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Impact of Pandemic COVID19 on Air and Water Quality in India: A Systematic Review

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Abstract: The Pandemic COVID-19 outbreak has significantly affected all sections of life, including a substantial reduction in economic development and production, from industrial activities to tourism and automobile congestion. During this phase, the maximum human activities were restricted, but COVID-19 came out as a blessing for the environment. Globally reported that all the environmental variables have improved since the pandemic outbreak, including water and air quality and water quality while minimizing the restrictions for wildlife even in urban areas. India has always been a hotspot of pollution, with rising air quality index (AQI) readings in all large cities due to its vast population, traffic congestion, and polluting industries. However, after the lockdown announced during the pandemic, air quality started improving, and Other environmental factors, such as the water quality of rivers, started to improve. This paper reviewed the studies conducted to define the improvement in India's air and water quality during the lockdown period. Different tools such as remote sensing technologies and onsite real-time monitoring are used in many studies to monitor India's air and water quality during this period.

Keywords: Air quality; COVID-19; India; Pandemic; Water quality;

I. INTRODUCTION

Around 12,000 years ago, during the Neolithic era, small family/clan groups abdicated migratory hunting and gathering to settle down in stable locations, grow crops, and keep domestic animals for food, labour, and clothing. Humans and newly tamed animals coexisted for the first time in the complex environment of villages, towns, cities, and farms. Several transmit diseases emerged due to close human-animal interaction and environmental changes.

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Measles, tuberculosis, smallpox, stomach cancer (*Helicobacter pylori*), and other epidemic diseases occurred due to animal infections that switched hosts to human infectious agents. These agents started epidemics and pandemics when human populations continued to grow (Fig. 1). Some of the biblical plagues were most likely new infectious diseases [1]. Smallpox lesions were visible on the conserved mummy of Pharaoh Usermaatre Sekheperenre Ramesses V, revealing that fatal smallpox epidemics were prevalent almost 3,000 years ago [2]

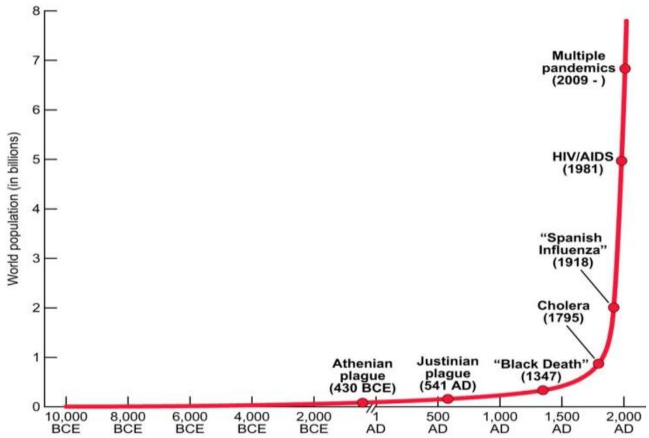

Fig. 1. Estimated world population and selected known pandemics/widespread disease emergence, from 10,000 BCE to 2020 AD (Source:[3]).

Smallpox spread through much of the world until the 16th century, when the first reported pandemic emerged in 1520, sparing the Western Hemisphere. Smallpox killed millions of people for at least three millennia until it was proclaimed eradicated in 1980. The mortality rate from benign diseases such as measles has been very high during the last few decades, mainly in the population having Vitamin A scarcity [4]. The catastrophic "plague of Athens" (430 to 425 BCE), which marked the end of Greece's Golden Age, was the first known pandemic, spreading across the world, including the Mediterranean and Northern African areas [5] Looking into factors like overpopulation and ever-increasing pollution, comparing it with historical data, the scientific community has forecasted the threats of epidemics and pandemics [6]. As evident from history, there were several outbreaks of deadly diseases in the past, but they were limited due to less population, settlement, and a pollution-free environment [7]. But in the last century quick rise in outbreaks of diseases such as smallpox, cholera, Plague, AIDS, SARS, Ebola, and COVID-19 have been documented throughout history [8] due to a tremendous increase in population and environmental degradation.

When the World Health Organization (WHO) declared the COVID-19 a pandemic, that put a dangerous reality in front of the world [9], [10], a novel and deadly virus that infected humanity severely, this virus reached quickly from Wuhan, China, to Japan, South Korea, Europe, and the United States, reaching globally. Before the declaration of the pandemic, numerous economic indicators indicated that the world was on the cusp of an unexpected watershed in the era, if not in human history [11]. Including many casualties, substantial economic losses reported during and after the lockdown limitations suspended all industrial and public transit activity, imprisoning the entire globe in their homes. All of this works like immunization for Mother Earth. [12].

II. AIR QUALITY IN INDIA

Depleted air quality has been a concern in India for more than a century. However, the previous several decades have been challenging, with high population expansion, unplanned urbanization, and industrialization as the principal causes. Many Indian cities are among the most polluted in the world [13]. According to the World Health Organization (WHO) database, from 2008 to 2013, India was among the most polluted countries, according to the World Health Organization (WHO) database. In 2019, air pollution overtook the consequences of other well-known chronic illnesses, including obesity (high BMI), high cholesterol, and malnutrition, to become the world's fourth-largest cause of death [14]. According to the global burden of illness study's 2019 predictions, ambient air pollution is responsible for 17.8% of all fatalities in the country [15]. However, these figures have yet to be validated using hospital records. Ambient particulate matter (PM) and residential air pollution were factors in most of these fatalities. According to the study, India's ambition of becoming a $5 trillion economy by 2024 may be impeded by the high mortality and disease burden caused by air pollution The International Agency for Research on Cancer (IARC) has categorized outdoor air pollution as a category I carcinogen [16]. The legal framework, a suitable monitoring network, and the identification and load estimation of emission sources are essential factors in evaluating air quality. The National Environmental Engineering Research Institute in India began measuring air quality in 1967 (NEERI). The Central Pollution Control Board took the next step in 1984 when it launched the National Ambient Air Quality Monitoring (NAAQM) program with seven sites in Agra and Anpara. With each passing year, the number of monitoring stations grew. The initiative was later called the National Air Monitoring Program (NAMP). From 1985 to 2011, India's network of air monitoring stations increased from 28 to 456 sites. Four air pollutants, sulfur dioxide (SO_2), nitrogen oxides (NO_2), suspended particulate matter (SPM), and respirable suspended particle matter (RSPM/PM10), have been identified for routine monitoring at all locations under the NAMP. In addition, other indicators, including respirable lead and other harmful trace metals, hydrogen sulfide (H_2S), ammonia (NH_3), and polycyclic aromatic hydrocarbons (PAHs), are being studied in seven metropolises around the nation. Air quality monitoring included meteorological characteristics, such as wind speed, direction, relative humidity, and temperature. In addition, automated monitoring stations have set up in a select location for real-time data collecting. National ambient air quality standards based on an 8-hour average time until 1994, when the requirements were updated to a 24-hour averaging time. Six 4-hourly observations of gaseous parameters averaged to achieve a 24-hour average or daily average, whereas three 8-hourly readings averaged to generate a 24-hour average value for SPM [17]. Most cities have a mix of RSPM concentrations, with the majority of them falling between 50 and 150 g/m3.

Further, due to fast and rapid expansion in the industrial sector, several industries have been working for several years and polluting the atmosphere by discharging seriously polluted gases such as SO_2 and NO_2. It was important to notice that the oil industries deteriorated the Taj Mahal and other monuments in the Fatehpur Sikri. In addition to this, several thermal power plants are also doing the same thing because coal used in these plants, releasing hydrocarbons, fly ash and SO_2, and other gases as primary pollutants [18]. The cause of the country's air pollution was the number of vehicles on the road, which doubled in the past 8 to 10 years and rapidly increased. Nearly several tons of pollutants are released into the atmosphere per day across major cities in India, out of which 50% is due to automobile emissions. By 2035 the fuel demand increased by six times in 2005.

