Disaster Medicine and Public Health Preparedness

www.cambridge.org/dmp

The Effect of the COVID-19 Pandemic on Environmental Health (Two Sides of the Same Coin): A Systematic Review

Mehrdad Farrokhi PhD[1], Hamidreza Khankeh PhD[1,2], Mohammad Saatchi PhD[1], Zoya Hadinejad PhD[1,3], Sadegh Ahmadi-Mazhin PhD[4], Yazdan Mohsenzadeh PhD[1,5], Zahra Mehraein Nazdik PhD[1], Javad Shojafard PhD[1], Negar Pourvakhshoori PhD[6] and Shokoufeh Ahmadi PhD[1]

[1]Health in Emergency and Disaster Research Center, Social Health Research Institute, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran; [2]Department of Clinical Science and Education, Karolinska Institute, Stockholm, Sweden; [3]Department of Education and Research, Emergency Medical Sciences, Mazandaran University of Medical Sciences, Sari, Iran; [4]Department of Public Health, School of Health, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran; [5]Department of Nurse Sciences, Faculty of Emergency Medicine, Alborz University of Medical Sciences, Karaj, Iran and [6]Department of Nursing, School of Nursing and Midwifery, Guilan University of Medical Sciences, Rasht, Iran

Systematic Review

Cite this article: Farrokhi M, Khankeh H, Saatchi M, *et al*. The Effect of the COVID-19 Pandemic on Environmental Health (Two Sides of the Same Coin): A Systematic Review. *Disaster Med Public Health Prep*. **17**(e499), 1–14. doi: https://doi.org/10.1017/dmp.2023.139.

Keywords:
COVID-19; pandemic; air pollution; water pollution; environmental pollutants

Corresponding author:
Shokoufeh Ahmadi;
Email: ahmadi.shokoufeh@gmail.com.

Abstract

Background: The outbreak of the COVID-19 pandemic in late 2019 has led to many changes such as reduced human activities and effects on the environment. There is no big picture of the effects of pandemics on the environment using related evidence.

Objectives: This study was conducted to investigate the effect of the COVID-19 pandemic on environmental health.

Methods: A systematic search of English language studies was performed in major electronic databases; Web of Science, PubMed, Scopus, and Google scholar web search engine from December 2019 to February 2022. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standard guidelines were used to follow up the review process. finally 58 articles entered the review procedure.

Results: The results of indicate a significant reduction of air pollutants and improved air quality. It improved the water quality of some rivers, canals, and seas during the lockdown of the COVID-19 pandemic. The effects of this disease on the environment cannot be fully described yet.

Conclusion: In the short term, the amount of air, water, and coastal pollution has been reduced. few studies have examined the effects of pandemics on the environment in the long run, which paves the way for more researches.

On February 11, 2020, the World Health Organization identified the causative agent as the coronavirus and named it *coronavirus disease (COVID-19)*.[1,2] As of May 31, 2023, more than 767 364 million people have been infected with the disease and nearly 7 million deaths have been recorded. In addition to endangering the lives of millions of people worldwide and a variety of social and economic consequences, its direct and indirect effects on the environment have also been discussed.[3]

Negative effects related to human activities in the environment include global warming, urban sprawl, and accelerated species extinction. The view that humans play a major role in threatening species and ecosystems suggests that global human quarantine to reduce COVID-19 health hazards may reduce human impact and result in positive environmental responses. Indeed, initial reports indicate that the restrictions have led to an immediate reduction in air, land, and water travel, with similar reductions in industry, commercial exploitation of natural resources and production, and lower levels of PM10, NO_2, CO_2, SO_2, and noise pollution.

However, a more comprehensive examination of the links between human activities, species, and ecosystems acknowledges the role of humans as conservationists, who participate in environmental protection research, biodiversity monitoring, habitat restoration, and wildlife-related executive activities. Indeed, COVID-19 global human quarantines have disrupted conservation, research, and policy processes to improve the global environment and biodiversity. The quarantine has also created economic insecurity in rural areas, which may pose a threat to biodiversity as humans seek to earn a living through illegal hunting and fishing. Reducing ecotourism in and around national parks and other protected areas has reduced funding for hunting restrictions and invasive species management programs. In general, there is a combination of positive and negative effects of lockdown following an epidemic on nature,

which has the potential to lead to chain reactions that in turn affect wildlife and nature conservation. However, the effect of an issue such as *lockdown* requires more than several years of evaluation, and with the availability of data and the emergence of persistent epidemic effects, the response is being mapped around the world.[4,5]

As mentioned, COVID-19 is one of the emerging infectious diseases that, along with the increase in human population, has increasingly disrupted natural ecosystems.[6] The outbreak of COVID-19 has caused concern around the world and changed the way people live. This change in human lifestyle has brought advantages and disadvantages to the environment, which necessitates research on these effects focusing on the presence and evolution of the COVID-19 pandemic in water, soil, and other environmental factors, as well as providing solutions to improve the environment. Despite the positive effects of coronavirus on the environment such as improving air quality, cleaning beaches, and reducing noise pollution, there are primary and secondary negative aspects such as excessive water consumption, reduced waste recycling, and increased organic and inorganic waste that lead to air, water, and land pollution. Policy-makers' responses to the epidemic have also had profound effects on the environment. These effects include a combination of aggravating and improving factors of environmental pollution.[7] Since the positive and negative effects of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) on the environment are not clear, this research aims to review the published articles examining the effects of the COVID-19 pandemic on environmental health.

Material and Methods

A systematic review was conducted to investigate the association between the COVID-19 pandemic with air quality, water resources, and the environment. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standard guidelines were used to follow up the review process and report findings.[8]

Search Strategy and Selection Criteria

This review focused on studies about environmental pollution and or environmental impact that were published in English language journals up to the end of February 2022. The databases of Web of Science, PubMed, and Scopus were searched for medical subject headings (MeSH) and relevant key words, including "Environment," "environmental pollution," "Environmental Impact," "COVID-19," "COVID-19 virus," "coronavirus disease 2019," "SARS-CoV-2," "pandemic," and "outbreak." They were used in isolation or combination through the Boolean method.

Inclusion and exclusion criteria

All English-language articles published in the world on air quality, water, environment, or a combination of these indicators and COVID-19 that were of high quality entered the study.

Exclusion criteria included articles of low quality, and studies conducted on other infectious diseases were excluded from the study. Those articles published in non-English language were also excluded. Additionally, meta-analysis, case reports, or series of cases were excluded, as well.

Quality assessment

The quality of the articles was assessed using the Strobe checklist (Strengthening the Reporting of Observational Studies in Epidemiology). This checklist has 6 scales, including: title, abstract, introduction, methods, results, and discussion. Some of these scales have subscales, resulting in a total of 32 subscales. Therefore, the maximum score that can be captured from the assessment using the checklist is 32, considering the score of 16 as the cutoff point.[9] In this study, an acceptable score of 16 was considered. Scores 16–24 were medium, and scores greater than 24 (high quality) were considered.

Screening and Data Extraction

The search results were imported into the Mendeley software and duplicate titles were deleted. Selected studies were entered into abstract reading and were checked against the inclusion criteria, of which the most relevant studies were selected for independent full-text reading by 2 researchers (SD, JB) and a third person as the expert-epidemiologist checked the result. Reasons for the rejection of studies were mentioned and in case of disagreement between the researchers, the perspective of a third researcher was sought. A checklist was used to extract data from the selected studies in terms of the sample size, study location, study year, type of study, COVID-19 pandemic, environmental pollution, and/or environmental impact.

Selection of articles

By searching databases, 264 studies were extracted. Initially, the articles were entered into Mendeley software and after an initial review, 27 articles were removed from the study due to duplication. Then, by reviewing the titles and abstracts of articles, 5 articles were excluded due to not corresponding with inclusion criteria and 169 articles were removed due to irrelevance, and after reviewing the full text of articles, 5 articles were excluded due to lack of the required information. Finally, 58 articles met the inclusion criteria and entered the process of systematic review (Figure 1).

Findings and Discussion

Of the total 58 studies presented, 26% of the articles worldwide reported their results, and about 28% of these studies were dedicated to India. About 69% of the articles were published in 2020, according to the time of publication (Figure 2).

Among the findings of this study, out of a total of 58 articles, 47 studies referred to the impact of positive aspects of the COVID-19 pandemic on water, air, and environmental quality, and the remaining 11 articles simultaneously examined the positive and negative effects of this disease (Table 1).

In total, 62% of the studies examined only air quality variables such as NO_2, NO, CO, CO_2, PM10, and PM2.5[10,12,20,22,35,40]; 15.5% [34,41,43,50] examined water quality variables; 10.5%[11,15,17,33,44] probed both climate quality indicators; and 12%[13,14,16,18,42] assessed the overall effects of COVID-19 pandemic on the environment. Due to the emergence of this disease, there are still many unknown aspects, but the main research in this field can be divided into 3 parts: the impact of the pandemic on air quality, water quality, and other environmental resources. These articles have studied positive or negative, or both (+ and-), aspects of the pandemic.

