diversifying, threatening nature and human health. Air pollution is prominent among these threats. Air is the fundamental source of life and indispensable for humans and living things. Air pollution has massive consequences, diseases related to air pollution are increasing and the standard of living is decreasing. In recent years, fossil fuels emerge as the biggest cause of air pollution. Although the use of coal for heating purposes has decreased, especially in big cities, it is still used in thermal power plants for energy production. In addition,

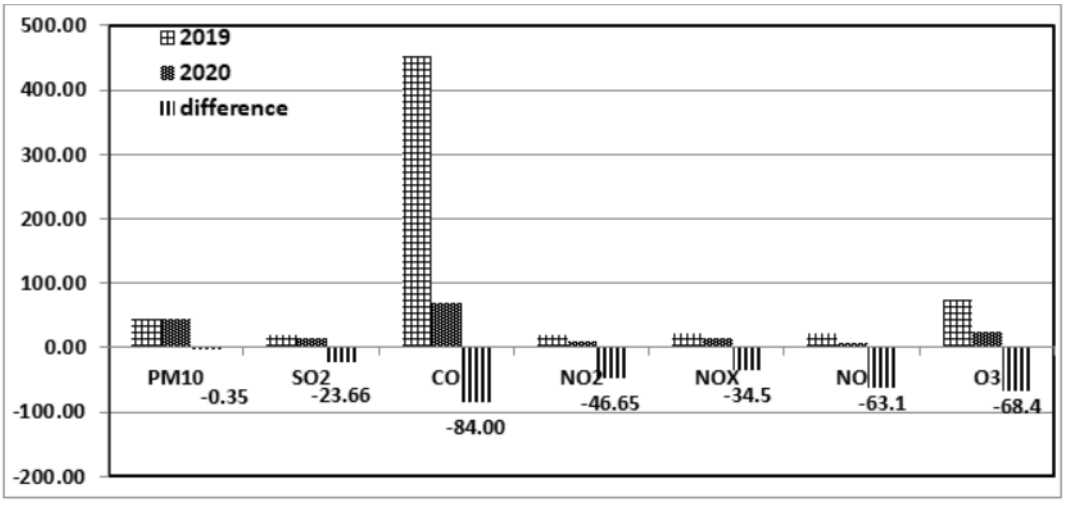

Figure 1. Differences in PM_{10}, SO_2, CO, NO_x, NO, NO_2, O_3 measurements from March 1st to May 1st in 2019 and 2020

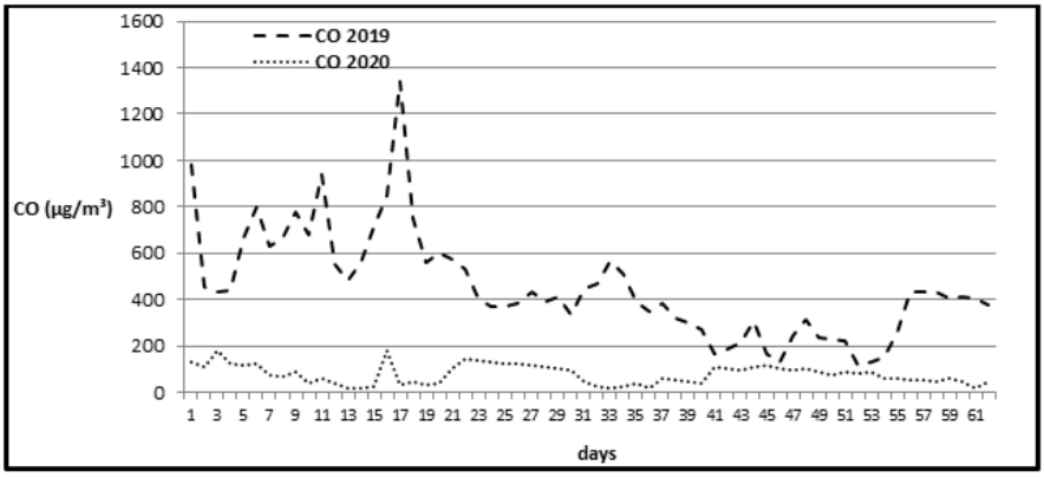

Figure 2. Carbon monoxide values from March 1st to May 1st in 2019 and 2020

unlike the mid-20th century, emissions particularly from urban transportation are notably high today, leading to an increase in the extent and times of exposure to air pollution of people in urban settings. Fossil fuel combustion and vehicle emissions lead to sulphur dioxide (SO_2) production, while nitric oxides (NOx) originate from vehicle emissions and high-temperature combustion processes, particulate matters (PM) from industrial activities, vehicle emissions, fossil fuel combustion, agriculture and secondary chemical reactions, carbon monoxide (CO) from incomplete combustion products, vehicle emissions, ozone (O_3) from nitrogen oxides (NOx) arising from vehicle traffic, and from the conversion of volatile organic compounds (VOC) under sunlight.[6,7] The main sources of external pollution can be nominated as vehicles, energy production, heating systems in buildings, agriculture, waste incineration and industry.[8]