Furthermore, small and fuel-efficient vehicles are often used by most people. It is anticipated that India will save up to 65% of its energy consumption and reduce CO_2 equal to removing 7 million (approx.) four-wheelers. There is an increase of 6% in the amount of CO_2 released into the atmosphere every year, and 15% of total CO_2 emission was due to automobile exhausts in India. [19]. Other significant sources of increase in air pollution are the burning of discarded crop residues, stoves, incinerators, and freezers. The deposition of trash and waste in landfills produce methane dust particles from natural resources; volcanic eruptions produce high levels of fumes and ash, uncertain forest fires, and the decomposition of animals [20].

Another critical relationship to air pollutants is justified, as air sheds have a restricted ability to absorb emissions within acceptable air quality levels. Transport sources account for 4% of worldwide carbon dioxide emissions and 18% of industrialized countries' emissions. Except for lead and diesel particles, developing countries contribute less than 30% of worldwide harmful pollutant emissions (e.g., CO, NOx). Because of the low quality of transportation fuels and the increased use of large engine vehicles powered by diesel, developing countries' contribution to lead and diesel particle emissions may be slightly more significant. [21].

Migration of people towards the cities from the village is the primary concern. In India, a large percentage of the population lives in the villages. Still, if we talk about people in the metro cities, it is growing due to the migration of people from the town to cities for their livelihood generation. So the anthropogenic pressure in the metro cities is rapidly increasing, resulting in an increasing environmental degradation.

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Also, the ingrowing development in the country in the transport and construction sector is a rising threat to the environment in terms of increasing pollution [22]. Air quality is an important aspect; as far as environmental quality is concerned.

However, in the last five years, the concentration in Delhi and Jaipur has increased dramatically from 150 to 220 g/m3. The concentration of SO_2 in all cities is within the legal limits (5 to 20 g/m3). For the most part, NO_x concentrations vary from 15 to 40 g/m3 in most cities. Over the last decade, it has fallen in Kolkata and Pune. The NO_x content in Delhi, on the other hand, has increased from 40 to 60 g/m3. In early November 2017, $PM_{2.5}$ particle levels in Delhi exceeded WHO regulations by 25 times (11 times by Indian standards), causing an environmental health emergency [19} World Health Organization (WHO) also amended its prior air quality guidelines from 2005 to 2021, setting revised annual and 24-hour requirements for six classic [23], with an intermediate aim. The average yearly standard for PM_{10} and $PM_{2.5}$, for example, has been reduced from 20 g/m3 to 15 g/m3 and from 10 g/m3 to 5 g/m3, respectively. However, there have been advances in air quality due to new technology and government initiatives [24]. SO_2 concentrations have declined over time, according to the Central Pollution Control Board (CPCB), although PM_{10} concentrations have fluctuated and $PM_{2.5}$ concentrations have remained consistent [25].

The transportation industry, power plants, and residential sector contribute to India's deteriorating air quality. Almost all cities violate the Central Pollution Control Board's particle matter regulations. These high pollution concentrations are harming the public's health. As a result, it is critical to reducing pollution levels by reducing emissions from various sources. If appropriate and stern steps are not implemented promptly. NO_x emissions from the road transport industry are expected to grow fivefold by 2030 compared to present levels. Also, particle emissions, particularly $PM_{2.5}$, will rise due to bricks, open burning, and the transportation sector. In addition, total emissions for all pollutants will increase thrice by 2047.

III. FRESHWATER IN INDIA

Freshwater scarcity is becoming the central issue due to increasing industrialization and urbanization, creating extra pressure on water resources [26]. Water pollution is threatening the sustenance of both land and the aquatic environment. So collaborative work between all the fields is a need of today's time to save the freshwater ecosystems, a significant part of sustainable development [27]. While good wastewater treatment can conserve the natural environment, implementing environmental policies into the fundamental goals of the actor firms, as well as ongoing periodical enlightenment on the existing and future implications of ecological/water pollution, can help significantly in water conservation [28]. One of humanity's significant issues is the growing global chemical pollution of water sources, mainly with undetermined short and long-term consequences on aquatic life and human health. Chemical pollution can come from various sources, and its temporal and spatial effects on water quality can range from short-term local to long-term worldwide. The most crucial pollution sources are agriculture, mining, landfills, and industrial and urban wastewater. Mitigating a specific chemical water pollution problem is frequently challenging due to the great diversity of micro-pollutants.

The state of water quality in India may estimate the extent of water contamination in the country. The poisoning of aquatic bodies caused by manufactured activity is water pollution. Suspended Solids, biodegradable organic matter, non-biodegradable organic matter, inorganic dissolved solids, nutrients, and pathogens are all examples of pollutants. The principal human activities leading to water pollution in India include population increase, urbanization, contemporary agriculture techniques, and rising industries. Sewage and wastewater, solid waste dumped in catchment areas, and industrial waste are the primary sources of water contamination.

Water pollution is a significant issue in India, with about 70% of its surface water resources damaged and an increasing percentage of its groundwater supplies. Anthropogenic activities and massive industrialization to meet humanity's needs have a significant and terrible impact on aquatic life and are causing severe pollution [29]. The enormous flow of sewage and industrial waste into rivers causes high organic and pathogenic pollution in rivers [30]. Surface water contamination can affect groundwater quality, becoming a severe problem in many developing nations [31]. Each situation needs a unique set of interdisciplinary scientific knowledge and methods and technical, economic, and societal elements. Efficient wastewater collection and treatment systems are essential for sanitation and human and ecological health. Many issues can be solved with centralized municipal wastewater systems, but they come at the cost of US$100 billion per year in infrastructure costs over the next 20 years. For low-income countries, such a financial expenditure may be excessive. One-third of the world's population lacks access to adequate sanitation, and a lack of proper sanitation systems is accountable for the growth of waterborne diseases and dangerous drinkable water. Despite this, 80 percent of funding assistance for geogenic discharge for water-related initiatives invested in drinking water rather than sanitation issues. Currently, low-cost production in emerging economies is all too frequently coupled with the intolerable pollution of water sources. International chemical regulation, consumer education, and good exercise codes should thus work in conjunction to prevent large-scale chemical emissions into the hydrosphere worldwide [32]. All the species, including humans, requires water to survive. To ensure the maintenance and preservation of water quality for optimum use, water resource managers were strongly dependent on wastewater treatment. It is estimated that 5 billion out of 8 billion people will be living in water-stressed areas by 2025 [33]. The rising global contamination of freshwater systems due to industrial and chemical compound materials discharged into their pathways/runways, primarily in micro-pollutants, is one of the biggest environmental challenges impacting humanity.

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According to Schwarzenbach et al., [34], most pollutants have low concentrations; many can be a reason for significant toxicological concerns, mainly when such compounds are present as constituents of composite blends. Several micropollutants have been documented in other research [35], [36], which subsequently go to the water environment. These include pesticides, pharmaceuticals, steroid hormones, industrial chemicals, *etc*.

Aquatic and human life can both be affected by them. So freshwater pollution requires global attention. Climate change expected to alter the thermal and hydrological stages of rivers. Considering these facts, it is necessary to deeply study climate change and its impact on different regions worldwide. According to IPCC, the current observational data and the future prediction in different climate scenarios show that the aquatic ecosystem can be strongly impacted due to increasing global climate change shortly, negatively affecting human societies and our environment

IV. INFECTIOUS DISEASES AND HUMAN RACE

"Pandemic" is a widely used term that has never been scientifically defined. The word "pandemic" (or "pandemick"), which has been in use since the 16th century, was initially so confusing that it could be the mean opposite in different contexts [37]. The word derived from the Greek language' pan,' and 'demos' means all and people, respectively, showings the epidemic's natural phenomenon. The meaning of "Epidemic" derived from Greek is "that which is upon the people," which means a rising or overall situation and is commonly used when there is fast spatial and temporal spread. The narrower definition of "pandemic" was given following the report of the surprising rise of global influenza in1889, *i.e.*, "...occurring widely over an area, country, continent, or globe" [37]. The term "pandemic" has alternatively classified as Trans-regional (widely spread over the continent or different central regions), inter-regional (covering two or more areas), and worldwide [38]. Specific organisms drive pandemics, but these same creatures, or their descendants, have virtually always been present in our environment for millennia without creating any pandemic threat. The historical assemblage of people and domestic animals in villages and towns allowed ancient microbes to transfer hosts and cause infections. Although these infection-causing pathogens get life in once-wild animals that are then tamed, our expanding ecological footprint appears to be driving incremental growth in the spillage of different microorganisms directed towards humans from nature [39]. Due to these activities, new diseases such as hemorrhagic fevers, Hantavirus, and Nipah infection, have emerged [40], [3]. Several animal marketplaces in China have undoubtedly resulted in three significant epidemics and, most recently, a pandemic, even though pandemic origins are rarely understood with certainty. A lethal "bird flu" strain introduced led to poultry-adapted influenza. H5N1 and H7N9 viruses have diminished thousands of human populations; SARS is a deadly virus causing the death of 774 people and appeared dangerously near to triggering a global pandemic from 2002 to 2003; then, from 2019 to 2020, SARS-like SARS-CoV-2 is causing this pandemic, COVID-19. We have not been able to stop its spread which caused due to seemingly simple human behaviour, the formation of substantial animal marketplaces in densely populated areas, or significantly increased human-wild animal contacts within two decades [3], [7].