Effect of the COVID-19 Pandemic on Air Quality

The results of studies in this regard indicate a significant reduction in air pollutants and improved air quality in the short lockdowns and national quarantines of the COVID-19 pandemic.[10,11,13,16–18,43] Air pollutants, such as emissions of NO_2 and carbon dioxide

https://doi.org/10.1017/dmp.2023.139 Published online by Cambridge University Press

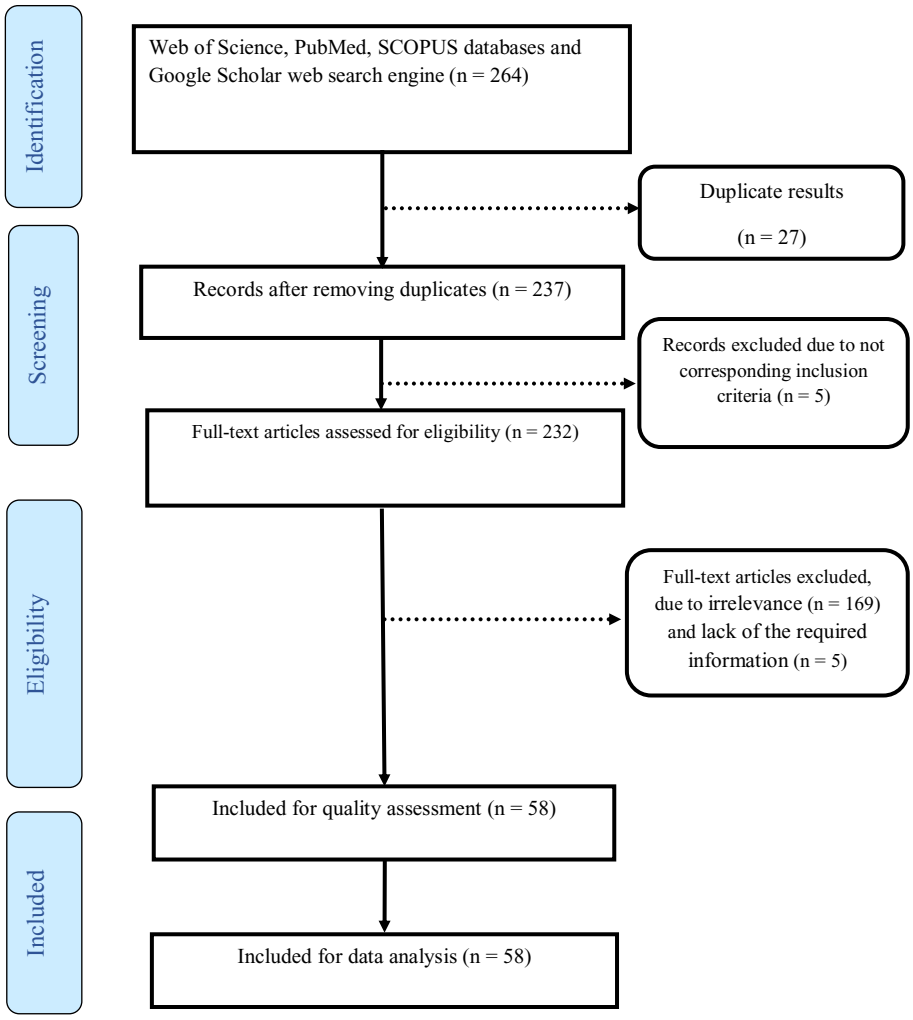

Figure 1. In total, 58 articles met the inclusion criteria and entered the process of systematic review.

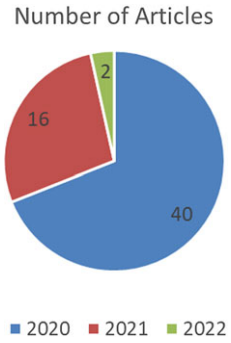

Figure 2. Number of articles published by year.

(CO_2), were significantly reduced due to industrial shutdowns and reduced worldwide transportation.[28] Also, the amount of greenhouse gases has decreased significantly in the short term.[10,11] In the study of Muhammad et al., air pollution was reduced by 30% and the level of mobility was reduced by about 90%.[22] Collivignarelli reported a significant decrease in NO_2 concentration due to reduced traffic in different cities: in London from 71.1-80.8%, in Milan from 8.6-42.4%, and in Paris from 65.7-79.8%, respectively.[23] In their study of Southeast Asia, Kanniah reported that levels of PM10: 26-31%, PM2.5: 22-32%, NO_2: 63-64%, SO_2: 9-20%, and CO: 25-31% have decreased.[24] By analyzing air quality before and after 21 days of lockdown in India, Srivastava showed that these restrictions had major effects on reducing the levels of NO_2, SO_2, CO, and PM2.5.[35] During the COVID-19 pandemic, global demand for coal fuel in March and April 2020 decreased by 8% compared to the same time in 2019. In terms of emissions, the lockdown has reduced nitrogen oxide emissions by 20 to 30% in China, Italy, France, and Spain and by 77.3% in Sao Paulo, Brazil. Emissions of nitrogen oxides in India decreased between 20 and 77% and in different cities this reduction varied between 16 and 67%. Some studies have reported a reduction in particulate matter from 5–15% in Western Europe to 200% in New Delhi, which in turn has increased air quality in an unprecedented way in recent times. In some areas, such as New York, CO_2 emissions have been reduced by 5–10%.[46] The air quality index in Baghdad improved by 13% compared to before the quarantine period and NO_2 emissions decreased by 35–40% compared to before.[31]

Despite what has been said, studies have shown that the reduction in pollutants is short-lived and the level of PM2.5 has not changed.[25] The findings do not support a reduction in greenhouse gases in the long run, because, after the cancelation of the national holiday, the start of economic activities, increased energy consumption, and subsequent increase in traffic, greenhouse gas

https://doi.org/10.1017/dmp.2023.139 Published online by Cambridge University Press

Table 1. General characteristics of the studied articles that were eligible for the review

No.	Author	Year	Quality	Environmental pollution	Country	Main conclusion
1	Wang and Su[10]	2020	High	NO_2 Co PM2.5 PM10 O_3	China	Significant reduction of air pollution due to full or partial lockdown in the short run, which results in reduced GHG. Findings do not support the reduction of GHG in the long run because, after the removal of lockdown, the economic activities and traffic will be higher, which may result in more energy consumption and higher GHG emissions.
2	Zambrano-Monserrate et al.[11]	2020	High	NO_2 PM 2.5 Beaches	China, USA, Italy, and Spain	COVID-19 improved air quality, beaches, and reduced noise levels. It increased the bulk amount of domestic and medical waste and reduced initiatives to recycle waste. GHG reduction is for a shorter time.
3	Chakraborty and Maity[12]	2020	High	Greenhouse gases Toxic tiny, suspended particles	Global	COVID-19 helps recover the environment and create a positive effect on the environment.
4	Saadat et al.[13]	2020	Moderate	Medical waste Air and water quality	Global	Improved air and water quality worldwide. Generated bulk amount of medical waste.
5	Cheval et al.[14]	2020	High	Air quality and local climate Aquatic systems and water resources Soil environment Sustainable development Goals	Global	Results showed positive effects such as enhanced air and water quality. Results indicated negative effects such as shoreline pollution due to the disposal of sanitary consumables. Results showed an early overview of the observed and potential impacts of the COVID-19 on the environment. The impacts of COVID-19 on cities and public health will be continued in the coming years.
6	Barcelo[15]	2020	High	Meteorology and air quality Sewage waters	Global	Referring to the interaction of disease and air quality. Air quality has improved. SARS-CoV-2 is present in sewage waters.
7	Lal et al.[16]	2020	High	NO_2 CO AOD Temperature Humidity	Global	The reduction in the emission of atmospheric pollutants because of forced shutdowns. In general, meteorological factors may not be directly related to the number of outbreaks. High humidity can facilitate transmission process.
8	Ansari MKA[17]	2020	High	NO_2 level PM 2.5 level Particulate matter (PM10) Nitrogen oxide (NOx)	Global	Decreases in global water pollution. Significant reduction of air and water pollution due to full or partial lockdown.
9	Shakil MH[18]	2020	High	Carbon monoxide NO_2 PM10 Carbon emissions Pollution in beaches	Global	COVID-19 improved air quality and reduced noise levels and sound pollution, increased O_3 level and nitrogen oxide. Improved air and water quality and reduced water pollution.
10	Khan et al.[19]	2020	Moderate	PM2.5 NO_2 CO O_3	Global	Positive indications from all over the world that COVID-19-induced lockdown is improving environmental conditions, including air and water quality and causes a significant concurrent reduction in PM2.5, NO_2 and CO concentration, which resulted in a significant increase in O_3 concentration.
11	Abdullah et al.[20]	2020	High	PM2.5	Malaysia	-Results revealed a significant influence of MCO of Malaysia on reduction of PM2.5.
12	Dantas et al.[21]	2020	Moderate	CO NO_2 PM10 O_3 NO_2	Brazil	CO decreases significantly during lockdown period. NO_2 decreases due to lockdown. PM10 reduced to a low level. O_3 increased due to reduction in NO_2.

