



A Review of the Impacts of COVID-19 on Air Pollution in the World

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ARTICLE INFO

REVIEW ARTICLE

Article History:

Received: 05 May 2023

Accepted: 10 July 2023

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Keywords:
Air pollution,
COVID-19,
Pneumonia,
Epidemic.

ABSTRACT

Introduction: The COVID-19 epidemic has polluted millions of people and has caused millions of deaths worldwide. Therefore, this study aims to review the effects of COVID-19 on global air pollution.

Materials and Methods: In this narrative review, articles related to the objectives of the study were selected in reliable scientific databases such as Web of Science, Ovid, Google Scholar, PubMed, and Scopus. A total of 294 browsing sources and ultimately 90 sources were selected.

Results: In the COVID-19 pandemic, NO₂ dropped from 53 to 11% in most countries, and PM_{2.5} and PM₁₀ from 91 to 6% in some countries. CO dropped from 92 to 5% and SO₂ had a decreasing trend from 77 to 7% in most countries, except for the largest cities in Britain, Poland, Taiwan, and Iran. Unlike other pollutants, O₃ in most countries increased from 0.3 to 63%, but O₃ decreased in some countries.

Conclusion: In the lockdown period, the reduction of most air pollutants except O₃ was observed in many countries. But after restarting, polluting activities have increased again. Therefore, the rules implemented during lockdown time can be introduced as an appropriate option in emergencies to reduce air pollution.

Citation: Akbari M, Fallahzadeh RA, Dehghani R. *A Review of the Impacts of COVID-19 on Air Pollution in the World*. J Environ Health Sustain Dev. 2023; 8(3): 2024-38.

Introduction

Air pollution is one of the main public health problems. According to World Health Organization (WHO), air pollution is responsible for 7 million deaths worldwide ¹. Nowadays, the lives of more than one billion people in the world are threatened due to urban air pollution ². In 2016, 91% of the world's population was exposed to air pollutants, which was more than the WHO standard. Studies have shown that air pollutants such as particulate matter with an aerodynamic diameter less than 10 micrometers (PM₁₀) and particulate matter with a diameter less than 2.5

micrometers (PM_{2.5}), nitrogen oxides (NO_x), sulfur oxides (SO_x), Ozone (O₃), carbon monoxide (CO), and volatile organic compounds (VOC) are associated with adverse health implications. Respiratory disorders, cardiovascular disease, and early death are among the consequences ³. SARS-CoV-2 is a zoonotic virus that causes COVID-19 infectious pneumonia ⁴. COVID-19 was first identified in December 2019 in Wuhan China ^{5, 6}, and on March 11, 2020, it was announced by the World Pandemic Health Organization ⁷⁻¹⁰. This virus has caused millions of deaths worldwide. It is the fifth epidemic that has occurred in the world in

the last few years^{11, 12}. The COVID-19 epidemic has significantly challenged people's daily lives¹³. In Iran, the first official report of death from COVID-19 was reported by the Ministry of Health and Medical Education February 2019¹⁴. The first cases of COVID-19 were accompanied by severe air pollution¹⁵. Air pollutants can increase the risk of viruses that damage the respiratory tract. Hence, it is said that long-term exposure to air pollution puts people exposed to COVID-19. Although the role of air pollution in the transmission of virus through the air is still uncertain, the initial evidence confirms that the SARS-CoV-2 virus may exist in particulate matter. In this case, exposure to air pollution can help spread the virus¹⁶. Previous studies have suggested that exposure to high concentrations of contaminants such as PM_{2.5}, PM₁₀, CO, NO₂, and O₃ can increase the risk of damage to the health of people infected with COVID-19¹⁷. Feng et al. and Llaguno-Munitxa et al. reported reductions in air pollution in China and London during the COVID-19 lockdown, respectively^{18, 19}. Dubey et al. also reported that in India even a short period of closure can lead to a significant improvement in air quality²⁰. In 2003, it was reported that patients with SARS-CoV-1, who lived at the average level of air pollution, lost lives 84% more than those living in areas with less air pollution²¹. COVID-19 has had an impact on human society, particularly health-care economic

systems and social connections. As a worldwide strategy involving employment closure and social distancing, lockdown has had extraordinary regional implications. Although the severe health impacts of the COVID-19 are still in the main priority, it is not yet clear how the epidemic can affect other factors, especially air pollution²². Therefore, the present study was conducted to investigate air pollution and its impacts simultaneously on the prevalence of COVID-19 in the world.

Materials and Methods

This study was conducted as a narrative review using the keywords of air pollution, COVID-19, Iran, and the world in websites related to reliable journals in scientific databases such as Web of Science, Ovid, Google Scholar, PubMed, Scopus and SID. The articles were initially chosen based on their titles, which were linked to the research goals, and then their abstracts and related articles were separated. After a careful evaluation of the articles, studies that were relevant to the study's goals were chosen. Articles between 2014 to 2023 were evaluated to investigate air pollution and its effects simultaneously with the prevalence of COVID-19 in the world. Ultimately, 90 sources were selected by emphasizing the objectives of the study. Figure 1 shows the flowchart of how to select the articles investigated in the study.