Infectious diseases have caused chaos in societies around the globe for several centuries. Contagious diseases are originating and re-originating at a phenomenal rate. The world has experienced the appearance of various disease outbreaks and epidemics caused by more than 20 infectious agents, according to the World Health Organization (WHO), during the last decade. Novel contagious pathogens such as H1N1 and MERS were responsible for several epidemics. The rise of coronavirus-associated diseases (SARS and MERS) has posed significant challenges to public health systems throughout the last two decades. SARS-CoV-2 (the causative agent of the coronavirus disease COVID-19) is the most recent addition to this list of unwanted new agents. On January 30, the WHO proclaimed COVID-19 a public health crisis of worldwide concern and was declared a pandemic on March 11, 2020. [41].

V.INFECTIOUS DISEASES AND ENVIRONMENTAL CHANGE

Which alter the well-mixed fluid envelopes of the planet earth (atmosphere and oceans), and also those that occur in discrete sites but are so widespread can be defined as the global environmental changes. The changes in atmospheric composition, climate, stratospheric ozone, and ultraviolet input come first. Changes in land use and land cover, biodiversity, biological invasions, and changes in atmospheric chemistry fall under the second category [42]. In the past 100 years, the Earth's temperature has increased by around 1°F. This may not appear to be a significant level. However, small variations in the Earth's temperature can have serious implications. The problem of global climate change remains a source of concern with the increasing greenhouse gas concentration in the atmosphere. Global climate models developed to study the effects of growing carbon dioxide and methane levels continue to predict temperature rises at the surface of the Earth. On the other hand, an increase in mean annual temperature will not be evenly distributed over the globe. Instead, the Polar Regions predicted to have the highest average temperature increases. [43], [44], [45]. According to the IPCC report (2013), there might be a temperature rise of another 0.3 to 1.7 to 2.6 to 4.8degreese Celsius shortly [46]. As a continuous and persistent threat to the global environment (Biodiversity and Ecosystems), climate change directly impacts the individual species, their interaction, and niche, which leads to the dysfunctionality in the ecosystems and the services they provide [47]. Due to differences in exposure, vulnerability, and ability to adapt, its impacts may vary as a function of related vulnerability because the impacts of climate change are not uniform [48], [49], [50]. It can observed at each level and population by analyzing their specific traits such as morphology, phenology, and the shift in their habitat range [51].

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Humans can influence climate change, which is a firm belief of most scientists. People use automobiles and energy resources for domestic purposes such as cooling and heating their homes and cooking. Some of the energy sources are coal, oil, and gas. Gases are released into the atmosphere by burning these substances, which leads to a rise in the air temperature and can change the climate of a region. These activities can also change the Earth's atmosphere [52]. The incomplete burning of fossil fuels changes the environment and pollutes the air by increasing CO_2 emissions that lead to global warming. Other pollutants, *i.e.*, Oxides of Sulfur and Nitrogen (SO_x and NO_x) and particulate matter, are the primary sources of air pollution [53].

With a few probable outliers, such as small island states, global environmental change does not instantly affect the sustainability of nation-states. We have argued, however, that global ecological change reduces nation states' ability to effectively fulfill their conceptual operations without the collaboration of other states and that with this, the extra pressure that global environmental change places on nation-states tends to increase the requirement for adaptive capacities, thereby further reducing the resources states have at their disposal for accomplishing their essential functions. Because developing countries struggle the most from a shortage of resources to handle the social, economic, and environmental problems within their borders, we anticipate that global environmental change will place the most significant strain on these governments' capacities [54]. The following quotation. It is essential for the well-being of all the human race and the environment to deeply study climate change and its negative impacts and reduce it immediately.

Even though environmental issues have been the most critical issues and have been at the top of the United Nations General Assembly agenda since their gathering in 2019, the Earth has been suffering environmental threats for decades. All the components (air, water, and land) of the environment across the world are contaminated with industrial waste due to the expansion of the industrial sector in the last century, which leads to health issues n the human [55], [56], [57]. . However, it predicted that by taking into account the population growth, the world energy per capita consumption in most developing countries would be reduced due to increasing population and industrial development [58]. According to the estimation of WHO in 2016, due to fine particulate air pollution (especially $PM_{2.5}$), a total of 4.2 million deaths attributed across the globe per year [59] and globally, approximately 2 billion people drink the contaminated water with faeces, which leads to the transmission of diseases such diarrhoea, cholera, dysentery, typhoid, and polio and also the cause of more than 4.5 lakh casualties annually due to diarrhoea [60].

Impact of Pandemic COVID-19 on the global environment

COVID-19 is wreaking havoc on economies and society, yet it has improved the environment by drastically reducing pollutants [61]. Governments have imposed limitations on the movement of persons and vehicles, and economic activity has halted due to COVID-19 [62]. The results of such lockdowns have been excellent, with considerable reductions in pollution levels by the drastic drop in different parameters [61], [62], [63]; [64], [65]. COVID-19 has helped heal mother earth as all the economic and industrial activities have been stopped [61]. Due to full and partial lockdown imposed by several governments worldwide, Greenhouse gas emissions, NO_2, SO_2, and water pollution have reduced drastically [61], [62]; [63]; [64]. These strict regulations have played an essential role in improving the region's environmental quality [61]. However, this will not remain the same because of the resume of the industrial and human movement across the globe, which results in increasing energy demand and increasing pollution levels and certainly exceeds the limits during the lockdown period [64]. The gains in air quality, on the other hand, are especially significant. Following the implementation of lockdowns to prevent the spread of SARS-CoV-2, satellite data show substantial reductions in NO_2 in large Indian, Chinese, European and United States cities (Fig. 2) [66].

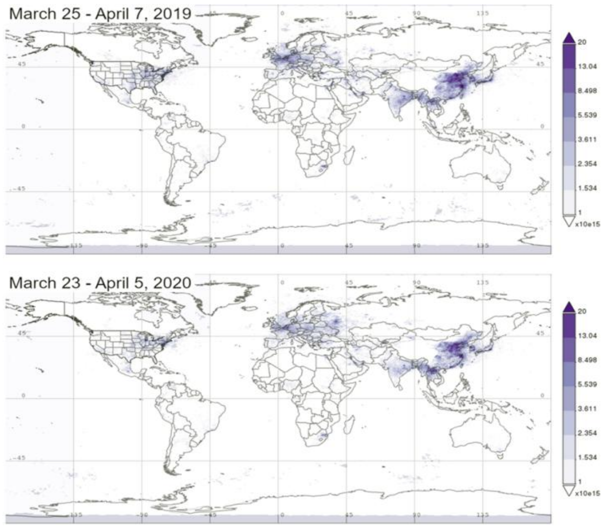

Fig. 2: NO_2 in the tropospheric column (mol cm^{-2}) for the first 14 days of spring 2019 (top) and 2020 (bottom), respectively, after the lockdown imposed in different countries (Source: Hallema et al., [66])

Furthermore, Zambrano-Monserrate et al., [62] illustrated the indirect impact of lockdown on the planet, claiming the reduction in sound pollution and polluting sea shore and reduced air pollution. Large-scale industrial activity contributed to sound pollution, affecting public health and destroying natural ecosystems [67], [68].. Water on beaches has become clean because of restricted tourism activities, and pollution has also reduced drastically [62]. Depletion in air quality in Wuhan, China, gets reduced significantly [62]. Although the rising concentration of household and clinical residues cause the infection of transmitted diseases if not properly managed, such contaminants have negative environmental repercussions. The cause of the household waste increase is the dependency on e-commerce websites [62]. To prevent the spread of this virus and other diseases shortly, the post-lockdown period is critical for maintaining a low level of environmental contamination and taking the appropriate actions to dispose of hazardous medical waste.