(*Continued*)

https://doi.org/10.1017/dmp.2023.139 Published online by Cambridge University Press

Table 1. (*Continued*)

No.	Author	Year	Quality	Environmental pollution	Country	Main conclusion
13	Muhammad et al.[22]	2020	High	NO_2 emissions	China, Spain, France, Italy, and USA	Air pollution reduced by around 30% during COVID-19. Mobility reduced by around 90%.
14	Collivignarelli et al.[23]	2020	High	NO_2	UK, France, Italy	Significant decrease in NO_2 concentration due to traffic (London: 71.1%–80.8%; Milan: 8.6%–42.4%; Paris: 65.7%–79.8%).
15	Kanniah et al.[24]	2020	Moderate	NO_2, PM10, PM2.5, SO_2, and CO	Southeast Asia region	Reduction in Himawari AOD at urban areas is not affected by seasonal biomass burning large reductions (~27%–34%) of tropospheric NO_2 over urban agglomerations. Reductions in PM10, PM2.5, NO_2, SO_2, and CO are 26-31%, 23-32%, 63-64%, 9-20%, and 25-31%, respectively.
16	Bekbulat et al.[25]	2021	High	O_3, NO_2 CO PM10 PM2.5	USA	During stay-at-home orders, ozone, NO_2, CO, and PM10 were lower and PM2.5 was higher than expected levels by 1%-30% of their IQR. Ozone, NO_2, and CO concentrations returned to expected levels and PM2.5 and PM10 levels were higher than expected. Reductions in ozone, NO_2, and CO levels were modest and short-lived. PM10 levels did not change and PM2.5 levels increased.
17	Tobias et al.[26]	2020	Moderate	NO_2 PM10 O_3	Spain	NO_2 and BC reduced by 50% during the lockdown. PM10 reduced. O_3 increased by more than 50% during the lockdown.
18	Rupani et al.[27]	2020	High	CO_2 emissions NO_2 PM2.5	Global	NO_2 and CO_2 pollution have dramatically declined in many cities across the globe. The reduction in air and water pollution was noticeably recognized in many regions.
19	Lokhandwala et al.[28]	2020	High	PM 2.5 PM10 SO_2 NO_2 O_3 NO NH3 CO C6H6	India	Carbon emissions have decreased, and the quality of air has seen an unprecedented improvement. It is remarkable to see a reduction of 85.1% in PM2.5 concentration in one of India's most polluted cities. The other parameters lime PM10, NO_2, and CO have also reduced.
20	Bera et al.[29]	2020	Moderate	PM10 PM2.5 O_3 SO_2 NO_2 and CO	India	The pollutants like CO, NO_2, and SO_2 have significantly decreased, while the average level of O_3 has been slightly increased. Around 17.5% was the mean reduction of PM10 and PM2.5 during lockdown compared with previous years.
21	Nakada et al.[30]	2020	High	CO NO NO_2 O_3	Brazil	Up to 64.8% decrease in CO concentrations (ppm) were observed in the city center. Up to 77.3% decrease in NO concentrations (μg·m−3) was observed in urban road. Up to 54.3% decrease in NO_2 concentrations (μg·m−3) was observed in urban road. Approximately 30% increase in O_3 concentrations (μg·m−3) was observed.
22	Hashim et al.[31]	2020	Moderate	NO_2 O_3 PM2.5 and PM10	Iraq	NO_2 concentrations were reduced by 6, 7, 8, and 20%, respectively, in Baghdad during the lockdown. O_3 concentrations increased by 13%, 75%, 225%, and 525%, for the same periods. AQI improved in Baghdad by 13%, compared to the pre-lockdown period. NO_2 emissions were reduced up to 35 to 40% in Iraq compared to the pre-lockdown.

(*Continued*)

https://doi.org/10.1017/dmp.2023.139 Published online by Cambridge University Press

Table 1. (*Continued*)

No.	Author	Year	Quality	Environmental pollution	Country	Main conclusion
23	Aydın et al.[32]	2021	High	PM2.5 O_3 NOx	Turkey	PM2.5 had a maximum reduction in most cities, although ozone increased. The increase in ozone was due to a reduction in PM, which increased sunlight penetration, in-turn increasing the breakdown of NOx.
24	Mukherjee et al.[33]	2020	High	Water and sanitation Water cycle Air quality and climate	Global	Water quality improvement in both ground and surface waters was reported. Reduction in NO_2 concentration has resulted in an increase in surface level O_3 concentration.
25	Selvam et al.[34]	2020	High	Physicochemical parameters: pH, total dissolved solids (TDS) and electrical conductivity, nitrate (NO_3), fluoride (F), chromium (Cr), iron (Fe), copper (Cu), zinc (Zn), cadmium (Cd), lead (Pb), arsenic (As), and selenium (Se), during the lockdown	India	Mirrored reduction in industrial waste during COVID-19 lockdown was seen. NO_3 and coliform reduced due to closure of industrial activities including fisheries. Area under industrial use and surface water availability exhibited better imprints. Factor analyses illustrated diminishing of water quality contrast following lockdown. Significant reductions in Se (42%), As (51%), Fe (60%) and Pb (50%) were reported. Reduction in NO_3 (56%), total coliform (52%) and fecal coliforms (48%) indicated less organic sewage from the fishing industries. Contents of Cr, Cu, Zn and Cd, however, remained similar and fluoride did not show any change. E. coli and fecal streptococci had no significant change.
26	Srivastava et al.[35]	2020	Moderate	PM2.5 NO_2, SO_2 and CO	India	The analysis was based on air quality data for before lockdown and after lockdown (first phase of 21 days) periods of 21 days each. The major impact was seen in the levels of PM2.5, NO_2 and CO. The levels of SO_2 showed less significant decline during the lockdown period.
27	Rodríguez-Urrego et al.[36]	2020	High	PM2.5	Global	PM2.5 (12%) decreases of quarantines.
28	Gautam et al.[37]	2020	Moderate	Air quality	India	Significant reduction of fatalities due to degradation of air quality.
29	Seo et al.[38]	2020	High	PM2.5 PM10 NO_2	Korea	During the COVID-19 pandemic, PM2.5, PM10, and NO_2 concentrations decreased significantly.
30	Islam et al.[39]	2020	High	PM2.5, CO, NO_2, SO_2	Bangladesh	The study found that all pollutants, including PM2.5, NO_2, SO_2, and CO, have been decreased during the lockdown.
31	Gupta et al.[40]	2020	Moderate	Air quality	India	Lockdown due to COVID-19 caused reduction in toxic gases like nitrogen dioxide, aerosols, atmosphere ozone, particulate, and an improvement in air quality.
32	Karunanidhi et al.[41]	2020	High	Fluoride Na+, K+, Cl–, Ca2+ Mg2+ SO_4 NO_3-N NO_3 and F– ions HCO_3^- ion	India	Na+> Ca2+ > K+ > Mg2+ for cations and HCO3– > Cl- > SO_4 > NO_3-N > F- for anions. Seventeen percent (17%) of the wells are affected by high fluoride concentrations. Nitrate pollution declined by 33.4%. COVID-19 lockdown considerably reduced groundwater pollution by Na+, K+, Cl, NO_3, and F– ions. Increased HCO_3^- ion concentration was reported. Overall results illustrate the positive benefits to groundwater quality.

(*Continued*)

https://doi.org/10.1017/dmp.2023.139 Published online by Cambridge University Press

Table 1. (*Continued*)

No.	Author	Year	Quality	Environmental pollution	Country	Main conclusion
33	Bar[42]	2020	High	NO CO NO_2 PM2.5 and PM10 SPM	Global	The major pollutants like oxides of nitrogen and carbon were reduced significantly. The concentration of NO_2 dropped from 45 to 54%. In the lockdown period, the level of NO_2 and carbon emission remarkably decreases. The intensities of particulate matter like PM2.5 and PM10 decreased by 43% and 31%, respectively. SPM lowered down up to 15.9%, causing an improvement in surface water quality. Noise pollution remarkably dropped below 60 db.
34	Chakraborty et al.[43]	2021	High	Na2+ K+ Ca2+ Mg2+ Cl− So_4− No_3− F− WPI	India	The physical, chemical, and heavy elements were found beyond the standard limit during pre-lockdown period. The cation and anion were arranged in an order of Na2+ > K+ > Ca2+ > Mg2+ and Cl−> So_4− > No_3− > F− in both the sessions. WPI of pre-lockdown showed that about 100% of water samples are highly polluted. WPI of the lockdown period showed that around 90.90% of samples improved to good quality and 9.10% of samples are moderately polluted.
35	Mousazadeh et al.[44]	2021	High	NO CO_2 CO Water-dissolved oxygen levels	Global	COVID-19-induced lockdowns have resulted in 20–77% reductions in emissions of nitrogen oxides, reducing by 16–60% in different cities. Emissions of CO_2 were also reduced between 5 and 10%. Similarly, the particulate matter level globally was found to reduce by 9–200%, and New Delhi, India. A reduction in CO levels was seen. The quality of several water bodies has improved.
36	Venter et al.[45]	2020	High	NO_2 PM2.5 O_3 NOx	Global	The decline in nitrogen dioxide (NO_2: 60% with 95% CI 48 to 72%), and fine particulate matter (PM2.5: 31%; 95% CI: 17 to 45%), with marginal increases in ozone (O_3: 4%; 95% CI: −2 to 10%) was observed.
37	Menut et al.[46]	2020	High	NO_2 PM O_3	Western Europe	Reduction in NO_2 concentrations, a lower reduction in particulate matter (PM) concentrations, and a mitigated effect on ozone concentrations were reported.
38	Kotnala et al.[47]	2020	Moderate	PM2.5 and PM10 NOx	India	The sharp decline in concentrations (nearly 200%) of PM 2.5 and PM10 was seen. The concentration of nitrous oxides (NOx), recorded at its maximum (342 ppb).
39	Baldasano[48]	2020	High	NO_2	Spain	The reductions in NO_2 concentrations in Barcelona and Madrid (Spain), under COVID-19 lockdown during March 2020, were 50% and 62%, respectively.
40	Yunus et al.[49]	2020	High	Suspended particulate matter (SPM)	India	Business lockdown due to the COVID-19 spread improved adjacent lake water quality. Suspended particulate matter concentration in Vembanad Lake decreased by 15.9%. Eleven out of 20 zones showed the lowest April SPM in 2020. Business activities have a significant impact on the lake water quality.
41	Najah et al.[50]	2021	High	Water quality index (WQI)	Malaysia	Noticeable enhancements of varying degrees in the WQI had occurred in the 2 investigated rivers.