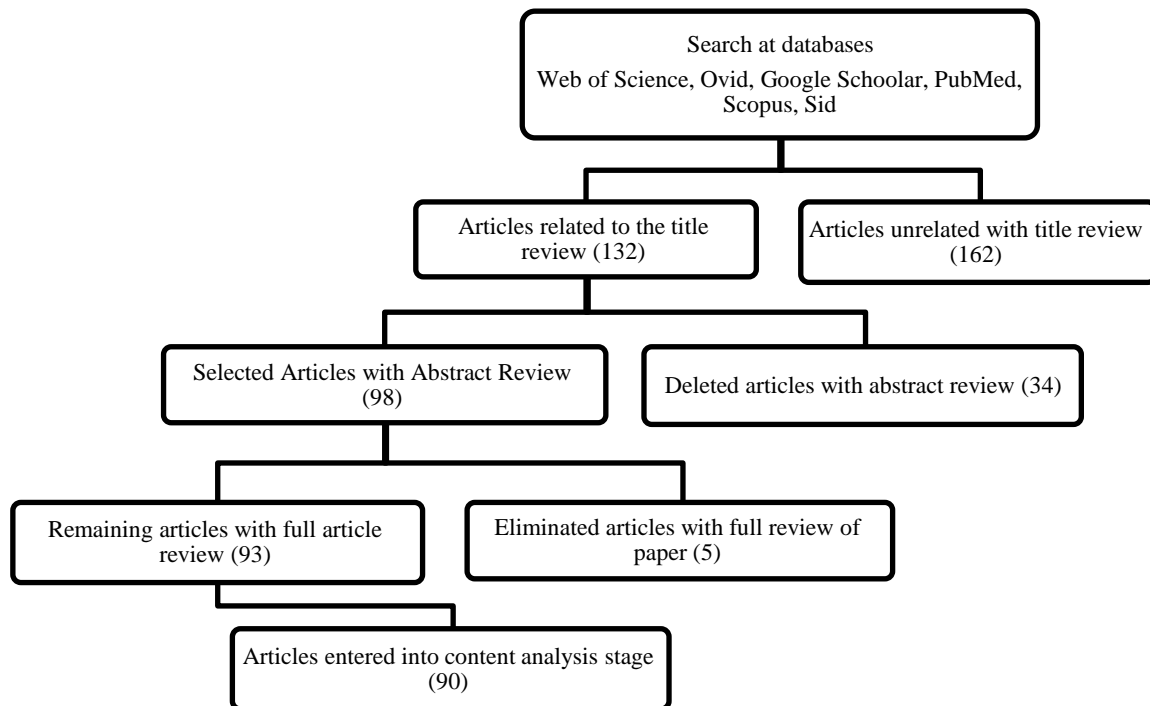


Figure 1: Flowchart of how to select the articles in the study

Ethical Issue

The present study has been approved by Kashan University of Medical Sciences with the ethics code IR.KAUMS.NUHEPM.REC.1400.043.

Results

Increase and decrease of air pollutants in the world during the COVID-19 pandemic

In Asia, Calcutta had the highest decrease, and Iran had the lowest decrease in $PM_{2.5}$ ^{23, 24}. In Mumbai and Delhi, India, South Korea, Wuhan, and Dhaka, decreasing in $PM_{2.5}$ was reported²⁵⁻²⁹. However, $PM_{2.5}$ increased in Tehran, Lahore, Karachi, and Peshawar^{11, 30}. SO_2 had the highest decrease in Istanbul and the lowest in Wuhan^{25, 31}. In Jeddah, Mumbai and Delhi, Tianjin and Dhaka SO_2 dropped^{27, 29, 32, 33}, but in Taiwan and Iran, this pollutant increased^{23, 34}. In Mecca, Istanbul, and Dhaka O_3 decreased^{27, 31, 32}. The highest increase was reported in O_3 in Iran and the lowest in Tianjin^{23, 33}. In Cairo and Alexandria, Wuhan, Mumbai and Delhi, Tel Aviv and Haifa, O_3 increased^{25, 29, 35, 36}. CO had the highest decrease in Istanbul and the lowest decrease in Cairo and Alexandria^{31, 36}. This pollutant also dropped in Mumbai and Delhi,

Bangalore, Wuhan, Tianjin, South Korea, Tehran, Dhaka, and Iran^{23, 28, 30, 33}. Only in Taiwan was an increase of CO reported³⁴. In Mumbai and Delhi, NO_2 has fallen highest in South Korea^{28, 29}. In Riyadh, Wuhan, Alexandria, India, Cairo, Istanbul, Tianjin, Dhaka, Tehran, Iran and Israel, NO_2 also decreased^{23, 25-27, 33, 35, 36}. PM_{10} had the highest decrease in Riyadh and the lowest decrease in Iran^{23, 32}. PM_{10} fell in Mumbai and New Delhi, India, South Korea, Istanbul, Wuhan and Tianjin^{25, 26, 29, 31, 33}. In Europe, $PM_{2.5}$ decreased in Poland and the largest cities in the UK, but in Warsaw it was reported to increase³⁷⁻³⁹. O_3 increased in the largest cities of Britain³⁹. In metropolitan areas in Spain, the highest decrease was observed in NO_2 and the lowest decrease in the Czech Republic and Greece⁴⁰⁻⁴². In Italy, Poland, Portugal, the largest cities of Britain and Warsaw the NO_2 decreased^{37-39, 43, 44}. PM_{10} had the highest decrease in metropolitan areas of Spain and the lowest in France⁴⁰. It reduced in Warsaw, Portugal, and the Czech Republic^{37, 41, 43}. $PM_{2.5}$ decreased in North and South America, California, Toronto, Montreal, Vancouver, Calgary, Chile and seven states and

capitals in the United States. CO decreased in Canada, California and Chile. O₃ increased in California and Chile. NO₂ decreased in California and Toronto, Argentina, Montreal, Vancouver, Calgary and Canada. PM₁₀ increased in California. The highest decrease in PM_{2.5}, CO, and PM₁₀ was in Mexico^{17, 45-50}. In New Zealand, the highest reduction was in NO₂⁵¹. Tables 1, 2, and 3 show the decrease and increase of air pollutants in the world during the COVID-19 period. In Nigeria, the Aerosol Optical Depth (AOD), which is one of the important parameters in dust study, decreased significantly compared to the pre-lockdown period.

During lockdown, the average level of air pollution decreased by about 69% compared to pre-lockdown. The increase in air quality is attributed to seasonal changes in climatic circumstances rather than lockdown efforts, since the average level of pollution during lockdown in Nigeria in 2020 was 0.22 greater than in the same time in 2013 or 2014⁵². NO₂ in Casablanca was 12 µg/m³ and in Morocco was 7 µg/m³. PM_{2.5} in Casablanca was 18 µg/m³ and in Morocco was 14 µg/m³. CO in Casablanca was 0.04 mg/m³ and in Morocco 0.12 mg/m³⁵³.