The climatic system influences COVID19 transmission in the same way other infectious diseases can. Temperature, humidity, rainfall, and wind speed are all climate variables. Studies have discovered a linkage between COVID-19 and climatic conditions. According to Bashir et al., [69], poor air quality accelerated the transmission of COVID-19 infections in New York City. Furthermore, in the case of Turkey and China, Sahin [70] and Zhu et al., [71] investigated the impact of different climatic conditions on the virus spread [69] studied a favorable relationship between wind speed and crowds in highly affected contaminant cities. All the air pollution parameters exhibited a positive relationship with the transmission rates of this virus, according to Zhu et al., [71], however, Sulphur dioxide (SO_2) had a negative association with COVID-19 impact. To determine spatio-temporal fluctuations, ERA5 reanalysis data were used to map global temperature and absolute humidity every week throughout the COVID-19 pandemic period (January to March 2020). Seasonality fluctuations caused the temperature rise in the tropical areas compared to other sites. The likelihood of a global COVID-19 epidemic may have increased due to these regional temperature fluctuations. Medical facilities, lockdown measures and social distancing are essential in preventing the virus spread.

Impact of Pandemic COVID-19 on Air quality in India

A large population suffers from serious health issues and dies due to air pollution every year. Globally, 4.9 million deaths were caused due to air pollution only in 2017, with the maximum percentage being from low-income countries [72]. During the lockdown, investigations indicated a considerable decrease in air pollution [65], [73]. Because of the worldwide suspension in industrial and transportation operations, carbon dioxide (CO_2) and NO_2 concentrations have decreased substantially [74]. Air pollution has declined drastically in some nations, including China, Italy, the United States, and India, due to reduced fossil fuel consumption [74]. Mumbai, Pune, and Ahmedabad showed a drop-down in NO_2 concentrations by 40 to 50 per cent. Due to the lockdown, CO_2 levels in Europe predicted to decline by 390 million tonnes [74]. Carbon emissions in the United States fell by roughly 40% due to reduced transportation during the shutdown [74]. Furthermore, Dantas et al., [73] found that during the global shutdown, carbon monoxide (CO), nitrogen dioxide (NO_2), and PM_{10} (particulate having a diameter less or equal to 10μm) all reduced dramatically, but ozone concentration rises because of the sudden drop in nitrogen dioxide. According to Tobias et al., [65] and Dantas et al., [73], black carbon and NO_2 levels decreased 50% in the period of lockdown, but PM_{10} levels decreased significantly. During lockdown in Barcelona, however, the amount of O_3 was boosted by more than 50%. Similarly, NO_2 and BC levels fell by 45 to 51 per cent in Barcelona [65]. Similarly, Muhammad et al., [75] and Abdullah et al., [76] investigated COVID-19's impact on pollutants before and after the restricted period. According to Muhammad et al., [75], the restriction in the lockdown has a positive effect on the air quality by a 30 per cent decrease in pollution level.

Pollutants emitted to the atmosphere before and during the COVID-19 pandemic

Satellite-based remote sensing data products for NO_2, CO, and aerosol optical depth (AOD) help determine the COVID-19 impacts on environmental pollution [77]. From January to March 2020, NO_2 concentrations dropped dramatically in the Southern Hemisphere and tropical regions (Europe, North America, and the Indo Gangetic Plain [77]. The incomplete combustion of carbon-based fuels produces CO, dispersed across the lower atmosphere via wind circulation patterns. The Sentinel 5-P TROPOMI daily observation showed a higher CO column number density concentration in tropical regions, *i.e.*, southwest African countries and the eastern part of India. There was a slight rise in CO value in the northern hemisphere compared to other parts of the world in 2020. In the Indian scenario, the concentration of CO was observed at moderate to high values but slightly low during the period of lockdown, especially in the National Capital Region [77], [78].

Chauhan and Singh [79] conducted a study on air quality in India using geospatial technology. Fig. 3 shows the NO_2 concentration in different parts of India. The NO_2 concentration in an insignificant portion of India declined due to the zero anthropogenic activities. Still, high concentrations observed over southern India due to biomass and fossil fuel burning. Parts of eastern and northeastern states watched its decline due to coal-based power plants and forest fire restrictions. In Northeastern states, the local people burn crop residues to make agri-fields ready for new crops [80], [81]. These findings demonstrate that tropospheric NO_2 values are mainly linked to the decrease in fossil fuel use and other human-induced activities in India because of the country's complete lockdown.

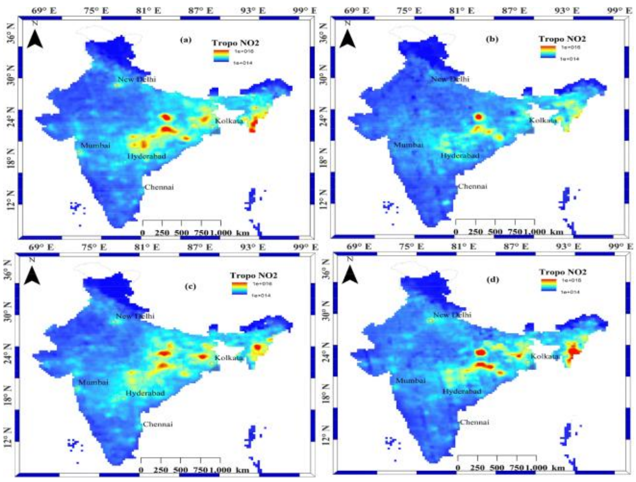

Fig. 3: Spatial variations of tropospheric NO_2 in India between (a) 10–21 March 2019, (b) 10–21 March 2020, (c) 22–31 March 2019, and (d) 22–31 March 2020. (Source: Chauhan and Singh, [79])

During the travel of light into the atmosphere, how it is observed or reflected by the airborne particles is called aerosol optical depth (AOD). The value of AOD varies from 0 to 1, as the value of 0.1 AOD indicates a clean environment, and one means darkened or polluted environment. So the data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite showed the anomaly of the AOD from 2016 to 2019 and compared to 2020, which gives a positive sign to the air quality in terms of AOD concentration (Fig. 4) [81]. Some other studies also justified these results [82].

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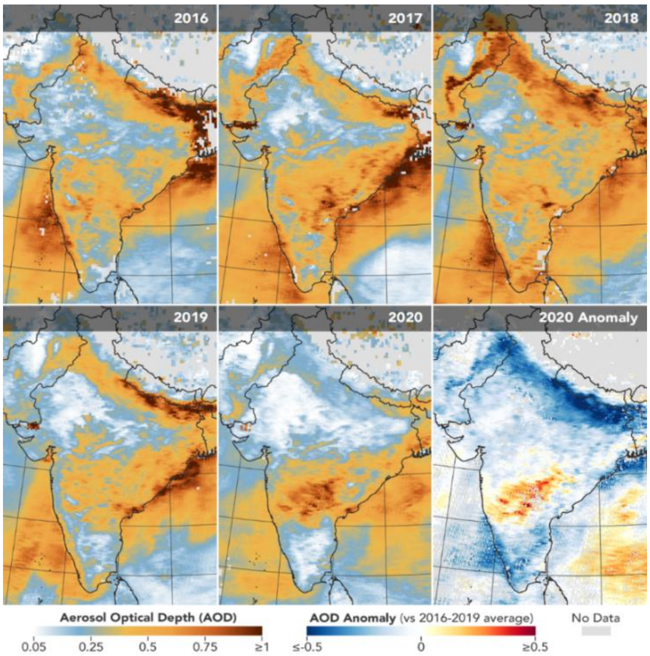