(*Continued*)

https://doi.org/10.1017/dmp.2023.139 Published online by Cambridge University Press

Table 1. (*Continued*)

No.	Author	Year	Quality	Environmental pollution	Country	Main conclusion
42	Patel et al.[51]	2020	Moderate	Water quality parameters	India	Reductions in turbidity and suspended particulate matter were observed in some reaches. The extent of improvement dependent on flow conditions and point-pollution sources was seen. Domestic sewage increases pollution load markedly, despite no industrial effluents.
43	Braga et al.[52]	2020	High	Water transparency	Italy	Unprecedented water transparency in the city canals was determined by the reduction of boat traffic and tourism. Turbidity remained at usual levels in sustained wind conditions.
44	Shen et al.[53]	2021	High	Water quality parameters and intensities of fluorescent components	China	After peaking of COVID-19, the intensities of WT-C1(20) and WT-C2(20) decreased again.
45	Chowdhuri et al.[54]	2022	High	Air quality	India	The major air pollutants like particulate matter (PM2.5, PM10), sulfur dioxide (SO_2), carbon monoxide (CO), and Ozone (O_3) were observed the maximum reduction (-40 to - 60%) in the COVID-19 lockdown period. The AQI has been improved by 54.94% in the lockdown period.
46	Khan et al.[55]	2021	Moderate	Air quality (PM2.5)	Pakistan	A significant decrease in the levels of PM2.5 pollution across Pakistan (ranging from 15 to 35% for satellite observations, while 27 to 61% for ground-based observations) was seen.
47	Ganguly et al.[56]	2021	Moderate	Air pollutants, that is, PM10, NO_2	India	An overall decrease of pollutant concentrations was in the ranges of 30–60% and 52–80% of PM10 and NO_2, respectively, in the 3 cities during lockdown in comparison with the previous year and pre-lockdown period.
48	Keshtkar et al.[57]	2022	High	Air pollution quality, that is, PM2.5, PM10, NO_2, SO_2, O_3, CO	Iran	Findings indicated that changes in pollution rate during the study period can be due to reduced urban traffic, small industrial activities, and dust mites of urban and industrial origins. Although pollution has declined in most regions during the COVID-19 quarantine period, the PM2.5 rate has not decreased significantly, which might be of natural origins such as dust.
49	Pata et al.[58]	2020	High	PM2.5 emissions	USA	Positive shocks in COVID-19 cause negative shocks in PM2.5 emissions. The pandemic reduces environmental pressure in the largest cities of the USA.
50	Shakoor et al.[59]	2020	High	Environmental pollutants (CO, NO_2, SO_2, PM2.5 and PM10)	USA and China	The overall concentrations of CO, NO_2, and PM2.5 were decreased by 19.28%, 36.7%, and 1.10%, respectively, while PM10 and SO_2 were increased by 27.81% and 3.81%, respectively, in 5 selected states of the USA during the lockdown period. However, in the case of chosen provinces of China, overall, the concentrations of all selected pollutants, that is, CO, NO_2, SO_2, PM2.5, and PM10, were reduced by 26.53%, 38.98%, 18.36%, 17.78%, and 37.85%, respectively.
51	Kour et al.[60]	2021	Moderate	Water quality (pH, alkalinity, hardness, conductivity, BOD, and COD)	India	The overall water quality in the river during lockdown was good and falls in Class B with pH (7.0–8.5), alkalinity (23.25–185.0 mg/L), hardness (84.25–177.5 mg/L), conductivity (117–268 ms/cm).
52	Ali et al.[61]	2021	Moderate	Air pollution	Cities of Asia–Pacific	Visible reductions were found in Aerosol Optical Depth (AOD), sulfur dioxide (SO_2), carbon monoxide (CO), and nitrogen dioxide (NO_2) concentrations before and during the lockdown periods of 2020 as compared to those of 2019. The highest NO_2 emission reduction (~ 50%) was recorded in Wuhan city during the lockdown of 2020.

(*Continued*)

https://doi.org/10.1017/dmp.2023.139 Published online by Cambridge University Press

Table 1. (*Continued*)

No.	Author	Year	Quality	Environmental pollution	Country	Main conclusion
53	De Maria et al.[62]	2021	High	Air pollution (NO_2, PM10)	Italy	Decrease in the weekly mean NO_2 concentration recorded by urban traffic stations during the lockdown period. Regarding PM10 levels, the average concentrations at the individual traffic stations showed no particular variation compared to those in the same months of the previous year.
54	Mostafa et al.[63]	2021	Moderate	Air pollution	Egypt	AAI decreased by about 30%, the NO_2 decreased by 15% and 33% over Cairo and Alexandria Governorates, respectively, and the CO decreased by about 5% over both governorates. In addition, the GHG emissions in Egypt were reduced by at least 4% during the pandemic.
55	Yang et al.[64]	2021	High	Global environmental pollution	Global	COVID-19 improved PM2.5, PM10, NO_2, and CO levels but not SO_2 and O_3 levels. COVID-19 improved surface water, coastal water, and groundwater except for reservoirs. Medical and protective equipment waste increased during the COVID-19 lockdown. Carbon emissions are reduced due to travel restrictions except for essential shipping.
56	Edward et al.[65]	2021	High	Coastal environment Water quality	India	Water parameters such as turbidity, nutrient concentration, and microbial levels have come down from the pre- to post-lockdown period, and parameters such as dissolved oxygen levels, phytoplankton, and fish densities have improved. The concentration of macroplastics has also dropped from the range of 138 ± 4.12 and 616 ±12.48 items/100 m to 63 ± 3.92 and 347 ± 8.06 items/100 m. Fish density in the reef areas has increased.
57	Aman et al.[66]	2021	Moderate	Water and air quality	India	Improvements in ambient water quality in terms of decreased turbidity levels for a section of the Sabarmati River in the Ahmedabad region of India were seen. The suspended particulate matter (SPM) concentrations are evaluated to underline the turbidity levels in the study area before and during the lockdown period using the Landsat 8 OLI images. They noticed that the average SPM has significantly decreased by about 36.48% when compared with the pre-lockdown period, and a drop of 16.79% was observed from the previous year's average SPM.
58	Pacheco et al.[67]	2021	Moderate	NO_2 levels	Ecuador	Reduction in NO_2 concentrations (-13%) was observed because of the COVID-19 lockdown in Ecuador.