Table 1: Decrease and increase in air pollutants in Asia during the COVID-19 period (%)

City or country	Pollutants	Increased	Decreased	References
South Korea	PM _{2.5}		45.45	28
Mumbai and New Delhi India			42	29
Kolkata			85	24
India			34.84	26
Wuhan			32.92	25
Dhaka			26	27
Iran			6	23
Tehran		4		30
Xian	PM		32-51	54
Istanbul	SO ₂		77	31
Jeda			44.16	32
Bombay and Delhi			41	29
Tianjin			32.7	33
Dhaka			17.5	27
Wuhan			6.95	25
Taiwan		8.7		34
Iran		15		23
Cairo and Alexandria	O ₃	2		36
Mecca			18.98	32
Wuhan		2.26		25
Tianjin		0.3		33
Bombay and Delhi		2		29
Istanbul			56	31
Dhaka			9.7	27
Tel-Aviv		11		35
Haifa	CO	1		23
Iran		12		31
Istanbul			92	29
Bombay and Delhi			37	24
Bangalore			58	25
Wuhan			18.24	33
Tianjin			17.8	28
South Korea			17.33	27
Dhaka			8.8	36
Cairo and Alexandria			5	34
Taiwan		6.8		23
Iran			11	30
Tehran			6	

City or country	Pollutants	Increased	Decreased	References
Bombay and Delhi	NO ₂		53	29
Riyadh			44.35	32
Wuhan			38.33	25
Alexandria			33	36
Cairo			15	
Istanbul			24	31
Tianjin			22.7	33
Dhaka			20.4	27
South Korea			4.16	28
India			48.68	26
Iran			15	23
Tehran			12	30
Israel			41	35
Riyadh			91.12	32
Bombay and Delhi	PM ₁₀		50	29
South Korea			35.56	28
Istanbul			32	31
India			33.89	26
Wuhan			30.25	25
Tianjin			18.3	33
Iran			10	23

Table 2: Decrease and increase in air pollutants in Europe during the COVID-19 pandemic

City or country	Pollutants	Increased	Decreased	References
London	PM _{2.5}		26	39
Glasgow			25	
Belfast			30	
Birmingham			28	
Manchester			28	
Newcastle			29	
Liverpool			28	
Warsaw		12.4		
Poland urban site			20	
Poland a background site			23	
London	O ₃	16		39
Glasgow		5		
Belfast		8		
Birmingham		16		
Manchester		12		
Newcastle		7		
Liverpool		12		
Metropolises in Spain			24	40
London	SO ₂	116		39
Glasgow		117		
Belfast		168		
Birmingham		130		
Manchester		116		
Newcastle		135		
Liverpool		142		
Warsaw		190.8		37
metropolises in Spain	NO ₂		51	40
Italy (urban background sites)			30	44

City or country	Pollutants	Increased	Decreased	References
Italy (regional background sites)	AOD		40	38
Poland (urban site)			20	
Poland (background site)			18	43
Portugal			41	
Greece			11	42
London			36	
Glasgow			44	39
Belfast			41	
Birmingham			39	41
Manchester			37	
Newcastle			39	37
Liverpool			38	
Uherske Hradiste			11	40
Warsaw			19.6	
metropolises in Spain			27	43
Portugal			18	
Warsaw			9.9	37
Uherske Hradiste			9.23	
France			8.3	55
Poland			15	

Table 3: Decrease and increase in air pollutants in North and South America and Oceania during the COVID-19 period

City or country	Pollutants	Increased	Decreased	References
California	PM _{2.5}		31	45
Toronto, Montreal, Vancouver and Calgary			17-6	46
7 states and capital of America			12.8	48
Mexico			44.52	17
Chile			11	47
California	CO		49	45
Canada			20	50
Mexico			46.20	17
Chile			13	47
California	O ₃	14		45
Chile		63		47
Canada	NO ₂		20	50
California			38	45
Argentina			30	49
Toronto, Montreal, Vancouver and Calgary			31-34	46
California	PM ₁₀	21		45
Mexico			44.56	17
Argentina			44	49
Argentina	AOD		38-66	49
New Zealand	NO ₂		48-54.5	51

Impact of pollutants and meteorological parameters on increasing mortality due to COVID-19 in the world

In nine cities of Saudi Arabia, there was no change in humidity, temperature and wind speed parameters before and after quarantine during the COVID-19 pandemic³². In 219 Chinese cities, the relationship between wind speed and corona virus was negative. In northern China, COVID-19

transmission increased by increasing ambient temperature. However, in southern China, COVID-19 transmission decreased by increasing ambient temperature⁵⁶. There was a relationship between moisture and wind speed in Islamabad with COVID-19. In Lahore, there was a positive relationship between temperature and COVID-19⁵⁷. In Singapore, short-term exposure to higher concentrations of Pollutant Standard Index (PSI)

and NO₂ was associated with a higher number of COVID-19 contamination cases, while short-term exposure to higher concentrations of PM₁₀, O₃, SO₂, CO, rainfall, and humidity was associated with a lower incidence of COVID-19⁵⁸. The incidence of COVID-19 is caused by climatic factors such as temperature, relative humidity, and wind speed, according to research conducted in five major Indian cities (Bangalore, Chennai, Delhi, Calcutta, and Mumbai). The frequency of COVID-19 and fatality during and after lockdown was highly linked to temperature. The concentration of PM_{2.5}, PM₁₀, CO and O₃ and air quality index (AQI) were also correlated with positive cases and deaths during lockdown²⁴. In India, there was a strong association between COVID-19 mortality and PM₁₀²⁶. Cities with poor air quality have also been associated with higher incidence and mortality of COVID-19⁵⁹. In Japan, COVID-19 did not significantly correlate with precipitation, wind speed, humidity, NO, NO₂, O₃, and PM_{2.5}. However, there is a significant relationship with the average temperature, minimum and maximum daily temperature, and sunny hours⁶⁰. During the lockdown period in Moscow, the primary pollutants levels in the environment reduced from 30 to 50% along roads and in residential areas⁶¹. In the city of Lombardy, Italy, the decrease in temperature and increase in humidity have been associated with the increase in the incidence of COVID-19 and the resulting deaths⁶². In 36 Italian provinces, there was a strong relationship between PM₁₀ and mortality. Moreover, a high correlation between PM₁₀ and PM_{2.5} was reported¹. In Vento and Emilia Romania, there was also a positive and nonlinear relationship between the high level of NO₂ in the troposphere and the mortality rate of COVID-19⁶³.