In our study, the effect of the measures taken in the context of combat with COVID-19 pandemic like travel bans, curfews, closure of schools, changing of working schedules, etc., to reduce the social spread of the virus on air pollution parameters was examined. According to the results of our study, when the same periods of 2019-2020 were compared, the measures taken resulted in a decrease of 0.35% in PM_{10}, 23.6% in SO_2, 84% in CO, 46.5% in NO_x, 34.5% in NO, 63.1% in NO_2 and 68.4% in O_3 concentrations in our province of Adana. The reason why the decrease in PM was not significant may be related to the fact that domestic activities also contribute to PM emissions. It was interestingly observed that emissions were higher in the days following the long curfews, when compared to the values of the same time-points of the previous year. This was related to a relatively higher human activities in curfew-free days, when almost

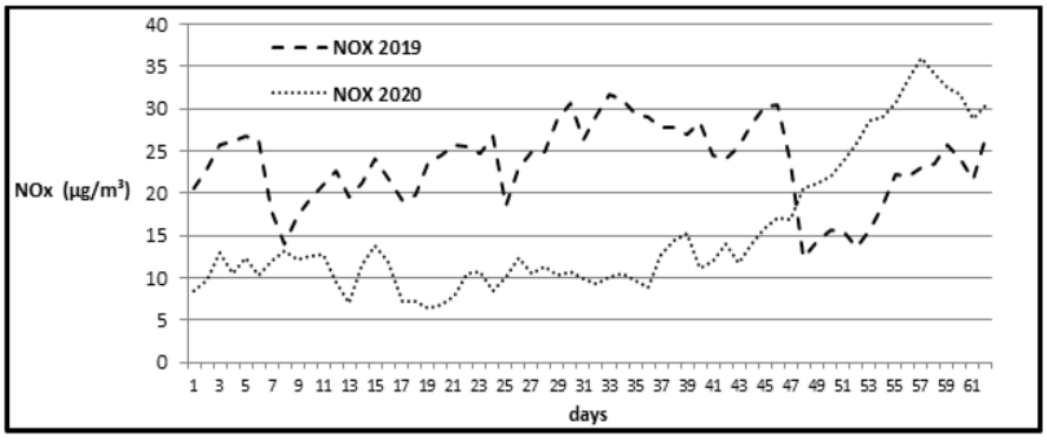

Figure 3. Nitrogen oxide values from March 1st to May 1st in 2019 and 2020

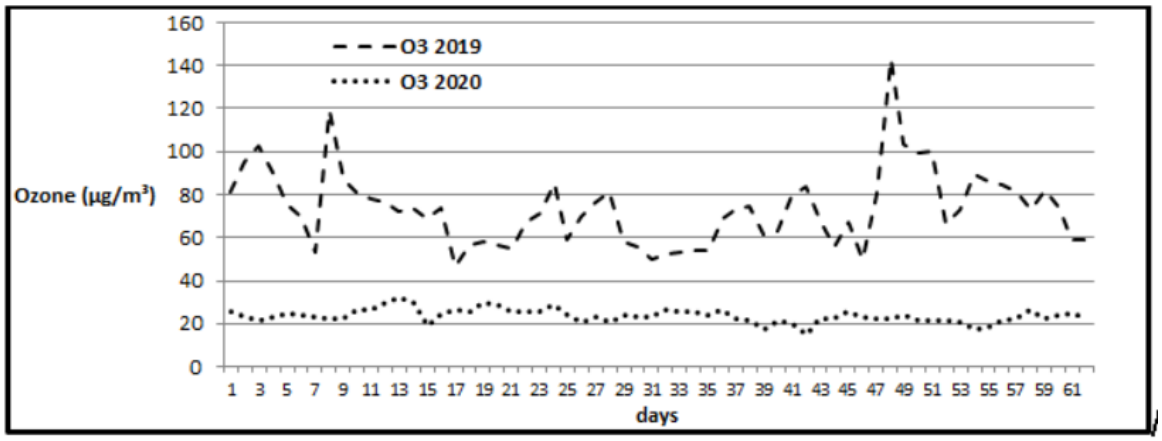

Figure 4. Ozone values from March 1st to May 1st in 2019 and 2020

everyone leaves home and prefer outdoor activities. The temperature parameter were observed to be significantly higher in 2020 when compared to the same period of 2019, which may indirectly reflect the global warming again due to the industrial activities.