Fig.4: Sequence of Aerosol Optical Depth (AOD) concentration (month—Terra/Modis) in India during the period of March 31 to April 5 in 2016, 2017, 2018, 2019 and 2020 [81]

The Spatio-temporal composite data of Aerosol optical depth, Fine mode fraction, and active fire from different airborne sensors help analyze the Spatio-temporal variability, sources, and mode of transportation of aerosols [124][125]. There is an average decrease of 0.16 in AOD value during the lockdown period in 60 per cent of the Indian region, especially in the Indo Gangetic plain, because of restrictions in the industrial automobile sector leading to improved air quality [83]. Other studies observed a similar trend using different space-borne sensors [77], [84], [85]. In addition to this, during the lockdown, $PM_{2.5}$ concentrations in all metropolitan cities dropped drastically and met national standards [79], [85], [86]. During the pandemic, several investigations were conducted in India. For example, Sahoo et al., [87], conducted a study to analyze the impact on air quality throughout different phases of the COVID-19, including the lockdown and post-lockdown compared to pre-lockdown, to define relationships between environmental and demographic factors. During the lockdown and unlock periods, air pollutants such as NOx, CO, $PM_{2.5}$, and PM_{10} were drastically decreased, with the highest reduction in areas with higher automobile emissions. Average $PM_{2.5}$ and PM_{10} decreased by 51% and 47% during the lockdown periods, respectively, resulting in a satisfactory air quality index (AQI) due to reduced automobile traffic and industrial closure. Because of the additional effect of climate (rainfall and temperature) paired with the lockdown situations, these values continued to decrease by up to 80% throughout the unlock phases.

Sathe et al., [82] used satellite data to monitor NO_X and AOD in India's metropolitan cities and showed that these cities had reduced AOD/NO_2 column density. The results showed that AOD / NO_2 column density is lower in 2020 between the lockdown and previous years for the same time phase. Similarly, several studies have been conducted that observed a significant improvement in the air quality index of several metropolitan cities during the lockdown phase compared to the pre lockdown phase [88], [89], [90], [91], [92], [93], [94], [95], [96], [97], [98], [99], [100] [101]. Although in the second wave of COVID-19 during this phase of lockdown [116][117][118], the air quality in the metro cities in India is not getting much improved because of the partial relaxation of economic activities to avoid the economic damage to the country's economy as experienced during the 1st wave [119][120][121][122].

Although also noticed in the second wave of COVID-19 that there is a more minor improvement in air quality in metro cities than lockdown during the 1st wave, a study showed 39% more progress in the air quality of megacity Delhi than 2nd wave of pandemic lockdown (Fig. 5) [123].

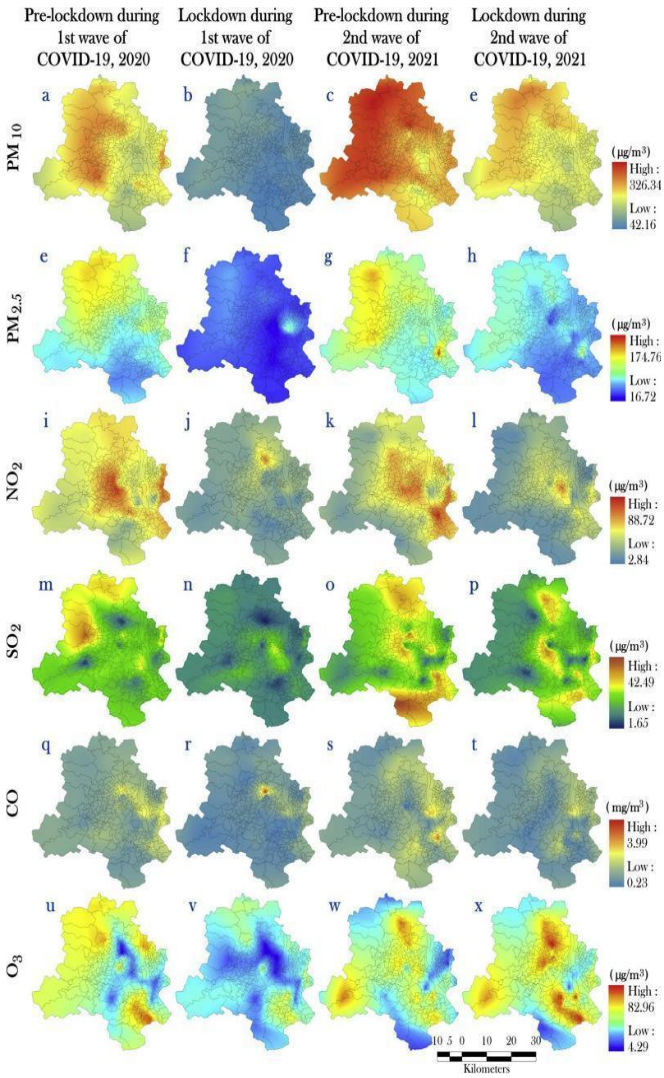

Fig 5: Pre and during lockdown pollutant spatial concentrations in Delhi during the first and second waves of the pandemic COVID-19. (Source: Mahato and Pal, [101])

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Table 1: Summary of some recent studies on air quality assessment during COVID-19 lockdown in different countries across the globe

Reference & Title	Study area	Type of used datasets	Techniques used	Outcomes
Grivas et al., [102] Integrating into situ Measurements and City Scale Modelling to Assess the COVID–19 Lockdown Effects on Emissions and Air Quality in Athens, Greece	Greater Area of Athens, Greece	The analysis of CO and nitrogen oxides were done using APMA360 and APNA360 gas analyzers, respectively, at 1-min resolution, $PM_{2.5}$ concentrations by a reference-grade beta attenuation monitor (PX–375, Horiba Ltd.), providing measurements averaged on 3-h intervals.	In situ observations with estimations from a meteorology atmospheric chemistry model.	Mean concentration reductions of 30–35 per cent for traffic-related pollutants in Athens (NO2, CO, BC from fossil fuel burning) as compared to pre lockdown period.. The decrease in urban CO_2 concentration was also appreciable (53 %), although reduction in $PM_{2.5}$ was average (18 per cent). Significant reduction in air quality was also observed in years before 2020.
Hashim et al., [103] Impact of COVID-19 lockdown on NO_2, O_3, $PM_{2.5}$, and PM_{10} concentrations and assessing air quality changes in Baghdad, Iraq	Baghdad, Iraq	Daily concentrations of four air pollutants were measured, including NO_2, O_3, $PM_{2.5}$, and $PM_{10,}$ from an online platform (https://air.plumelabs.com/en/) monitoring and analyzing the air quality. S-5P/TROPOMI global daily gridded data at 0.05° × 0.05° derived from the near-real-time operational product obtained via the Copernicus open data access hub derived from European Space Agency (ESA), (https://s5phub.copernicus.eu) for NO_2 tropospheric column data	Comparison of pollutants levels before and after the lookdown restriction.	Overall, 6, 8, and 15% decrease in NO_2, $PM_{2.5}$, and PM_{10} concentrations, While there was a 13% increase in O_3. The air quality index (AQI) improved by 13. The NO2 tropospheric column extracted from the Sentinel-5P satellite showed that the NO_2 emissions reduced up to 35 to 40% across Iraq.
Kutralam-Muniasamy et al., [104]. Impacts of the COVID-19 lockdown on air quality and its association with human mortality trends in megapolis Mexico City	Mexico, USA	Manual and automated atmospheric monitoring networks (REDMA and RAMA), atmospheric deposit network (REDDA), and meteorology and solar radiation network (REDMET). Meteorological data (*i.e.*, temperature, relative humidity, wind speed, and precipitation) were acquired from the official website of the atmospheric monitoring system (http://www.aire.cdmx.gob.mx)	The concentration of air pollutants during the same months of 2015-2019 compared with the attention during the entire lockdown period of 2020 to estimate the long-term changes	NO_2, SO_2, CO, PM_{10}, and $PM_{2.5}$ reduced by 19–36%, and O_3 enhanced by 14% compared to the average of 2015–2019
Broomandi et al., [105] Impact of COVID-19 Event on the Air Quality in Iran	Iran (7 megacities)	Hourly concentrations of SO_2, NO_2, CO, PM_{10}, and $PM_{2.5}$, were obtained from Tehran Air Quality Control Company monitoring stations network (TAQCC) (https://aqms.doe.ir/Data/Index). From Department of Environment (DoE) I Level-3 Aura/OMI Global OMSO2e Data Products (Sulfur Dioxide (SO_2) Total Column) with a resolution of 0.25 × 0.25 degree, Level-3 Aura/OMI Global OMNO2d Data Products (Nitrogen Dioxide (NO_2) Cloud-Screened Total and Tropospheric Column) with a solution of 0.25 × 0.25 degree, and daily NASA MODIS/AQUA Atmosphere Level 2 Aerosol Product (MYD 04) (deep blue Aerosol Optical Depth (AOD) at the spatial resolution of a ten × ten km Iran.	air quality a month prior and during the lockdown and compare it with the same time frame in 2019 to show the fluctuations in air pollution	Tehran city observed decrease in concentration of CO, NO_2, SO_2, and PM_{10} in the extreme weather conditions also. Although, the O_3 and $PM_{2.5}$ concentrations were increased.