AAI, absorbing aerosol index; CO, carbon monoxide; and GHG, greenhouse gas.

emissions have increased again.[10] A study by Bekbulat in the United States found that PM 2.5 was reported to be 1–30% higher than expected during home quarantine and that shortfalls in O_3, NO_2, and CO levels were short-lived after lockdown and PM2.5 did not change.[25] According to the results of studies by Lal, Wang, Barchelo, and Zambrano, air pollution improves in the short term after closures and its long-term effects need further investigation.[10,11,15,16]

Effect of the COVID-19 Pandemic on Water Quality

Findings from some studies have shown that the lockdown and COVID-19-induced quarantine have improved the water quality of some rivers, canals, and seas, and the pandemic has had beneficial effects on surface water quality in some areas. In total, 34% of the articles mentioned an increase in water quality indicators, its transparency, and an increase in the amount of dissolved oxygen in water.[13,17,18,27,34,41,43]

In Selvam's study, a mirrored reduction in industrial waste was reported in industrial waste following the COVID-19 pandemic, and coliforms were reduced following the lockdown, COVID-19-induced quarantine, and closure of industrial activities, including fisheries. In addition, analytical factors showed better water quality. A significant decrease was observed in AS: 51.3%, Se: 42%, Fe: 60%, Pb: 50%, and NO_3: 56%. Total coliform and fecal coliform were estimated to be 52% and 48%, respectively.[34] In another study by Chakraborty in India, the heavy physical and chemical elements

https://doi.org/10.1017/dmp.2023.139 Published online by Cambridge University Press

were beyond the standard in the pre-lockdown period. Cations and anions, including Mg, Ca, K, Na, NO_3, SO_4, Cl, and F, were observed in the lockdown period. Examination of water quality in the pre-lockdown period and COVID-19-induced quarantine showed that 100% of the water was highly polluted, and during the outbreak of COVID-19 disease and restrictions, about 90.90% of the samples were upgraded to good quality and 9.10% of the samples were moderately infected.[43] In some studies, a decrease in water turbidity and suspended particles was also reported during the pandemic.[49,51] In Karunanidhi's study in India, fluoride concentration decreased by 17%, and water pollution by nitrates decreased by 32.4%.[41] Another study reported an improvement in surface water quality at Vembanad Lake, India, showing that suspended particulate matter (SPM) concentrations decreased by an average of 15.9% compared to last year.[49]

In contrast, in some studies, the content of Cr, Ca, Zn, and Cd was similar to before and fluoride did not show any change. E. coli and fecal streptococci did not change significantly in the waters of industrial coastal cities.[34] In a post-peak study in China, the re-reduction of water quality parameters and intensity of fluorescent components were recorded.[53] In the study conducted by Patel, the amount of changes in water quality was reported to be variable, and the need for more attention to increase domestic wastewater production during the disease and its impact on receiving water sources such as rivers was highlighted.[51] In Bar's study, it was reported that during the lockdown and COVID-19-induced quarantine, the use of a variety of means of transport on the river, such as motor boats and steamboats, was restricted. Some people in East Asia are economically dependent on river fishing. During this period, economic activities in rivers, including fisheries, stopped significantly.[33] Overall, water quality worldwide has improved,[13,14] water pollution has been reduced, and surface and groundwater quality has been improved following the COVID-19 pandemic.[13,14,18,27,33,41]

The Effect of the COVID-19 Pandemic on the Environment

The effects of this disease on the environment cannot yet be fully described. However, it seems that with the outbreak of the COVID-19 pandemic and the closures that have occurred in different parts of the world, especially in industrialized countries, the amount of air, water, and coastal pollution has decreased.[10–14] The results of some studies indicate that noise pollution has decreased with the onset of the lockdown and COVID-19-induced quarantine.[11,18,42] In Bar's study, noise pollution was reported to be significantly below 60 db.[42] The quality of coastlines has improved, but household and medical waste has increased, and this increase in non-recyclable waste and medical waste leads to environmental and water pollution. For example, masks are used for a short time and usually daily.[11,13] Their contamination is palpable after the outbreak of COVID-19. These contaminants have entered the living environment of animals on land and at sea, which will have consequences such as death and disease for them.[13] On the other hand, the resumption of activities and efforts to compensate for the lockdown and COVID-19-induced quarantine have different effects, which highlight the need for more research to identify these effects in the long run.[14]

This study aimed to investigate the effect of the COVID-19 pandemic on air quality, water resources quality, and the environment. The findings of most studies in this regard have compared previous measures with the post-lockdown and COVID-19-induced quarantine period. In this regard, quarantines and restricting communications have been effective in reducing toxic gases such as nitrogen dioxide, aerosols, atmospheric ozone, and particulate matter and improving air quality.

In a systematic review by Silva et al.[68] (2022), it was reported that air quality improved during quarantine compared to before the quarantine. According to the findings of this research, reductions between 9% and 60%, 21.4% and 61.6%, were reported for PM2.5, PM10, respectively. Studies have reported a reduction in pollutant concentrations during quarantine compared to the same period in previous years and even more robustly with historical data of more than 5 years.[68] Based on the results of a systematic review by Bakola et al. (2022), several air pollutants, including NO_2, NO, PM2.5, PM10, CO, carbon dioxide (CO_2), benzene, black carbon, and air quality index (AQI)) related to the quarantine of COVID-19, showed a significant and strong decrease.[69]

According to the results of a systematic review study by Faridi et al.,[70] in 2021, quarantine measures related to the COVID-19 epidemic significantly reduced the concentration of PM2.5, NO_2, PM10, SO_2, and CO globally. Apart from measuring pollutants at ground stations, studies using satellite data have confirmed the results obtained with ground-level measurements and found that AQI improved during the quarantine period. A higher decrease was observed mainly for industrial areas.[71]

Several mechanisms have been reported to significantly reduce pollutant levels: reducing people's driving and public transportation,[69,71] reducing or stopping the activity of industries and factories,[69] and reducing energy consumption[68]; A remarkable point is that, in the case of some pollutants such as ozone, different results have been reported. Based on the results of the systematic review by Faridi et al.[70] (2021), Silva et al.[68] (2022), and Bakula et al.[69] (2022), O_3 concentration has increased compared to the conditions before COVID-19. Various reasons for the increase in O_3 have been reported: decrease in NO and increase in solar radiation,[68] decrease in the titration of O_3 by NO_X due to a significant decrease in local emission sources of NO_X, possible increase in solar activity level due to decrease in PM2.5, and increase in the number of Hydroperoxyl radicals (HO_2) as a mediator to increase ozone production.[71]

However, the findings do not indicate a long-term reduction in these gases because industrial activity has increased significantly after the restrictions were reduced. The results of some studies also indicate that the reduction of air pollutants during the pandemic is temporary, and after the end of the imposed restrictions and the removal of quarantine regulations, we will see an increase in air pollutants again. In the systematic review study by Silva et al. (2022), the increase in pollutants in the post-quarantine period was also reported.[68]

On the other hand, a significant increase in household and medical waste has led to further environmental pollution. China Center for Energy and Clean Air Research reports that SARS-CoV-2 emission control methods, such as quarantines and travel bans, have reduced carbon emissions by 25%.[72] The LIU's study, published in May 2020, also found that global carbon emissions fell by 17% since quarantine in early April, which could reduce annual carbon emissions by up to 7%, the largest drop since World War II. Second, researchers attribute these reductions mainly to reduced use of transportation and industrial activities.[73]

Following the application of traffic restrictions, the air pollution index decreased significantly and vehicle emissions such as sulfur dioxide and nitrogen dioxide were reduced, so the EU Air Pollution Monitoring Service reported the production of particulate matter

https://doi.org/10.1017/dmp.2023.139 Published online by Cambridge University Press

by 20 to 30% and the reduction of sulfur dioxide and nitrogen dioxide emissions.[17]

According to the results of the systematic review by Silva et al.[68] (2022), the amount of nitrogen dioxide has decreased 30-66% during the COVID-19 pandemic, and in the systematic review by Faridi et al.[70] (2021), this reduction was 18-96%.

Overall, the outbreak of the COVID-19 pandemic appears to have reduced air, water, and coastal pollution in the short term. This finding, in line with some other studies that have made it possible to compare atmospheric composition with and without the lockdown and COVID-19-induced quarantine, showed that the effect of lockdown was particularly important for several atmospheric components through the widespread reduction of traffic and industrial activity, which has been accompanied by a large decrease in NO_2 concentration, a decrease in particulate matter (PM) and air pollutants.[10,16,20,21,27,36]

According to satellite imagery, one of the positive effects of COVID-19 has been clearer waters after 1 month of the national COVID-19 pandemic-induced lockdowns and quarantines.[19,43,49,51]

Based on the results of the systematic review by Jiang et al.[74] (2022), the improvement of the quality of coastal waters and the reduction of underwater pollution have been reported. It is noteworthy that COVID-19 has caused an increase in some environmental pollutants for several reasons. Due to the frequent washing of hands and the use of chemical detergents and the release of the resulting effluents, an increase in environmental pollution is expected. According to the results of a systematic review by Chirani et al.[75] (2021), during the COVID-19 epidemic, frequent and increasing use of handwashing products leads to environmental pollution. Furthermore, the increase in the use of personal protective equipment (PPE) such as masks and gloves has also caused an increase in the production of waste and the release of these wastes into the environment and increased environmental pollution, especially with microplastic particles.[76–86] According to the results of a systematic review by Jiang et al.[74] (2022), the increase in medical waste related to COVID-19, such as PPE, leads to severe pollution that threatens the marine ecosystem and wildlife.

Travel bans and reduced boat traffic have led to sedimentation and reduced water turbidity, which have made the water clearer. The canals of Venice are illustrative; in the pre-pandemic period, the TSM concentration averaged 3 g/m, but during the COVID-19 pandemic it dropped to 1.4 g/m, that is, a 50% reduction in concentration was observed.[52] The unprecedented increase in the use of the mask and its release into the water and the environment has been one of the negative consequences of the COVID-19 pandemic. Other issues include the increasing use of detergents and their role in the state of wastewater.