In order to reduce the spread of the COVID-19 pandemic, China preferred to take similar measures such as stopping travel and transportation out of Wuhan, reducing local business travels, closing schools, colleges and universities, and establishing multiple quarantines.[9] These measures were reported to reduce NO_2 levels by 30%. This decrease started in China was observed to spread to nearby countries and the rest of the World: CO_2 emissions decreased by 25% in China and 6% globally. In China, it was estimated that mortality had decreased by 6% in the two-month period. Paradoxically, it was stated that total deaths had decreased in number amid pandemic due to the considerable decrease in air pollution following the quarantine periods.[10] When $PM_{2.5}$, NO_2, SO_2, CO and O_3 concentrations in the quarantine period in Almaty province of Kazakhstan between March 19th and April 14th, 2020 were compared with the values of the same period in the previous years 2018 and 2019, it was observed that $PM_{2.5}$ concentration was 21% lower, while CO and NO_2 concentrations were 49% and 35% lower, respectively. However, O_3 levels were found to increase by 15%.[11] Wang et al. observed the emissions to have decreased in parallel to the decrease in anthropogenic activities during the COVID-19 epidemic in China, among them transportation and industry was reported to notably contribute to the reduction of $PM_{2.5}$ concentrations by 20%.[12] The National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) recently declared that the quarantines in action worldwide since January 23rd, had significant impact on the