In Italy, cities with high wind speeds were found to have a lower number of people with COVID-19. This study showed that high concentrations of air pollutants, along with low wind speed, cause more viral particles in the air and indirect emission of COVID-19⁶⁴. In Taragona, there was a positive correlation between COVID-19 deaths and chronic exposure to PM₁₀ and NO₂, but O₃ had a negative relationship⁶⁵. In Germany, temperature is the only climatic index that has significantly affected the COVID-19 epidemic in this country⁶⁶. In France, a direct relationship between air pollution and mortality caused by COVID-19 was reported⁶⁷. In Uherske Hradiste, a total of 2300 deaths due to reduced exposure to PM_{2.5} and 1200 deaths due to decreased exposure to NO₂ have been estimated⁴¹. In Mexico, a positive relationship between PM_{2.5} and the probability of death of a person after COVID-19 was found. This relationship increases with age, especially for people aged 40 years¹⁶. A study conducted in 422 cities in the US showed that long-term exposure to air pollution, in addition to the negative impact on the respiratory system and increasing the risk of death, also affects the sensitivity and severity of COVID-19⁶⁸. In the US, a decrease in PM_{2.5} during the corona period has reduced air pollution-related deaths⁴⁸. In Chile, the concentration of NO₂ and CO showed a strong association with COVID-19, while SO₂ had no significant relationship⁶⁹. Lima is the largest city with air pollution problems in Latin America. In this city, there was a significant correlation between NO₂ and the prevalence of COVID-19. Industrial areas with NO₂ above 26 grams per cubic metrology can increase COVID-19⁷⁰. Table 4 shows the impact of pollutants on the increase in deaths caused by COVID-19 in the world.

Table 4: Impact of pollutants on the increase in mortality caused by COVID 19 in the world

Continent	City or country	The rate of increase of pollutants	Increased morbidity	Decreased morbidity	Increased mortality	References
Asia	China	10 µg/m ³ NO ₂	37.8%			71
		10 µg/m ³ PM _{2.5}	32.3%			
		10 µg/m ³ PM ₁₀	14.2%			
	Iran	1 µg/m ³ NO ₂			2.7%	72
	China	Per 10 unit AQI	5-7%			56
Europe	Dhaka	1 µg/m ³ O ₃		2.9%		27
		1 µg/m ³ CO		53.9%		
	Italy	10 µg/m ³ PM _{2.5}	58%			62
		10 µg/m ³ PM ₁₀	34%			
		10 µg/m ³ PM _{2.5}			23%	
	Northern Italy	1 µg/m ³ PM			9%	73
	Catalonia	1 µg/m ³ NO ₂	2.7%			74
	Spain	1 µg/m ³ PM ₁₀	3%			
	England	1 µg/m ³ PM _{2.5}			1.4%	75
		1 µg/m ³ NO ₂			0.5%	
	Netherlands	1 µg/m ³ PM _{2.5}	9.4%		2.3%	55
	England	1 µg/m ³ PM _{2.5}	12%			76
	Germany	1 µg/m ³ NO ₂	5.58%			77
	Germany		199.46			
		1 µg/m ³ PM _{2.5}	morbidity per 100,000 inhabitants			78
North and South America	America	1 µg/m ³ PM _{2.5}			8%	79
		1 µg/m ³ PM _{2.5}	26%		34%	80
	Los Angeles	8.7 ppb (IQR) in mean annual NO ₂	31%			81

Discussion

COVID-19 lockdown in Saudi Arabia significantly reduced air pollution through traffic control, industry activities, and environmentally friendly transportation programs. Despite the decrease in concentrations of pollutants during lockdown concentrations, concentrations of CO, PM₁₀, SO₂, NO₂, and O₃ were still higher than the 24-hour standard and the annual WHO limit³². The major cause for the extraordinary improvement in air quality in Wuhan was climatic elements such as wind direction, wind speed, temperature, and humidity²⁵. In another study, the optimal wind direction was found to reduce PM_{2.5} in Wuhan. Decreased NO emission also led to an increase in O₃ during lockdown¹³. In Beijing, high concentration of PM_{2.5} during the lockdown period was caused by the smoke from industry emissions, non-stop fireworks, and adverse weather conditions⁸². In Tianjin, PM_{2.5}, the slight increase

of O₃, and reducing NO₂ indicates that the synergistic control of NO_x and VOC should be considered. The humidity of the air in the lockdown period was abnormal and may be due to an increase in nitrate in this period. The reduction of SO₂ could be due to the reduction of wind speed and consequently less pollution. The reduction of NO₂ and CO might be due to the reduction of pollutant emissions from vehicles³³. In Xian, the decrease in the concentration of suspended particles was due to restriction in human activity⁵⁴. During lockdown, high concentrations of PM_{2.5} in Karachi could be attributed to rapid population growth and business activity, while in Peshawar, the main source of PM_{2.5} particles was brick kilns operating around the city 24 hours a day¹¹. In Mumbai and New Delhi, O₃ was increasing due to reduced nitrogen oxide. Before the lockdown period, the AQI was at unhealthy and very unhealthy levels, but after the lockdown, it has