Conclusion

With the outbreak of the COVID-19 pandemic and the closures that have occurred in various parts of the world, especially in industrialized countries, the amount of air, water, and coastal pollution has been reduced in the short term. Due to the emergence of the disease, the study period has been limited in some studies. For better conclusions about the effect of the COVID-19 pandemic on environmental health, we will need to examine the quality of water, air, and the environment in the long run. On the other hand, few studies have examined the effects of pandemics on the environment, and most of them have focused on air quality, which paves the way for research into the effects of pandemics on the environment. The effects of quarantine on the quality of the environment have been different.

Acknowledgments. Hereby, the Research Committee of University of Social Welfare and Rehabilitation Sciences, Tehran, Iran is sincerely appreciated.

Authors' contributions. All authors contributed significantly to this paper. MF and HR KH contributed to the study design. MS and SH A created the search strategy. ZH and SAM and YM and ZMN completed the data extraction and analysis and critically appraised studies. JSH and NP drafted the manuscript. all authors contributed to its revision.

References

1. **Hoehl S, Rabenau H, Berger A, Kortenbusch M, Cinatl J, Bojkova D, *et al.*** Evidence of SARS-CoV-2 Infection in Returning Travelers from Wuhan, China. *N Engl J Med.* 2020 Mar 26;382(13):1278-1280.
2. **World Health Organization**. WHO advice for international travel and trade in relation to the outbreak of pneumonia caused by a new coronavirus in China [Internet]. Wold Health Organization. 2020 [cited 2022 Jul 29]. p. 22-24. Available from: https://www.who.int/news-room/articles-detail/who-advice-for-international-travel-and-trade-in-relation-to-the-outbreak-of-pneumonia-caused-by-a-new-coronavirus-in-china
3. **WHO**. Weekly Epidemiological Update on COVID-19 [Internet]. World Health Organization. 2020 [cited 2022 Jul 29]. p. 1;4. Available from: https://www.who.int/publications/m/item/weekly-epidemiological-update-on-covid-19—11-january-2022
4. **Bates AE, Primack RB, Biggar BS, *et al.*** Global COVID-19 lockdown highlights humans as both threats and custodians of the environment. *Biol Conserv.* 2021;263:109175. https://www.sciencedirect.com/science/article/pii/S0006320721002275
5. **Bates AE, Primack RB, Moraga P, Duarte CM.** COVID-19 pandemic and associated lockdown as a "Global Human Confinement Experiment" to investigate biodiversity conservation. *Biol Conserv.* 2020;248:108665. https://linkinghub.elsevier.com/retrieve/pii/S0006320720307230
6. Preventing the Next Pandemic: Zoonotic Diseases and How to Break the Chain of Transmission. UN Environment Programme (UNEP-ILRI). Published 2020. Accessed February 6, 2022. https://www.unep.org/resources/report/preventing-future-zoonotic-disease-outbreaks-protecting-environment-animals-and%0Ahttps://www.unenvironment.org/resources/report/preventing-future-zoonotic-disease-outbreaks-protecting-environment-animals-and
7. **Sunyer J, Dadvand P, Foraster M, *et al.*** Environment and the COVID-19 pandemic. *Environ Res.* 2021;195:110819. https://www.ncbi.nlm.nih.gov/pmc/articles/pmc7845501/
8. **Moher D, Shamseer L, Clarke M, *et al.*** Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev.* 2015;4(1):1. https://systematicreviewsjournal.biomedcentral.com/articles/10.1186/2046-4053-4-1
9. **Salari N, Mohammadi M, Vaisi-Raygani A, *et al.*** The prevalence of severe depression in Iranian older adult: a meta-analysis and meta-regression. *BMC Geriatr.* 2020;20(1):1-8.
10. **Wang Q, Su M.** A preliminary assessment of the impact of COVID-19 on environment—a case study of China. *Sci Total Environ.* 2020;728. https://www.sciencedirect.com/science/article/pii/S0048969720324323?casa_token=AK6uRlpmhY0AAAAA:u0f2xtlN595pCnEJnT0LVQwKUO9s9OS7kooIeQOAO3LSXNvrCGT397isMr1JGVbHUpxDE3nLZqI
11. **Zambrano-Monserrate MA, Ruano MA, Sanchez-Alcalde L.** Indirect effects of COVID-19 on the environment. *Sci Total Environ.* 2020;728. https://www.sciencedirect.com/science/article/pii/S0048969720323305?casa_token=MgYI9dgRyqQAAAAA:-wniaUij0H5q31nWqZCS9MbNxesl53II3EnjdEQfN6TH7p1rp9tfFMjvMCLCZczwtd0K83KH9Jo
12. **Chakraborty I, Maity P.** COVID-19 outbreak: migration, effects on society, global environment and prevention. *Sci Total Environ.* 2020;728. https://www.sciencedirect.com/science/article/pii/S0048969720323998?casa_token=SUQDdGXpMdUAAAAA:GQcnCN9yMqIpCG5M7xuMM21uoJuSEnpUfeOEHd0FpqeThpYVRClTExzlz6Lw6SK-DDPGlfCAnvo