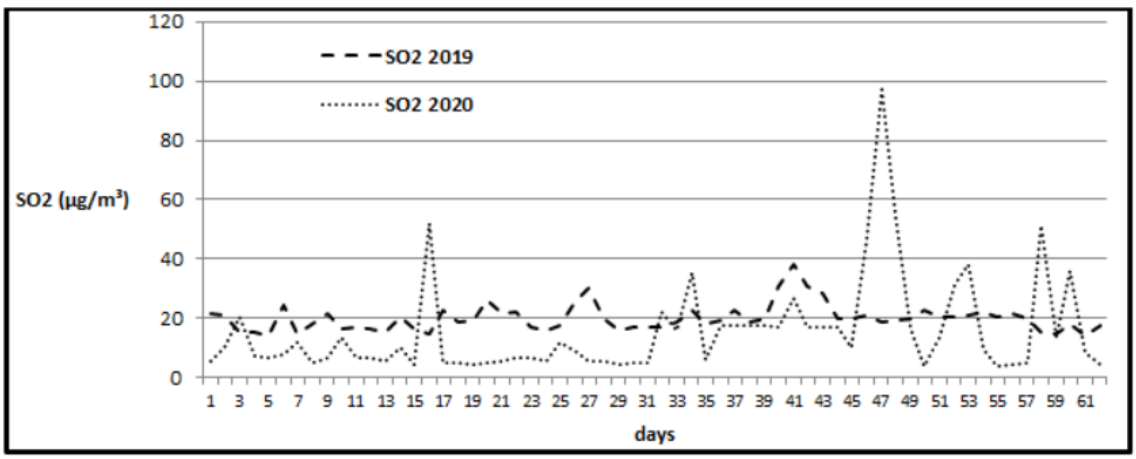

Figure 5. Sulfur dioxide values from March 1st to May 1st in 2019 and 2020

environment and the air quality of cities. In some epicentres such as Wuhan, there was observed a reduction of up to 30% in $PM_{2.5}$ emissions. When the before and after quarantine data from the World's 50 most polluted capitals were compared, $PM_{2.5}$ values were found to have decreased by 12% on average at local and global levels in these cities.[13] In a study conducted in India, when the same periods of 2019 and 2020 were compared, it was observed that there was a reduction of 46.1% in $PM_{2.5}$, 40.2% in PM_{10}, 34.4% in NO_2 and 16.3% in SO_2 emissions in 2020.[14] In a review by Wang et al., the effect of the restrictions applied after the COVID-19 pandemic on air pollution was examined and significant reductions in NO_2 emission, $PM_{2.5}$ level and other dangerous factors during quarantine periods were reported. In some areas, dark clouds were observed to turn silver. In addition to these positive results, it was stated that secondary pollutants such as ozone did not change and even increased significantly.[12] According to the ESA report, between March 2019 and 2020, the NO_2 level significantly decreased (by about 20-30%) in countries such as France, Spain and Italy as industrial factors also decreased.[15] The notable decrease of NO_2 observed in China during the pandemic was related to the decline in industrial activities utilising coal and fossil fuels.[16] According to satellite analysis in the study of Kanniah et al., it was found that the amount of tropospheric NO_2 decreased by 27-34% in the South Asian region. On the other hand, analyses made at ground stations revealed 33-46% and 64% of NO_2 decrease in industrial and urban areas, respectively.[17] A strict quarantine implemented between March 25th and April 20th, 2020 in India to reduce the case increase, 40% and 50% reductions were observed in NO_2 emissions in cities of Delhi and Mumbai, respectively, compared to the same period of the previous year.[18] According to the study of Berman, it was observed that NO_2 emissions decreased by 25.5% and $PM_{2.5}$ emissions continued to decrease during the pandemic period in the USA.[19] In European cities such as Rome and Paris, an important decline in human activities had a significant effect on air quality, when the period between March 14th and 25th, 2020 was compared to March 2019, with hourly decrease in NO_2 emissions by 62% in Madrid and by 50% in Barcelona.[20,21] In a recent study by Bao and Zhang, the analysis of data related to 44 cities in China, covering the period between January 1st and March 21st, revealed a 7.8% decrease in the air quality index and a significant improvement in air quality with specifically varying degrees of reduction in daily levels of five air pollutants was demonstrated: by 6.76% for SO_2, 5.93% for $PM_{2.5}$, 13.66% for PM_{10}, 24.67% for NO_2 and 4.58% for CO. After the strict implementation of the travel ban, human activities dropped dramatically by 69.85%. Reductions in $PM_{2.5}$ and CO were partly associated with stagnating mobility, and it was stated that the reduction in SO_2, PM_{10} and NO_2 levels could be attributed entirely to reduced human activities.[22] It is known that pollutants causing air pollution also contribute to global warming. The results of our study, when compared with the values of the previous year, revealed a significant increase in the average temperatures at the beginning of the pandemic.

Since the global warming is a cumulative process, the effects of the measures taken are not expected to be seen in the short term like several months. Recent studies have shown that combining local air pollution and greenhouse gas reduction activities is more cost-effective and more efficient. Climate-friendly measures such as improving energy efficiency, combining heat and electricity generation, fuel substitution and integrated coal gasification combined cycle plants can reduce SO_2, NOx and PM emissions without extra expenditure. When CO_2 emissions are reduced by 1%, the 1% negative impact originating from PM is significantly reduced.[23] Energy savings and emission reductions can be achieved by improving energy efficiency and using renewable energy sources.[24] Between the years 1860 and 2000, the amount of particulate matter increased by 5% and ozone concentrations near the surface increased by 2%.[25] Human-induced emissions affect climate change and alter the physical and chemical structure of the atmosphere.[26] According to the data of the World Health Organization (WHO); air pollution result in the death of about seven

million people worldwide each year. WHO data show that 9 out of 10 people breathe air containing high levels of pollutants. More than 80% of people living in urban areas where air pollution is monitored are exposed to pollutants at levels exceeding WHO guidelines. Outdoor air pollution causes approximately 4.2 million deaths annually due to stroke, heart disease, lung cancer and chronic respiratory tract diseases. About 91% of the World's population live in places where air quality levels exceed WHO limits.[8] Knowing that air pollution causes approximately 29% of lung cancer deaths, 43% of chronic obstructive pulmonary disease deaths and 25% of ischemic heart disease deaths, assessing the effects of quarantines on air quality is important when it will come to take action in favour of ecosystems, populations and cities once the emergency is over.[12]

Conclusion

When the same time intervals of the years 2019 and 2020 were compared, it was observed that the decrease in human activities due to the COVID-19 pandemic resulted in the improvement of the air quality index, and in a decrease in PM_{10}, SO_2, CO, NO_x, NO, NO_2, O_3 emissions in the same period of 2020.

It was seen that the main cause of emissions causing air pollution is human-induced activities. Quarantines, in which human activities are reduced or halted, appear to be helpful in understanding the causes and extent of air pollution. In order to reduce air pollution, substitution of fossil fuels with alternative energy sources, popularisation and encouragement of electrical vehicles, and emphasising efficiency-enhancing policies can be recommended.

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