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Roy et al., [106] Geospatial analysis of COVID-19 lockdown effects on air quality in the South and Southeast Asian region	South and Southeast Asia (19 countries)	open-source satellite-based data and software frameworks	assess the effects of COVID-19 induced lockdown measures on air quality in both regional, country, and city scales	compared to the same period of 2019, atmospheric NO_2, SO_2, $PM_{2.5}$, and CO levels decreased by an average of 24.16%, 19.51%, 20.25%, and 6.88%, respectively during the lockdown, while O_3 increased by a maximum of 4.52%
Zambrano-Monserrate, et al., [62] Has air quality improved in Ecuador during the COVID-19 pandemic? A parametric analysis	Quito, Ecuador	The Secretary of the Environment of the Municipal corporation of the Metropolitan District of Quito provided information on NO2, PM2.5, and O3 concentrations.	Using a parametric method, examine the impact of quarantine rules on air quality in Quito, Ecuador.	Since implementing shutdown measures, NO2 and PM2.5 values have dropped sharply. In 2020, although, O3 concentrations surged significantly.
Kerimray et al., [107] Assessing air quality changes in large cities during COVID-19 lockdowns: The impacts of traffic-free urban conditions in Almaty, Kazakhstan	Almaty, Kazakhstan	"Airkaz" public air quality monitoring network (www.airkaz.org) for $PM_{2.5}$ and Monitoring of benzene, toluene, ethylbenzene, and *o*-xylene (BTEX) was done manually	analyze the effect of the lockdown (27 days) on the concentrations of air pollutants in Almaty	The $PM_{2.5}$ concentration was reduced by 21% during the lockdown, with spatial variations of 6–34% compared to the average on the same days in 2018–2019. There were also substantial reductions in CO and NO_2 concentrations by 49% and 35%, respectively, but an increase in O_3 levels by 15% compared to the previous 17 days before the lockdown. The concentrations of benzene and toluene were 2–3 times higher than those during the same seasons of 2015–2019
Sharma et al., [108] Effect of restricted emissions during COVID-19 on air quality in India	India (22 cities in different regions)	Ground-based air quality and meteorological data from a network of air quality monitoring stations across 22 different cities in India for the past four years (2017–2020) from March 16th to April 14th.	Before/After comparison of $PM_{2.5}$, PM_{10}, CO, NO_2, and AQI concentration for tarch 16th to April 14th, from 2017 to 2020. – Assessment of the effect of meteorology on the $PM_{2.5}$ using the WRF-AERMOD model system	Compared to previous years (2017–2019), du, $PM_{2.5}$, PM_{10}, CO, and NO_2 concentrations reduced by 43, 31, 10, and 18% during the lockdown periodsspectively. – O_3 shows an increase (17%) and negligible changes observed in SO_2. – The mean excessive risks of PM reduced by ~52% nationwide due to restricted activities in the lockdown period.
Anil & Alagha, [109] The impact of COVID-19 lockdown on the air quality of Eastern Province, Saudi Arabia	Eastern Province, Saudi Arabia	General Authority of Meteorology and Environment Protection database (GAMEP), Davis® Vantage Pro 2+ wireless meteorology station for meteorological data	The impact of the lockdown on air quality was studied.	NO2 values were reduced at all locations during and after the lockdown, ranging from 12–86 percent and 14–81 percent, respectively. PM10 concentrations decreased by 21–70 percent, CO by 5.8–55 percent, and SO2 by 8.7–30 percent, whereas O3 concentrations surged by 6.3 to 45 percent.
Baldasano, [110] COVID-19 lockdown effects on air quality by NO_2 in the cities of Barcelona and Madrid (Spain)	Barcelona and Madrid (Spain)	Data from 24 automatic remote air quality monitoring stations in Madrid and 9 in Barcelona	impact of the adopted lockdown measures on air quality in the metropolitan areas of Madrid and Barcelona has been evaluated,	The reduction in NO_2 concentrations in Barcelona and Madrid (Spain) under COVID-19 lockdown during March 2020 was 50% and 62%, respectively

Chen et al., [111] Non-uniform impacts of COVID-19 lockdown on air quality over the United States	Across the U.S.	Data acquired from 28 long-term air quality stations across the U.S.	Air quality assessment during the first phase of lockdown (March 15–April 25, 2020) relative to a pre-lockdown reference period and historical baselines established in 2017–2019.	The reductions, up to 49% for NO_2 and 37% for CO are statistically significant at two-thirds of the sites and increase with local population density. Substantial reductions of particulate matter ($PM_{2.5}$ and PM_{10}) only occurred in the Northeast and California/Nevada metropolises where NO_2 declined the most, while the ozone (O3) changes were mixed and relatively minor.
Menut et al., [112] Impact of lockdown measures to combat Covid-19 on air quality over western Europe	Western Europe	9 EEA (European Environment Agency) stations used for model comparisons to surface concentrations	WRF-CHIMERE modelling suite to compare atmospheric composition with and without lockdown measures without the biases of meteorological conditions	At a resolution of 20 km, results show a decrease in NO_2 concentrations ranging from −30% to −50% in all western European countries. Ozone concentrations have been differently affected in urban areas throughout Western Europe by lockdown measures increasing concentrations. The effect on acceptable particle concentrations has been less pronounced than on NO_2 (−5 to −15%)
Wang et al., [113] Four-Month Changes in Air Quality during and after the COVID-19 Lockdown in Six Megacities in China	China (6 megacities)	Hourly observations of the ambient concentrations of significant pollutants (including NO_2, O_3, $PM_{2.5}$, and CO) were obtained from the China National Environmental Monitoring Center. Hourly meteorological data, including wind direction (*wd*), wind speed (*ws*), ambient temperature (*temp*), relative humidity (*RH*), and atmospheric pressure (*pressure*) downloaded from the NOAA Integrated Surface Database using the worldmet R package	Machine learning technique to analyze the air quality impacts of the COVID-19 lockdown from January to April 2020 for six megacities with different lockdown durations.	The lockdown reduced ambient NO_2 concentrations by 36–53% and reduced $PM_{2.5}$ concentrations during the most restrictive periods, but O3 was increased.
Ropkins and Tate, [114] Early observations on the impact of the COVID-19 lockdown on air quality trends across the UK	United Kingdom (UK)	1-Hour resolution of air pollutant (NO, NO_2, NO_x, O_3, PM_{10}, and $PM_{2.5}$) time-series data from monitoring stations were downloaded from the Defra AURN online archives using open-air function importAURN	Air pollutant levels across the UK were analyzed using break-point/segment methods during the lockdown.	NO, NO_2 and NO_x decreased (on average) 32% to 50% at roadsides on lockdown. O_3 concentrations increased by (on average) 20% on lockdown.
Ródenas et al., [115] Assessment of COVID-19 Lockdown Impact on the Air Quality in Eastern Spain: PM and BTX in Urban, Suburban and Rural Sites Exposed to Different Emissions	Valencia region, Eastern Spain	Three provinces as mentioned above	impact of the lockdown on the air quality of three provinces in the Valencia region, eastern Spain, in the years 2015–2020, focusing on particulate matter (PM)	Overall PM_{10} reduction of 16.5% when comparing the lockdown in 2020 and the 2015–2019 period, while $PM_{2.5}$ increased by 3.1%. The drastic drops of benzene, toluene, and xylene (77.4%, 58.0%, and 61.8%, respectively) on the PM values observed in urban sites.