13. **Saadat S, Rawtani D, Hussain CM.** Environmental perspective of COVID-19. *Sci Total Environ.* 2020;728. https://www.sciencedirect.com/science/article/pii/S0048969720323871?casa_token=sj39loaK3UsAAAAA:DcXdxx4gBeFNF-Y4c9T4MF_cxN4ic7hhTFrp44iJaAyoCB8uDpQe047G9Ths_brNjNYyo9NeMAs
14. **Cheval S, Adamescu CM, Georgiadis T, *et al.*** Observed and potential impacts of the COVID-19 pandemic on the environment. *Int J Environ Res Public Health.* 2020;17(11):1-25. https://www.mdpi.com/739342
15. **Barcelo D.** An environmental and health perspective for COVID-19 outbreak: meteorology and air quality influence, sewage epidemiology indicator, hospitals disinfection, drug therapies and recommendations. *J Environ Chem Eng.* 2020;8(4). https://www.sciencedirect.com/science/article/pii/S2213343720303547
16. **Lal P, Kumar A, Kumar S, *et al.*** The dark cloud with a silver lining: assessing the impact of the SARS COVID-19 pandemic on the global environment. *Sci Total Environ.* 2020;732. https://www.sciencedirect.com/science/article/pii/S004896972032814X?casa_token=ZxYFIdCkzC4AAAAA:l4QLI8IWGw0Coyx13NfBq7KDumzalQDuWlAZIs4WcFKDwezWgpL725jgEbYbv4dKYuyceWSBAv4
17. **Kafeel M, Ansari A, Khan NI, Owens G.** The environmental impact of COVID-19. Preprints. 2020. https://www.preprints.org/manuscript/202009.0334
18. **Shakil MH, Munim ZH, Tasnia M, Sarowar S.** COVID-19 and the environment: a critical review and research agenda. *Sci Total Environ.* 2020;745. https://www.sciencedirect.com/science/article/pii/S0048969720345514
19. **Khan I, Shah D, Shah SS.** COVID-19 pandemic and its positive impacts on environment: an updated review. *Int J Environ Sci Technol.* 2021;18(2):521-530. http://link.springer.com/10.1007/s13762-020-03021-3
20. **Abdullah S, Mansor AA, Napi NNLM, *et al.*** Air quality status during 2020 Malaysia Movement Control Order (MCO) due to 2019 novel coronavirus (2019-nCoV) pandemic. *Sci Total Environ.* 2020;729. https://www.sciencedirect.com/science/article/pii/S0048969720325390?casa_token=AP5nMnKCkmkAAAAA:Yq0BASTy146KL2cCxheSOlh1MBcbswYchYfkCHQgr-EjI0FKzkCz0tWTb3zJYWQgXnJwWVN_USE
21. **Dantas G, Siciliano B, França BB, *et al.*** The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. *Sci Total Environ.* 2020;729. https://www.sciencedirect.com/science/article/pii/S0048969720326024?casa_token=tkTA4O1u1RAAAAAA:5RFbK8EO4o3yxmFAXZVmdpmJ7W9xpCW5HRSMqjmWvC5YEeukqgm7BAWBC_wKYb3SSzjDYPp8ob0
22. **Muhammad S, Long X, Salman M.** COVID-19 pandemic and environmental pollution: a blessing in disguise? *Sci Total Environ.* 2020;728. https://www.sciencedirect.com/science/article/pii/S0048969720323378?casa_token=LnLlgZrbnZoAAAAA:rCrCeLRx_wSlGLlkoh4KFGtHIc1MuRE94mWtrJdFTBeknM1FMaLzbnwfc-2n0vFmMIIdA7XIYdI
23. **Collivignarelli MC, De Rose C, Abbà A, *et al.*** Analysis of lockdown for CoViD-19 impact on NO2 in London, Milan and Paris: what lesson can be learnt? *Process Saf Environ Prot.* 2021;146:952-960. https://www.sciencedirect.com/science/article/pii/S095758202031956X
24. **Kanniah KD, Kamarul Zaman NAF, Kaskaoutis DG, Latif MT.** COVID-19's impact on the atmospheric environment in the Southeast Asia region. *Sci Total Environ.* 2020;736. https://www.sciencedirect.com/science/article/pii/S0048969720331788?casa_token=cu5KJVdz0twAAAAA:ypkW9a2kn_6ASv_EdMrILdL0fsHL27nZUq7gE1W8J0QlC-0gDnuNqraZXTlpObwT9iEXvE1tuuk
25. **Bekbulat B, Apte JS, Millet DB, *et al.*** Changes in criteria air pollution levels in the US before, during, and after COVID-19 stay-at-home orders: evidence from regulatory monitors. *Sci Total Environ.* 2021;769. https://www.sciencedirect.com/science/article/pii/S0048969720382267?casa_token=Rj-HDnFPIEAAAAA:22huBx57Hpn7eNY6cky9a-u5t0ZZuyi4ax1TQFy3vfInFkn7r1FWYXQyxjiQU7P5XUAArAW2i8M
26. **Tobías A, Carnerero C, Reche C, *et al.*** Changes in air quality during the lockdown in Barcelona (Spain) one month into the SARS-CoV-2 epidemic. *Sci Total Environ.* 2020;726. https://www.sciencedirect.com/science/article/pii/S0048969720320532?casa_token=HwyNBzVSHhAAAAAA:HiE25wgVgA9TwxlGOxx5vDbdTQTUKZUQAdktGgaVeF58ElTJd_FkxLgqiDcDKeTUToo-Y9bCLQ0
27. **Rupani PF, Nilashi M, Abumalloh RA, *et al.*** Coronavirus pandemic (COVID-19) and its natural environmental impacts. *Int J Environ Sci Technol.* 2020;17(11):4655-4666.
28. **Lokhandwala S, Gautam P.** Indirect impact of COVID-19 on environment: a brief study in Indian context. *Environ Res.* 2020;188. https://www.sciencedirect.com/science/article/pii/S0013935120307027
29. **Bera B, Bhattacharjee S, Shit PK, *et al.*** Significant impacts of COVID-19 lockdown on urban air pollution in Kolkata (India) and amelioration of environmental health. *Environ Dev Sustain.* 2021;23(5):6913-6940.
30. **Nakada LYK, Urban RC.** COVID-19 pandemic: impacts on the air quality during the partial lockdown in São Paulo state, Brazil. *Sci Total Environ.* 2020;730. https://www.sciencedirect.com/science/article/pii/S0048969720326048?casa_token=7d0X4QtHefsAAAAA:yQXVO6CsMOEtJl7x0ZkTnx2ZupfEKdNLblPD6jajVgnrBSpYytZ_hY9JBdec6o0j_sklEahVeII
31. **Hashim BM, Al-Naseri SK, Al-Maliki A, Al-Ansari N.** Impact of COVID-19 lockdown on NO2, O3, PM2.5 and PM10 concentrations and assessing air quality changes in Baghdad, Iraq. *Sci Total Environ.* 2021;754. https://www.sciencedirect.com/science/article/pii/S0048969720355078?casa_token=UAfj6qlxWT4AAAAA:kKl-n13mHXPnKnrLObSU2f0yzonZN0rC9WwxB8NZY0PPbiYZLhBX5Pp5Ru5xhb58VQP6a-RfMiM
32. **Aydın S, Nakiyingi BA, Esmen C, *et al.*** Environmental impact of coronavirus (COVID-19) from Turkish perceptive. *Environ Dev Sustain.* 2021;23(5):7573-7580.
33. **Mukherjee A, Babu SS, Ghosh S.** Thinking about water and air to attain sustainable development goals during times of COVID-19 pandemic. *J Earth Syst Sci.* 2020;129:180.
34. **Selvam S, Jesuraja K, Venkatramanan S, *et al.*** Imprints of pandemic lockdown on subsurface water quality in the coastal industrial city of Tuticorin, South India: a revival perspective. *Sci Total Environ.* 2020;738. https://www.sciencedirect.com/science/article/pii/S0048969720333684?casa_token=xn_RIgEBfEUAAAAA:kPQEZMOcIGwKnZpnzVF8JYY_SxaqdOQlvk0U1F4aYcaQaiLozHtwe3InKsZbR1cCYu2KwOJmlsU
35. **Srivastava S, Kumar A, Bauddh K, *et al.*** 21-day lockdown in India dramatically reduced air pollution indices in Lucknow and New Delhi, India. *Bull Environ Contam Toxicol.* 2020;105(1):9-17.
36. **Rodríguez-Urrego D, Rodríguez-Urrego L.** Air quality during the COVID-19: PM2.5 analysis in the 50 most polluted capital cities in the world. *Environ Pollut.* 2020;266. https://www.sciencedirect.com/science/article/pii/S0269749120337635?casa_token=Es3k5FTCNWwAAAAA:nJfRxkwiVfBMUUQK3G9CE900tMEjr0KmgS9u6hzDgRiJfPVVN1p_eolGRSY7p3JNGvyJM8e9bqY
37. **Gautam S.** The influence of COVID-19 on air quality in India: a boon or inutile. *Bull Environ Contam Toxicol.* 2020;104(6):724-726.
38. **Seo JH, Kim JS, Yang J, *et al.*** Changes in air quality during the COVID-19 pandemic and associated health benefits in Korea. *Appl Sci.* 2020;10(23):1-15. https://www.mdpi.com/914760
39. **Islam MS, Chowdhury TA.** Effect of COVID-19 pandemic-induced lockdown (general holiday) on air quality of Dhaka City. *Environ Monit Assess.* 2021;193(6):343.
40. **Gupta N, Tomar A, Kumar V.** The effect of COVID-19 lockdown on the air environment in India. *Glob J Environ Sci Manag.* 2020;6:31-40. https://www.gjesm.net/article_39821.html
41. **Karunanidhi D, Aravinthasamy P, Deepali M, *et al.*** Groundwater pollution and human health risks in an industrialized region of southern India: impacts of the COVID-19 lockdown and the monsoon seasonal cycles. *Arch Environ Contam Toxicol.* 2021;80(1):259-276.
42. **Bar H.** COVID-19 lockdown: animal life, ecosystem and atmospheric environment. *Environ Dev Sustain.* 2021;23(6):8161-8178.
43. **Chakraborty B, Roy S, Bera A, *et al.*** Cleaning the river Damodar (India): impact of COVID-19 lockdown on water quality and future rejuvenation strategies. *Environ Dev Sustain.* 2021;23(8):11975-11989.
44. **Mousazadeh M, Paital B, Naghdali Z, *et al.*** Positive environmental effects of the coronavirus 2020 episode: a review. *Environ Dev Sustain.* 2021;23(9):12738-12760.
45. **Venter ZS, Aunan K, Chowdhury S, Lelieveld J.** COVID-19 lockdowns cause global air pollution declines. *Proc Natl Acad Sci U S A.* 2020;117(32):18984-18990. https://www.pnas.org/content/117/32/18984.short

https://doi.org/10.1017/dmp.2023.139 Published online by Cambridge University Press