been at a healthy level. Therefore, the lockdown had no long-term impact on air quality in Delhi and Mumbai ²⁹. In India, except for coal mine areas, air quality improved during lockdown ⁵⁹. In South Korea, air pollution reduction was probably due to the reduction of domestic sources and transnational pollutants after the start of the COVID-19 ²⁸. Contrary to most studies in Taiwan, increasing pollutants on working days was observed by the emergence of COVID-19. It was due to the fact that during the COVID-19 epidemic, using metro and bicycles decreased by 8 to 18%, while the use of cars and motorcycles increased by 11 to 21% in working days ³⁴. In Iran, a significant increase in the concentration of O₃ could be due to the reduction of PM, NO₂, and VOC. However, following the lockdown, it was discovered that the concentration of all pollutants, especially O₃, increased to some extent compared to the 5-year normal limit. The abolition of the traffic management plan and the increased usage of personal automobiles to preserve social distance were the key reasons for this increase. Starting different jobs ahead of time due to economic problems was effective ¹⁵. Compared to 2019, the mean concentrations of O₃, NO₂, SO₂, CO, PM₁₀, and PM_{2.5} increased during the COVID-19 in Tehran. It is due to the reduction of greenhouse gas emissions from traffic as a result of lockdown. The concentration of other pollutants has changed slightly, indicating that lockdown does not lead to severe changes in greenhouse gas emissions from resources ³⁰. In Iran, the mean concentration of contaminants in the second wave of the disease indicates that air pollution increased by resolving transport restrictions ²³. In the lockdown period, a significant reduction in NO₂ concentration was observed due to the reduction of motor vehicles and road traffic in many major cities in Poland. Furthermore, except for SO₂, the concentration of PM_{2.5}, PM₁₀, and NO₂ decreased, since some factories were working during the lockdown period. The main reason for decreasing PM_{2.5}, PM₁₀, and NO₂ was a significant reduction in international and local transportation, reducing crude oil consumption and coal, which has had a

great impact on air quality ³⁷. The implementation of the lockdown led to an increase in the highest O₃ concentrations at both the urban and regional background sites resulting from reduced titration of O₃ by NO ⁴⁴. In 10 Spanish metropolis, PM_{2.5} decreased due to increased traffic, increasing the fuel caused by burning biomass and household fuels, and weather conditions ⁴⁰. There was no significant decrease in air pollution in Greece. This might be related to the ruling conditions during the period of clustering of the corona virus, including meteorological conditions ⁸³. In another study in Greece, a reduction in NO₂ was further attributed to a reduction in vehicle emissions ⁴². NO_x reduced in the Ostrava region due to traffic loss during lockdown. PM_{2.5} contamination analysis showed that home heating is the main source of PM_{2.5} in the region. The highest decrease in PM_{2.5} concentration at Ostrava Českobratrská traffic station was due to vehicle traffic reduction ⁸⁴. In Hungary, 20 to 50% reduction of road traffic decreased NO_x and increased O₃ and PM₁₀ during lockdown ⁸⁵. New York has experienced a sharp decline in air pollution in during the COVID-19, but this decline was high in exchange for social and economic costs ⁸⁶. Unstable economic growth has increased the emission of pollutants (PM_{2.5} and NO₂) in New York ⁸⁷. Increasing PM₁₀ in California can be related to the growing increase in the fires around California ⁴⁵. In Phoenix, the lack of CO and NO₂ concentrations and the dramatic decrease in PM₁₀ indicate that reduced travel did not reduce emissions, since people were still traveling home on local roads ⁸⁸. In Chile, an increase in the concentration of O₃ can be explained by considering complex atmospheric photochemical reactions including a mixture of VOC and NO_x. The reduction of NO_x increases the OH radicals that react with VOC and produces more O₃. NO_x showed the highest decrease among all the studied pollutants that could be related to traffic loss ⁴⁷. Also, PM_{2.5} in the open space caused by wood heating increased in prosperous areas ⁸⁹. In Mexico, a low-traffic monitoring station has had the highest reduction in pollutants ¹⁷. COVID-19 lockdown reduced the level of traffic-related

pollutants (NO₂, PM_{2.5}, and CO) and improved air quality in Morocco. This unique scenario might be due to the reduction of transnational pollution as a result of neighboring nations' lockdown measures⁵³. Given that more than 900 million people in Africa rely on air-polluting energy sources such as domestic appliances, white oil, and coal, CO levels have been minimally reduced. Millions in Africa live in small houses with inappropriate building materials, which can increase air pollution⁹⁰. NO₂ reduction in New Zealand can be related to removing greenhouse gas emissions⁵¹.

Conclusion

Based on global studies, ambient air quality was significantly affected by the prevalence of COVID-19. In the lockdown period, the reduction of most air pollutants except O₃ was observed in many countries. But, after restarting work activities the pollutants concentrations increased again.

Therefore, policies used during lockdown period including traffic control, reduced industrial activity, transport constraints, reduction of polluted emissions, and restrictions in human activities can lead to improvement of air quality. Laws enforced during lockdown can be introduced as an appropriate option in resource planning and intervention policies to reduce air pollution. There is also a significant relationship between PM_{2.5}, PM₁₀, and NO₂ and the risk of COVID-19 incidence and death, indicating that air pollution exacerbates the disease's prevalence and fatality. As a result, decreasing air pollution is of importance in reducing the pandemic. The findings of this study may be relevant to public health policymakers and decision-makers seeking to reduce COVID-19 prevalence.

Acknowledgements

The present study has been approved by Kashan University of Medical Sciences with the ethics code IR.KAUMS.NUHEPM.REC.1400.043. Thanks are owed to the relevant authorities.

Funding

This study was supported by Kashan University of Medical Sciences.

Conflict of interest

The authors declare that they have no conflict of interest.