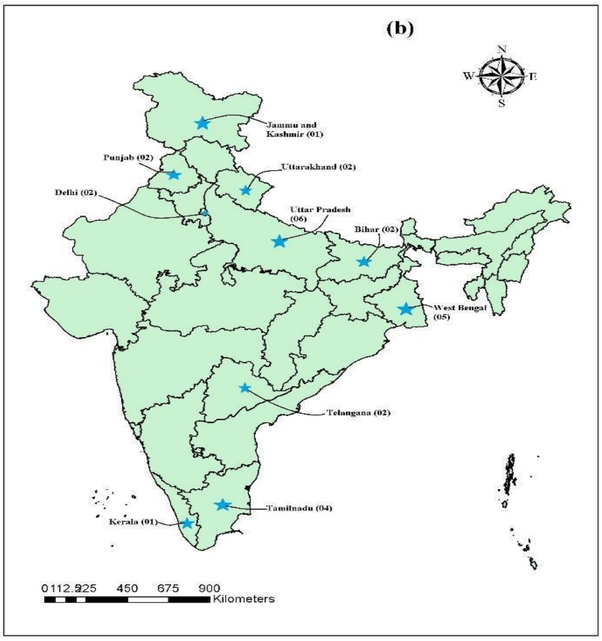

Fig 6. Maps representing the studies included in the review that are conducted during the period of lockdown in different states in India on (a) Air quality and (b) Water quality (QGIS software (3.4.1) QGIS.org (2020) were used, accessible from https://qgis.org/).

The sewage discharge into freshwater ecosystems due to the high speed of commercial and industrial activity emphasizes the importance of constant monitoring and prevention activities. [126], [127], [128], [129], [130], [131], [132], [133], [134]. The food chain may be at increased risk due to the entrance of toxic elements due to the increasing concentration of heavy metals [135], [136] [137], [138], [139], [140], [141] [142]. Heavy metals are highly toxic, persistent, and non-biodegradable, making them an issue for both environments [126]. COVID-19 breakout becomes an emerging challenge for countries worldwide, but India, the 2nd most populated country globally, is more prone to spreading this disease. The Government was taking preventive measures, i.e., lockdown and other advisories. Researchers worldwide collaborated for further study when the reports gained momentum on water quality improvement.

Several studies showed different results; Ganga river quality was improved in some areas, such as Haridwar [135]. On the other hand, some also show depletion in water quality of some significant rivers (Ganga, Beas, Chambal, Sutlej, and Svarnarekha [136], [143]. have conducted a similar study on Gomti river water quality deterioration during the lockdown phase. However, assessment of heavy metal pollution has not been assessed in previous studies to determine the impact of this pandemic.

Some studies on the heavy metal pollution in the rivers of India have been showing a remarkable reduction in the water of these rivers, highlighting the impact of the closure of agricultural, industrial, and commercial activities [144]. The analysis of the turbidity of the Ganga River along its route in different locations observed a drastic change in the turbidity during this lockdown period [145]. The salinity of the groundwater aquifers also decreased during this period [146], and the total coliform bacterial load in the river Ganga is drastically dropped [147]. Water quality in terms of turbidity was also improved during this period. Aman et al., [148] monitored the turbidity of the Sabarmati River in Ahmadabad using the Landsat 8 OLI images and concluded a significant improvement. The increasing concentration of DO and declining concentration of BOD and nitrate in River Ganga showed progress in overall water quality in just a 2-months lockdown period [135].

As the most sensitive and vulnerable place to address the impact of climate change, the Himalayas is one of the significant sources of water for many greatest rivers of Asia. During this period, a considerable improvement was observed in these Himalayan Rivers' physicochemical parameters (Ganga, Yamuna, Bhagirathi, Bhilangna, Alaknanda Song, Bindal, and Assan) as compared to the BIS drinking water standards. The air quality has also been significantly recovered, and noise levels are also found under the ambient air quality Standard [149]. The water quality parameters of the Ganga River near Kolkata concerning Dissolved Oxygen (DO) give a positive trend, *i.e.*, improved water quality observed [150]. In the eastern part of India, the water quality index of Damodar river water was significantly enhanced in terms of TDS [151], TH, BOD, Fe, NO_3^- and other water quality indexes during this period, [152]. A tropical Ramsar site in the southern part of India, Asthamudi lake water, showed a significant improvement in the water quality in terms of Suspended particulate matter (SPM) using the Landsat 8 OLI images [153]. The water quality of the Gomti River's stretch was assessed using a water quality index. There also needed to be a potential risk of faecal-oral transmission of coronavirus through the river water intake, which faces domestic sewage discharge [143]. Similarly, a study on the Tawi river water quality in the Jammu region showed a significant improvement in pH, alkalinity, hardness, and conductivity [154].

The water quality of the Yamuna River deteriorated in and around Delhi and U.P. states in India. During the lockdown phase, some water quality parameters such as pH, EC, DO, BOD, and COD were assessed, and they showed a marked decrease in their concentration compared to the pre-lockdown stage. The water quality was drastically recovered [155]. At the same time, Faecal Coliform was also reduced by 40%. Using structural cluster analysis, a similar investigation of 20 main drainages that join the Yamuna indicated decreasing wastewater loads and discernible improvements in drain contamination quality. For 117 channel segment zones, multi-temporal Landsat-8 images of past and ongoing lockdown periods estimated reach-wise suspended particulate matter content, turbidity, and algal signatures. These metrics also decreased significantly [156].

Groundwater samples taken in the Coimbatore region's drastically increasing industrial and housing sector in southern India between the post-monsoon season and the pre-monsoon period in 2020. These sampling intervals corresponded to before and during the region's industrial lockdown and reduced agricultural activity due to the COVID-19 pandemic. This presented a once-in-a-lifetime opportunity to assess the impact of less human activity on groundwater quality.

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According to pre-monsoon statistics, roughly 17% of the wells afflicted by excessive fluoride values in the post-monsoon phase reverted to safe levels for human utilization. Ion exchange activities, precipitation penetration during the yearly monsoon, diluting ion concentrations, particularly geogenic fluoride, and anthropogenic input reductions during the lockdown was most likely to be responsible; because industries are shut down and agricultural operations were restricted, COVID-19 lockdown significantly reduced groundwater pollution by Na^+, K^+, Cl^-, NO_3^-, and F^- ions. Overall, the findings indicate that interventions to mitigate anthropogenic pollution can positively impact groundwater quality [157].

Different types of the index are Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Normalized Difference Chlorophyll Index (NDCI), Nitrogen Content Index (NI), Normalized Difference Turbidity Index (NDTI), and Total Suspended Matter (TSM)) were used to determine the changes observed before and during the lockdown period. So an indicative change was observed, and indices showed a positive trend in the water quality index of the water resources [158]. A similar study on the water quality analysis of Ganga River on different stretches analyzed using Sentinel 2A data by calculating chromophoric dissolved organic matter (CDOM), total suspended matter (TSM), and chlorophyll-a (Chl-a) and showed marked improvement in water quality along these stretches [159]. A study in the Hussain Sagar Lake in Telangana, India, showed a lack of pollution load in lake water using Landsat 8 OLI images with the CDOM mentioned above and Chl-a parameters [160].

In terms of Some heavy metals (Fe, Pb, Se, As), total coliforms, and faecal coliforms, the groundwater quality was also improved due to the closure of large and small scale industries limited human-induced activities. [161]. A significant decline in dissolved inorganic Nitrogen was observed in the water quality of Chennai's urban river Adyar between pre-lockdown and lockdown. It suspended particulate matter during the latter period Suspended particulate matter (SPM) is also an essential parameter of water quality that can assess using spaceborne satellite images. Vembanad Lake in Kerala also showed a significant decrease in SPM concentration over this lockdown period. Similarly, SPM on the coastal water bodies also offered a positive trend [162].