46. **Menut L, Bessagnet B, Siour G, *et al.*** Impact of lockdown measures to combat COVID-19 on air quality over western Europe. *Sci Total Environ.* 2020;741. https://www.sciencedirect.com/science/article/pii/S0048969720339486
47. **Kotnala G, Mandal TK, Sharma SK, Kotnala RK.** Emergence of blue sky over Delhi due to coronavirus disease (COVID-19) lockdown implications. *Aerosol Sci Eng.* 2020;4(3):228-238.
48. **Baldasano JM.** COVID-19 lockdown effects on air quality by NO2 in the cities of Barcelona and Madrid (Spain). *Sci Total Environ.* 2020;741. https://www.sciencedirect.com/science/article/pii/S0048969720338754
49. **Yunus AP, Masago Y, Hijioka Y.** COVID-19 and surface water quality: improved lake water quality during the lockdown. *Sci Total Environ.* 2020;731. https://www.sciencedirect.com/science/article/pii/S0048969720325298
50. **Najah A, Teo FY, Chow MF, *et al.*** Surface water quality status and prediction during movement control operation order under COVID-19 pandemic: case studies in Malaysia. *Int J Environ Sci Technol.* 2021;18(4):1009-1018.
51. **Patel PP, Mondal S, Ghosh KG.** Some respite for India's dirtiest river? Examining the Yamuna's water quality at Delhi during the COVID-19 lockdown period. *Sci Total Environ.* 2020;744. https://www.sciencedirect.com/science/article/pii/S0048969720343758?casa_token=Qqi_-sm8dYsAAAAA:YRnYeSMPwSREKM4ncnjp3IMJC1-B8F1GjzWBcm0GC39xSArqrqomry6u75rb1PSWhz7add2qqFQ
52. **Braga F, Scarpa GM, Brando VE, *et al.*** COVID-19 lockdown measures reveal human impact on water transparency in the Venice lagoon. *Sci Total Environ.* 2020;736. https://www.sciencedirect.com/science/article/pii/S0048969720331326/pdf?isDTMRedir=true&download=true
53. **Shen J, Liu C, Lv Q, *et al.*** Novel insights into impacts of the COVID-19 pandemic on aquatic environment of Beijing-Hangzhou Grand Canal in southern Jiangsu region. *Water Res.* 2021;193. https://www.sciencedirect.com/science/article/pii/S0043135421000713
54. **Chowdhuri I, Pal SC, Arabameri A, *et al.*** Have any effect of COVID-19 lockdown on environmental sustainability? A study from most polluted metropolitan area of India. *Stoch Environ Res Risk Assess.* 2022;36(1):283-295.
55. **Khan YA.** The COVID-19 pandemic and its impact on environment: the case of the major cities in Pakistan. *Environ Sci Pollut Res.* 2021;28(39):54728-54743.
56. **Ganguly R, Sharma D, Kumar P.** Short-term impacts of air pollutants in three megacities of India during COVID-19 lockdown. *Environ Dev Sustain.* 2021;23(12):18204-18231. https://link.springer.com/article/10.1007/s10668-021-01434-9
57. **Keshtkar M, Heidari H, Moazzeni N, Azadi H.** Analysis of changes in air pollution quality and impact of COVID-19 on environmental health in Iran: application of interpolation models and spatial autocorrelation. *Environ Sci Pollut Res.* 2022;29(25):38505-38526.
58. **Pata UK.** How is COVID-19 affecting environmental pollution in US cities? Evidence from asymmetric Fourier causality test. *Air Qual Atmos Health.* 2020;13(10):1149-1155.
59. **Shakoor A, Chen X, Farooq TH, *et al.*** Fluctuations in environmental pollutants and air quality during the lockdown in the USA and China: two sides of COVID-19 pandemic. *Air Qual Atmos Health.* 2020;13(11):1335-1342.
60. **Kour G, Kothari R, Dhar S, *et al.*** Impact assessment on water quality in the polluted stretch using a cluster analysis during pre- and COVID-19 lockdown of Tawi river basin, Jammu, North India: an environment resiliency. *Energy, Ecol Environ.* 2021;1-12. https://link.springer.com/article/10.1007/s40974-021-00215-4
61. **Ali G, Abbas S, Qamer FM, Irteza SM.** Environmental spatial heterogeneity of the impacts of COVID-19 on the top-20 metropolitan cities of Asia-Pacific. *Sci Rep.* 2021;11(1). https://www.nature.com/articles/s41598-021-99546-9
62. **De Maria L, Caputi A, Tafuri S, *et al.*** Health, transport and the environment: the impacts of the COVID-19 lockdown on air pollution. *Front Public Health.* 2021;9:1-7.
63. **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. https://www.sciencedirect.com/science/article/pii/S0301479720314213?casa_token=wIyVYB6Fu7QAAAAA:pqzR5CxEpdpmZqXS_kAA431yjKLPqTcvZH6rUzTjqMH5AZSNZ1hZCAy1ZYzllNT6R5n-YOVDpB8
64. **Yang M, Chen L, Msigwa G, *et al.*** Implications of COVID-19 on global environmental pollution and carbon emissions with strategies for sustainability in the COVID-19 era. *Sci Total Environ.* 2022;809. https://www.sciencedirect.com/science/article/pii/S0048969721067334?casa_token=1AP5twWlGdgAAAAA:iCVepILRrPyqK9AScjmBc2VitjEVXSPtzE1qWNGZMh_rpJkFL8rYGFnJ36deEkkvwzeNPjOMRMQ
65. **Patterson Edward JK, Jayanthi M, Malleshappa H, *et al.*** COVID-19 lockdown improved the health of coastal environment and enhanced the population of reef-fish. *Mar Pollut Bull.* 2021;165. https://www.sciencedirect.com/science/article/pii/S0025326X21001582
66. **Aman MA, Salman MS, Yunus AP.** COVID-19 and its impact on environment: improved pollution levels during the lockdown period—a case from Ahmedabad, India. *Remote Sens Appl Soc Environ.* 2020;20. https://www.sciencedirect.com/science/article/pii/S2352938520302743
67. **Pacheco H, Díaz-López S, Jarre E, *et al.*** NO2 levels after the COVID-19 lockdown in Ecuador: a trade-off between environment and human health. *Urban Clim.* 2020;34. https://www.sciencedirect.com/science/article/pii/S2212095520302170
68. **Silva ACT, Branco PTBS**, Sousa SI V. Impact of COVID-19 pandemic on air quality: a systematic review. *Int J Environ Res Public Health.* 2022;19(4):1950. https://www.mdpi.com/1660-4601/19/4/1950
69. **Bakola M, Hernandez Carballo I, Jelastopulu E, Stuckler D.** The impact of COVID-19 lockdown on air pollution in Europe and North America: a systematic review. *Eur J Public Health.* 2022;32(6):962-968.
70. **Faridi S, Yousefian F, Janjani H, *et al.*** The effect of COVID-19 pandemic on human mobility and ambient air quality around the world: a systematic review. *Urban Clim.* 2021;38:100888. https://linkinghub.elsevier.com/retrieve/pii/S2212095521001188
71. **Gebeyehu DT, East L, Wark S, Islam MS.** Indirect positive health outcomes of COVID-19: a systematic review. *Public Health.* 2023;218:149-159.
72. **Zhang R, Zhang Y, Lin H, Feng X, Fu TM, Wang Y**. NOx emission reduction and recovery during COVID-19 in East China. *Atmosphere (Basel)* [Internet]. 2020 Apr 1 [cited 2022 Feb 21];11(4). Available from: https://www.mdpi.com/699996
73. **Liu Z, Ciais P, Deng Z, Lei R, Davis SJ, Feng S, *et al.*** Near-real-time monitoring of global CO2 emissions reveals the effects of the COVID-19 pandemic. *Nat Commun* [Internet]. 2020 Oct 14 [cited 2022 Feb 21];11(1):1-12. Available from: https://www.nature.com/articles/s41467-020-18922-7
74. **Jiang Q, Xu Z, Ye G, Pahlow M, Hu M, Qu S**. A systematic scoping review of environmental and socio-economic effects of COVID-19 on the global ocean-human system. *Sci Total Environ.* 2022;849:157925.
75. **Chirani MR, Kowsari E, Teymourian T, Ramakrishna S**. Environmental impact of increased soap consumption during COVID-19 pandemic: Biodegradable soap production and sustainable packaging. *Sci Total Environ.* 2021;796:149013.
76. **Ammendolia J, Saturno J, Brooks AL, *et al.*** An emerging source of plastic pollution: environmental presence of plastic personal protective equipment (PPE) debris related to COVID-19 in a metropolitan city. *Environ Pollut.* 2021;269:116160.
77. **Aragaw TA, De-la-Torre GE, Teshager AA**. Personal protective equipment (PPE) pollution driven by the COVID-19 pandemic along the shoreline of Lake Tana, Bahir Dar, Ethiopia. *Sci Total Environ.* 2022;820:153261. https://linkinghub.elsevier.com/retrieve/pii/S0048969722003527
78. **Haddad M Ben, De-la-Torre GE, Abelouah MR, *et al.*** Personal protective equipment (PPE) pollution associated with the COVID-19 pandemic along the coastline of Agadir, Morocco. *Sci Total Environ.* 2021;798:149282.
79. **Cordova MR, Nurhati IS, Riani E, *et al.*** Unprecedented plastic-made personal protective equipment (PPE) debris in river outlets into Jakarta Bay during COVID-19 pandemic. *Chemosphere.* 2021;268:129360.
80. **De-la-Torre GE, Rakib MRJ, Pizarro-Ortega CI, Dioses-Salinas DC**. Occurrence of personal protective equipment (PPE) associated with the

COVID-19 pandemic along the coast of Lima, Peru. *Sci Total Environ.* 2021;774:145774.

81. **Kannan G, Mghili B, De-la-Torre GE, *et al.*** Personal protective equipment (PPE) pollution driven by COVID-19 pandemic in Marina Beach, the longest urban beach in Asia: abundance, distribution, and analytical characterization. *Mar Pollut Bull.* 2023;186:114476.
82. **Kouvara K, Papatheodorou G, Kosmopoulou A, *et al.*** COVID-19-related litter pollution on Greek beaches and nearshore shallow water environments. *Mar Pollut Bull.* 2022;185:114250.
83. **Mghili B, Analla M, Aksissou M.** Face masks related to COVID-19 in the beaches of the Moroccan Mediterranean: an emerging source of plastic pollution. *Mar Pollut Bull.* 2022;174:113181.
84. **Ortega F, Calero M, Rico N, Martín-Lara MA.** COVID-19 personal protective equipment (PPE) contamination in coastal areas of Granada, Spain. *Mar Pollut Bull.* 2023;191:114908.
85. **Pizarro-Ortega CI, Dioses-Salinas DC, Fernández Severini MD, *et al.*** Degradation of plastics associated with the COVID-19 pandemic. *Mar Pollut Bull.* 2022;176:113474.
86. **Rakib MRJ, De-la-Torre GE, Pizarro-Ortega CI, *et al.*** Personal protective equipment (PPE) pollution driven by the COVID-19 pandemic in Cox's Bazar, the longest natural beach in the world. *Mar Pollut Bull.* 2021;169:112497.

https://doi.org/10.1017/dmp.2023.139 Published online by Cambridge University Press