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References

1. Dettori M, Deiana G, Balletto G, et al. Air pollutants and risk of death due to COVID-19 in Italy. *Environ Res.* 2021;192:110459.
2. Dehghani R, Takhtfiroozeh SM, Hosseindoost GH, et al. Investigation the air quality city of Kashan during 2012 based on the air quality index. *Armaghane Danesh.* 2014;19(4):314-25.
3. Barnett-Itzhaki Z, Levi A. Effects of chronic exposure to ambient air pollutants on COVID-19 morbidity and mortality - A lesson from OECD countries. *Environ Res.* 2021;195:110723.
4. Sobouti F, Moallem Savasari A, Aryana M, et al. Coronavirus as a new challenge for infection control in dentistry: A literature review. *Journal of Mazandaran University of Medical Sciences.* 2020;30(186):185-94.
5. Fallahzadeh RA, Ghadirian D, Eshaghpanah MS, et al. The relationship between ambient temperature and positive cases of COVID-19; A case study in Abarkouh and Qeshm Cities of Iran. *Journal of Environmental Health and Sustainable Development.* 2020;5(2):1016-20.
6. Fallahzadeh RA, Omid F, Ghadirian D, et al. Investigating the relation between meteorological parameters and the number of patients and clinical symptoms of outpatients with COVID-19: A case study in Abarkouh, Iran. *Journal of Environmental Health and Sustainable Development.* 2022;7(3):1708-18.
7. Akbari M, Dehghani R, Zavareh FH. A review of environmental factors for the spread of coronavirus and the role of expert healthcare workers in prevention. *Journal of Isfahan Medical School.* 2022;39(646):798-807.
8. Alikhani A, Maboudi M, Khademloo M, et al.

- Efficacy of new treatment modalities in patients with COVID-19, Qaemshahar Razi Hospital 2020. Journal of Mazandaran University of Medical Sciences. 2021;31(196):44-51.
9. Hosseini SH, Saleh Tabari Y, Assadi T, et al. Hospitals readiness in response to COVID-19 pandemic in Mazandaran Province, Iran 2020. Journal of Mazandaran University of Medical Sciences. 2021;31(196):71-81.
 10. Zazouli MA, Hashempour Y. A review of the stability of coronaviruses in different environments. Journal of Mazandaran University of Medical Sciences. 2021;31(195):141-55.
 11. Mehmood K, Bao Y, Petropoulos GP, et al. Investigating connections between COVID-19 pandemic, air pollution and community interventions for Pakistan employing geoinformation technologies. Chemosphere. 2021;272:129809.
 12. Shahbaznejad L, Hajjalibeig A, Jafari Savadkoobi K, et al. Clinical manifestations of multisystem inflammatory syndrome in children following COVID-19: A narrative review. Journal of Mazandaran University of Medical Sciences. 2021;31(201):178-91.
 13. Huang C, Wang T, Niu T, et al. Study on the variation of air pollutant concentration and its formation mechanism during the COVID-19 period in Wuhan. Atmospheric environment (Oxford, England : 1994). 2021;251:118276.
 14. Rahmani Samani F, Khodabakhshi A, Mobini GR, et al. Air and surface contamination with SARS-CoV-2 in COVID-19 admitting wards in Shahrekord Hajar Hospital, Iran. Journal of Mazandaran University of Medical Sciences. 2021;31(197):170-6.
 15. Aghashariatmadari Z. The effects of COVID-19 pandemic on the air pollutants concentration during the lockdown in Tehran, Iran. Urban Climate. 2021;38:100882.
 16. López-Feldman A, Heres D, Marquez-Padilla F. Air pollution exposure and COVID-19: A look at mortality in Mexico City using individual-level data. Sci Total Environ. 2021;756:143929.
 17. Tello-Leal E, Macías-Hernández BA. Association of environmental and meteorological factors on the spread of COVID-19 in Victoria, Mexico, and air quality during the lockdown. Environ Res. 2021;196:110442.
 18. Feng Z, Wang X, Yuan J, et al. Changes in air pollution, land surface temperature, and urban heat islands during the COVID-19 lockdown in three Chinese urban agglomerations. Sci Total Environ. 2023;892:164496.
 19. Llaguno-Munitxa M, Bou-Zeid E. Role of vehicular emissions in urban air quality: The COVID-19 lockdown experiment. Transportation Research Part D: Transport and Environment. 2023;115:103580.
 20. Dubey A, Rasool A. Impact on air quality index of india due to lockdown. Procedia Comput Sci. 2023;218:969-78.
 21. Sasidharan M, Singh A, Torbaghan ME, et al. A vulnerability-based approach to human-mobility reduction for countering COVID-19 transmission in London while considering local air quality. Science of The Total Environment. 2020;741:140515.
 22. Berman JD, Ebisu K. Changes in U.S. air pollution during the COVID-19 pandemic. Sci Total Environ. 2020;739:139864.
 23. Abdullah Kaviani R, Mohsen S, Mehdi Z. The impact of COVID-19 on air pollution in Iran in the first and second waves with emphasis on the city of Tehran. Journal of Air Pollution and Health. 2020;5(3).
 24. Kolluru SSR, Patra AK. Association of air pollution and meteorological variables with COVID-19 incidence: Evidence from five megacities in India. Environ Res. 2021;195:110854.
 25. Jiaxin C, Hui H, Feifei W, et al. Air quality characteristics in Wuhan (China) during the 2020 COVID-19 pandemic. Environ Res. 2021;195:110879.
 26. Naqvi HR, Mutreja G, Shakeel A, et al. Spatio-temporal analysis of air quality and its relationship with major COVID-19 hotspot places in India. Remote sensing applications: society and environment. 2021;22:100473.
 27. Rahman MS, Azad MA, Hasanuzzaman M, et al. How air quality and COVID-19 transmission