Table 2: Summary of some recent studies on water quality assessment during COVID-19 lockdown in different countries across the globe

Reference & Title	Study area	Type of used datasets	Techniques used	Outcomes
Molekoa et al., [163] Spatio-Temporal Analysis of Surface Water Quality in Mokopane Area, Limpopo, South Africa	Mokopane Area, Limpopo, South Africa	surface water samples collected from five sampling locations from 2016 to 2020	Time-series analysis of key surface water quality parameters was performed to analyze water quality. The analyzed water quality data were also used to calculate the heavy metal pollution index (HPI), heavy metal evaluation index (HEI) and weighted water quality index (WQI). Also, the spatial trend of water quality is compared with LULC changes from 2015 to 2020	Most of the physico-chemical parameters in the water samples was beyond the World Health Organization (WHO) adopted permissible limit, except for a few parameters in some locations. It is found that most of the sampling shows a deteriorating trend from 2016 to 2019. However, the year 2020 shows a slightly improving trend on water quality
Callejas et al., [164] Effect of COVID-19 Anthropause on Water Clarity in the Belize Coastal Lagoon	Belize Coastal Lagoon, Belize, Central America	moderate resolution imaging spectroradiometer (MODIS) satellite data	impacts of the COVID-19 shutdown on water quality in terms of attenuation coefficient at 490 nm, $K_d(490)$ in Four Coastal Management Zones classified by marine traffic as high traffic areas (HTAs) and two as low traffic areas (LTAs)	Through the shutdown, K_d was lower in 2020 at HTAs, but not for LTAs indicating improved water quality
Kutralam-Muniasamy et al., [165] Unfolding Water Quality Status During COVID-19 Lockdown for the Highly Polluted Santiago River in Jalisco, Mexico	Santiago River in Jalisco, Mexico	data for 12 water quality parameters from 13 sampling stations during April-May 2020 (lockdown) were compared with the levels for the same period of 2019 (pre-lockdown) and with the same interval of previous eleven-years (2009-2019	Water quality during April-May 2020 (lockdown) were compared with the levels for the same period of 2019 (pre-lockdown) and with the same interval of previous eleven-years (2009-2019	The values of BOD (14%), COD (29%), TSS (7%), f. coli (31%), t. coli (14%) and Pb (20%) declined, while pH, EC, turbidity, total nitrogen and As enhanced by 0.3-21% during the lockdown compared to the pre-lockdown period suggesting short-term improvements in river water quality

Dobson et al., [166] Integrated Modelling to Support Analysis of COVID-19 Impacts on London's Water System and In-river Water Quality	London, UK	Manual -river water sampling	CityWat-SemiDistributed (CWSD) integrated model to test the impact of a COVID-19 lockdown on in river quality starting from household water consumption	Pollutant concentrations in rivers simulated by the model were most sensitive in the tributaries of the River Thames, highlighting the vulnerability of smaller rivers and the important role that they play in diluting pollution.
Cherif et al., [167] COVID-19 Pandemic Consequences on Coastal Water Quality Using WST Sentinel-3 Data: Case of Tangier, Morocco	Tangier, Morocco	Sentinel 3 water surface temperature (WST) data	Prior and amid the COVID-19 pandemic-related emergency status, information from April 2019 and April 2020 were analyzed.	The results from April 2019 showed high WST values and consequently, the poorest water quality in the sites closest to the Boukhalef river mouth. On the other hand, the results from April 2020 showed normal WST values and high water quality in the same study area
Najah et al., [168] Surface water quality status and prediction during movement control operation order under COVID-19 pandemic: Case studies in Malaysia	Malaysia's Putrajaya Lake and two urban rivers (the Rivers of Klang and Penang).	Data from riverside water quality monitoring units	effect of lockdown on the water quality index (WQI) using four machine learning algorithms	In the two rivers studied, there were noticeable improvements in the WQI to varied degrees. In the case of Putrajaya Lake, the WQI Class I has increased significantly, from 24% in February 2020 to 94% over the MCO month of March 2020.
Custodio et al., [169] Surface Water Quality in the Mantaro River Watershed Assessed after the Cessation of Anthropogenic Activities Due to the COVID-19 Pandemic	Mantaro River Watershed, Peru	Surface water samples were collected in triplicate from 15 sampling sectors at the end of the rainy season, between March and April. Concentrations of Cu, Fe, Pb, Zn and As were determined by the method of atomic absorption flame spectrophotometry	Water quality of rivers in the Mantaro River basin was analyzed using multivariate statistical methods and heavy metal contamination indices during the health outbreak of the pandemic.	PCA showed a total variation percentage of 83.8%. The results gave a clear positive relationship between the five heavy metals and metalloids. The average concentrations of heavy metals and arsenic in the rivers evaluated did not exceed the environmental quality standards for drinking water of the global regulations, except for Pb, Fe and As in the Mantaro River
Liu et al., [170] COVID-19 lockdown improved river water quality in China	China	monthly field measurements (N = 1693) and daily auto monitoring (N = 65)	the influence of the COVID-19 lockdown on river water quality in China	Compared to April 2019, the Water Quality Index increased at 67.4% of the stations in April 2020, with 75.9% of increases being significant
Haghnazar et al., [171] COVID-19 and urban rivers: Effects of lockdown period on surface water pollution and quality- A case study of the Zarjoub River, north of Iran	Zarjoub River, north of Iran	A total of twenty six samples (thirteen samples in February, and thirteen samples in May) were collected in thirteen sites from the upstream to the downstream of the Zarjoub River	Water quality indices *i.e.* (1) heavy metal pollution index, *HPI*; (2) heavy metal evaluation index, *HEI*; (3) degree of contamination index, C_{deg}; and (4) water quality index, *WQI* during the lockdown period	Water pollution and associated human health risk decreased with an average of 30% and 39%, respectively, during the lockdown period. In addition, the multi-purpose water quality index also improved by an average of 34%.
Pandey et al., [172] Analyzing the Impact of Lockdown on Rejuvenation of Rivers in Uttar Pradesh, India	Ganga, Yamuna, Hindon and East Kali rivers of Uttar Pradesh	Geospatial data and water samples	spatio-temporal analysis of BOD, DO, Fecal Coliform and Total Coliform with respect to pollution sources was analyzed	The water quality of the Ganges and Yamuna rivers has enhanced. On the other hand, River Hindon exhibited a modest improvement, while River East Kali's water quality remained the same. When comparing the pre-lockdown and post-lockdown periods, a sudden and significant decrease of river water quality was noticed.

Tokatlı and Varol, [173] Impact of the COVID-19 lockdown period on surface water quality in the Meriç-Ergene River Basin, Northwest Turkey	Meriç-Ergene River Basin, Northwest Turkey	Data from 25 sampling stations in the river the basin	impact of the lockdown on water quality by measuring the levels of physico-chemical variables and metal(loid)s in water samples	Significant reductions in metalloid levels were recorded during the lockdown. BOD, COD, EC, turbidity, TSS and Mn levels did not show significant differences however, Cr, Ni, Zn, Cu, As, Pb and Cd concentrations decreased considerably during the lockdown

VI. CONCLUSION

With the increasing development in recent times in different disciplines, mainly in technology and medical science, we have not ever thought about this type of situation due to an infectious virus, which imprisoned almost all the people worldwide in their places. There is no surety that this situation will not become again as it is evident that the environment (air and water) can play a significant role in solving all the problems around the world. But if the domain is not better, how can we get the solutions. The studies on lockdown during this pandemic show a positive indication of environmental quality. In terms of air and water, it concluded that when the world was trying to find the solution for combating the impacts of COVID-19, these short-term lockdowns played a substantial contribution to enhancing environmental quality. As a result, the government and policymakers should make the necessary efforts to ensure this recovery process permanently. Short-term lockdowns need further studies to improve the quality of the environment and for a better future for human civilization.

DECLARATIONS

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