- change under different lockdown scenarios? A case from Dhaka city, Bangladesh. *Sci Total Environ.* 2021;762:143161.
28. Ju MJ, Oh J, Choi YH. Changes in air pollution levels after COVID-19 outbreak in Korea. *Sci Total Environ.* 2021;750:141521.
 29. Shehzad K, Xiaoxing L, Ahmad M, et al. Does air pollution upsurge in megacities after Covid-19 lockdown? A spatial approach. *Environ Res.* 2021;197:111052.
 30. Borhani F, Shafiepour Motlagh M, Stohl A, et al. Changes in short-lived climate pollutants during the COVID-19 pandemic in Tehran, Iran. *Environ Monit Assess.* 2021;193(6):331.
 31. Sahraei MA, Kuşkan E, Çodur MY. Public transit usage and air quality index during the COVID-19 lockdown. *J Environ Manage.* 2021;286:112166.
 32. Aljahdali MO, Alhassan AB, Albeladi MN. Impact of novel coronavirus disease (COVID-19) lockdown on ambient air quality of Saudi Arabia. *Saudi J Biol Sci.* 2021;28(2):1356-64.
 33. Ding J, Dai Q, Li Y, et al. Impact of meteorological condition changes on air quality and particulate chemical composition during the COVID-19 lockdown. *Journal of Environmental Sciences.* 2021;109:45-56.
 34. Chang HH, Meyerhoefer CD, Yang FA. COVID-19 prevention, air pollution and transportation patterns in the absence of a lockdown. *J Environ Manage.* 2021;298:113522.
 35. Agami S, Dayan U. Impact of the first induced COVID-19 lockdown on air quality in Israel. *Atmos Environ.* 2021;262:118627.
 36. Mostafa MK, Gamal G, Wafiq A. The impact of COVID 19 on air pollution levels and other environmental indicators -A case study of Egypt. *J Environ Manage.* 2021;277:111496.
 37. Filonchyk M, Hurynovich V, Yan H. Impact of Covid-19 lockdown on air quality in the Poland, Eastern Europe. *Environ Res.* 2021;198:110454.
 38. Grzybowski PT, Markowicz KM, Musiał JP. Reduction of air pollution in poland in spring 2020 during the lockdown caused by the COVID-19 pandemic. *Remote Sens.* 2021;13(18):3784.
 39. Higham JE, Ramírez CA, Green MA, et al. UK COVID-19 lockdown: 100 days of air pollution reduction?. *Air quality, atmosphere & health.* 2021;14(3):325-32.
 40. Querol X, Massagué J, Alastuey A, et al. Lessons from the COVID-19 air pollution decrease in Spain: Now what?. *Sci Total Environ.* 2021;779:146380.
 41. Vichova K, Veselik P, Heinzova R, et al. Road transport and its impact on air pollution during the COVID-19 pandemic. *Sustainability.* 2021;13(21):11803.
 42. Koukouli ME, Skoulidou I, Karavias A, et al. Sudden changes in nitrogen dioxide emissions over Greece due to lockdown after the outbreak of COVID-19. *Atmos Chem Phys.* 2021;21(3):1759-74.
 43. Gama C, Relvas H, Lopes M, et al. The impact of COVID-19 on air quality levels in Portugal: A way to assess traffic contribution. *Environ Res.* 2021;193:110515.
 44. Putaud JP, Pozzoli L, Pisoni E, et al. Impacts of the COVID-19 lockdown on air pollution at regional and urban background sites in northern Italy. *Atmos Chem Phys.* 2021;21:7597-609.
 45. Liu Q, Harris JT, Chiu LS, et al. Spatiotemporal impacts of COVID-19 on air pollution in California, USA. *Sci Total Environ.* 2021;750:141592.
 46. Mashayekhi R, Pavlovic R, Racine J, et al. Isolating the impact of COVID-19 lockdown measures on urban air quality in Canada. *Air Quality, Atmosphere & Health.* 2021;14(10):1549-70.
 47. Toro AR, Catalán F, Urdanivia FR, et al. Air pollution and COVID-19 lockdown in a large South American city: Santiago Metropolitan Area, Chile. *Urban Clim.* 2021;36:100803.
 48. Park JE, Son WS, Ryu Y, et al. Effects of temperature, humidity, and diurnal temperature range on influenza incidence in a temperate region. *Influenza Other Respir Viruses.* 2020; 14(1):11-8.
 49. Represa NS, Della Ceca LS, Abril G, et al. Atmospheric pollutants assessment during the

- COVID-19 lockdown using remote sensing and ground-based measurements in buenos aires, Argentina. *Aerosol Air Qual Res.* 2021;21(3): 200486.
50. Al-Abadleh HA, Lysy M, Neil L, et al. Rigorous quantification of statistical significance of the COVID-19 lockdown effect on air quality: The case from ground-based measurements in Ontario, Canada. *J Hazard Mater.* 2021;413: 125445.
 51. Talbot N, Takada A, Bingham AH, et al. An investigation of the impacts of a successful COVID-19 response and meteorology on air quality in New Zealand. *Atmos Environ (Oxford, England : 1994).* 2021;254:118322.
 52. Etchie TO, Etchie AT, Jauro A, et al. Season, not lockdown, improved air quality during COVID-19 state of emergency in Nigeria. *Sci Total Environ.* 2021;768:145187.
 53. Khomsi K, Najmi H, Amghar H, et al. COVID-19 national lockdown in morocco: Impacts on air quality and public health. *One health (Amsterdam, Netherlands).* 2021;11:100200.
 54. Tian J, Wang Q, Zhang Y, et al. Impacts of primary emissions and secondary aerosol formation on air pollution in an urban area of China during the COVID-19 lockdown. *Environ Int.* 2021;150:106426.
 55. Cole MA, Ozgen C, Strobl E. Air pollution exposure and Covid-19 in dutch municipalities. *Environ Resour Econ.* 2020;76(4):581-610.
 56. Zhang Z, Xue T, Jin X. Effects of meteorological conditions and air pollution on COVID-19 transmission: Evidence from 219 Chinese cities. *Sci Total Environ.* 2020;741:140244.
 57. Mehmood K, Bao Y, Abrar MM, et al. Spatiotemporal variability of COVID-19 pandemic in relation to air pollution, climate and socioeconomic factors in Pakistan. *Chemosphere.* 2021;271:129584.
 58. Lorenzo JSL, Tam WWS, Seow WJ. Association between air quality, meteorological factors and COVID-19 infection case numbers. *Environ Res.* 2021;197:111024.
 59. Naqvi HR, Datta M, Mutreja G, et al. Improved air quality and associated mortalities in India under COVID-19 lockdown. *Environ Pollut.* 2021;268:115691.
 60. Azuma K, Kagi N, Kim H, et al. Impact of climate and ambient air pollution on the epidemic growth during COVID-19 outbreak in Japan. *Environ Res.* 2020;190:110042.
 61. Ginzburg AS, Semenov VA, Semutnikova EG, et al. Impact of COVID-19 lockdown on air quality in Moscow. *Doklady Earth Sciences.* 2020;495(1):862-6.
 62. De Angelis E, Renzetti S, Volta M, et al. COVID-19 incidence and mortality in Lombardy, Italy: An ecological study on the role of air pollution, meteorological factors, demographic and socioeconomic variables. *Environ Res.* 2021;195:110777.
 63. Filippini T, Rothman KJ, Cocchio S, et al. Associations between mortality from COVID-19 in two Italian regions and outdoor air pollution as assessed through tropospheric nitrogen dioxide. *Sci Total Environ.* 2021;760:143355.
 64. Coccia M. How do low wind speeds and high levels of air pollution support the spread of COVID-19?. *Atmos Pollut Res.* 2021;12(1):437-45.
 65. Marquès M, Rovira J, Nadal M, et al. Effects of air pollution on the potential transmission and mortality of COVID-19: A preliminary case-study in Tarragona Province (Catalonia, Spain). *Environ Res.* 2021;192:110315.
 66. Bashir MF, Benghoul M, Numan U, et al. Environmental pollution and COVID-19 outbreak: insights from Germany. *Air Qual Atmos Health.* 2020;13:1385-94.
 67. Magazzino C, Mele M, Schneider N. The relationship between air pollution and COVID-19-related deaths: An application to three French cities. *Appl Energy.* 2020;279:115835.
 68. Chakraborty J. Convergence of COVID-19 and chronic air pollution risks: Racial/ethnic and socioeconomic inequities in the U.S. *Environ Res.* 2021;193:110586-.
 69. Tian X, An C, Chen Z, et al. Assessing the impact of COVID-19 pandemic on urban

- transportation and air quality in Canada. *Sci Total Environ.* 2021;765:144270.
70. Arias Velásquez RM, Mejía Lara JV. Gaussian approach for probability and correlation between the number of COVID-19 cases and the air pollution in Lima. *Urban Clim.* 2020;33:100664.
 71. Zheng P, Chen Z, Liu Y, et al. Association between coronavirus disease 2019 (COVID-19) and long-term exposure to air pollution: Evidence from the first epidemic wave in China. *Environ Pollut.* 2021;276:116682.
 72. Norouzi N, Asadi Z. Air pollution impact on the Covid-19 mortality in Iran considering the comorbidity (obesity, diabetes, and hypertension) correlations. *Environ Res.* 2021;204(Pt A):112020.
 73. Becchetti L, Beccari G, Conzo G, et al. Air quality and COVID-19 adverse outcomes: Divergent views and experimental findings. *Environ Res.* 2021;193:110556.
 74. Saez M, Tobias A, Barceló MA. Effects of long-term exposure to air pollutants on the spatial spread of COVID-19 in Catalonia, Spain. *Environ Res.* 2020;191:110177.
 75. Konstantinoudis G, Padellini T, Bennett J, et al. Long-term exposure to air-pollution and COVID-19 mortality in England: a hierarchical spatial analysis. *Environment International.* 2021;146:106316.
 76. Travaglio M, Yu Y, Popovic R, et al. Links between air pollution and COVID-19 in England. *Environ Pollut.* 2021;268(Pt A):115859.
 77. Huang G, Brown PE. Population-weighted exposure to air pollution and COVID-19 incidence in Germany. *Spat Stat.* 2021;41:100480.
 78. Prinz AL, Richter DJ. Long-term exposure to fine particulate matter air pollution: An ecological study of its effect on COVID-19 cases and fatality in Germany. *Environ Res.* 2021;204(Pt A):111948.
 79. Wu X, Nethery R, Sabath B, et al. Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study. *MedRxiv*; 2020;7:2020-4.
 80. Berg K, Romer Present P, Richardson K. Long-term air pollution and other risk factors associated with COVID-19 at the census tract level in Colorado. *Environ Pollut.* 2021;287:117584.
 81. Lipsitt J, Chan-Golston AM, Liu J, et al. Spatial analysis of COVID-19 and traffic-related air pollution in Los Angeles. *Environment international.* 2021;153:106531.
 82. Gao C, Li S, Liu M, et al. Impact of the COVID-19 pandemic on air pollution in Chinese megacities from the perspective of traffic volume and meteorological factors. *Sci Total Environ.* 2021;773:145545.
 83. Varotsos C, Christodoulakis J, Kouremadas GA, et al. The signature of the coronavirus lockdown in air pollution in Greece. *Water Air Soil Pollut.* 2021;232(3):119.
 84. Bitta J, Svozilík V, Svozilíková Krakovská A. Effect of the COVID-19 lockdown on air pollution in the ostrava region. *Int J Environ Res Public Health.* 2021;18(16):8265.
 85. Varga-Balogh A, Leelőssy Á, Mészáros R. Effects of COVID-induced mobility restrictions and weather conditions on air quality in hungary. *Atmosphere.* 2021;12(5):561.
 86. Perera F, Berberian A, Cooley D, et al. Potential health benefits of sustained air quality improvements in New York City: A simulation based on air pollution levels during the COVID-19 shutdown. *Environ Res.* 2021;193:110555.
 87. Magazzino C, Mele M, Sarkodie SA. The nexus between COVID-19 deaths, air pollution and economic growth in New York state: Evidence from Deep Machine Learning. *J Environ Manage.* 2021;286:112241.
 88. Miech JA, Herckes P, Fraser MP. Effect of COVID-19 travel restrictions on Phoenix air quality after accounting for boundary layer variations. *Atmos Environ: X.* 2021;10:100105.
 89. Martinez-Soto A, Avendaño Vera CC, Boso A, et al. Energy poverty influences urban outdoor air pollution levels during COVID-19 lockdown in south-central Chile. *Energy Policy.* 2021;158:112571.
 90. Gharbia R, Hassanien AE. Carbon monoxide

air pollution monitoring approach in Africa during COVID-19 pandemic. In: Hassanien AE, Darwish A, Gyampoh B, et al., editors. The Global Environmental Effects During and

Beyond COVID-19: Intelligent Computing Solutions. Cham: Springer International Publishing; 2021pp. 93-103.