Arabian Journal of Geosciences (2022) 15: 687
https://doi.org/10.1007/s12517-022-09986-4

ORIGINAL PAPER

Air and water health: industrial footprints of COVID-19 imposed lockdown

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Received: 15 June 2021 / Accepted: 23 March 2022 / Published online: 4 April 2022

Abstract

Overall lockdown limitations toward the start of the year 2020 are credited to the annihilation and fatalities worldwide because of COVID-19. Most of the nations revealed rapid growth of COVID-19 cases and subsequently declared lockdown in several stages. Because of these lockdowns, industries had to stop producing goods other than the actual merchandise needed to survive. The air quality and natural water quality witnessed a noticeable improvement from limited human activity. This paper presents an investigation demonstrating this improvement under various lockdown periods, specifically for the Indian subcontinent. The rivers and atmosphere of Indian settings have been utilized here as a contextual analysis associated with industrial pollution. This work aims to study the associations and interrelationships between lockdowns during COVID-19 and their effect on air and water quality. The paper presents then and now an analysis of the Indian atmosphere based on various particulate matters and river health based on the biological oxygen demand, chemical oxygen demand, and dissolved oxygen. The study indicated a significant dip in air and water pollution levels and a significant improvement in the atmosphere and rivers' quality during this period. Significant water bodies witnessed the pH level of 7.5 amidst lockdown, which is a good indicator of improved water health since the pH level of drinkable water is 7. The analysis carried out in this paper can also be mapped to other countries and landscapes of the world.

Keywords COVID-19 · Air Quality Index (AQI) · Index of Industrial Production (I.I.P.) · Lockdown · Water quality

Introduction

The world overall is dealing with phenomenal issues exacerbated by the COVID-19 pandemic. Because of its exceptionally infectious spread, individuals' lives all around the world have been put on hold. Policymakers, governments,

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and strategists implemented total lockdowns to limit social contact and forestall illness spread. The transmission of the virus and subsequent measures to hinder its further spread has had significant ramifications. Studying its effect on each portion of society is large, and a complete investigation is needed to look up to the difficulties that lie ahead (Moradian et al. 2020; Rzymski et al. 2020). The manufacturing sector is quite possibly the most impacted area, contributing predominantly to the gross domestic product (G.D.P.) of each country (Gupta et al. 2008).

On the one hand, halting industrial production is one of the reasons why G.D.P. growth has been diminished, while on the other hand, it has proven to be a boon for the quality of air and rivers. During the lockdown period, a significant drop in emission levels was observed. Lower offtake has decreased production and, subsequently, reduced toxic contaminants in the environment (Bagchi and Sahu 2020). Higher PM 2.5 and PM 10 levels have become a big problem for most of the regions, but their levels have decreased due to the imposition of lockdowns. Over several years, dumping untreated toxic waste in river beds has affected marine species, but lockdown has proved to be a breathing room over aquatic life. In other channels, the water quality was too low to get the whole channel covered with foam. This was the result of untreated poisonous effluents produced in the waterways. This drastically reduced during the COVID-19 pandemic due to the restrictions imposed during the lockdown. Changes in the environment are bound to have a significant effect on the ecological footprint. The eco-footprint is focused on any human operation, no matter how small it is. Suppose a nation does not have enough ecological resources within its jurisdiction relative to its consumption, in that case, the local ecological deficit will result, and the country will become an ecological debtor country. Thus, the mechanism of self-healing that nature has adapted during the lockdown period due to reduced human interference has the potential to cause a positive shift within the eco-footprint. The context of studying such analysis in this manuscript lies in its industrial significance to the eco-system and the urgency of such social reforms to regularly keep the pollution in check.

This paper puts forward a comprehensive and data intensive assessment of air and water health amidst COVID-19 specific to the Indian subcontinent's atmosphere because of lockdown limitations that halted industrial production. The driving motivation to consider India as a contextual investigation for this sort of examination lies in the fact that the Indian economy is one of the global economy's central pillars since India is the world's largest democracy.[1] This also arises from the fact that India has a vast landscape, thereby making the industrial production assessment vital not just for the country itself but also for Asia in its entirety.[2] Furthermore, the Indian climate varies across the country's geography, and the Indian atmosphere is severely impaired by air pollution[3] for many years due to human and industry intervention. India is the world's third largest emitter of greenhouse gases (GHGs), after China and the USA.[4] India has three extensively spread national watercourses (The Brahmaputra River system, The Ganga Bhagirathi Hooghly River, and The West Coast Canal). It is also surrounded by three global water bodies (the Arabian Sea, Bay of Bengal, and the Indian Ocean) along its boundaries, making it a rich water bodies,[5,6]. These facts and statistics propose why it is interesting to observe India's air and water health in particular, as impacted by COVID-19.

This paper throws light on the ground-breaking question, "Are there any correlations between the periods of restriction implemented during COVID-19 and its effect on air and water quality?".

The analysis presented in this paper is backed by observational information that we derive from the State Governments and the Government of India's data. It depicts the correlation between the periods of restriction implemented during COVID-19 and its effect on air and water quality. Industries, which are significant sources of pollution, were shut down to stop COVID-19 infection, which resulted in fewer pollutants being released into the environment. The positive impacts of these imposed restrictions on the environment are visualized through this paper. The government can use this strategy of imposing lockdown regularly to mitigate the damage caused by human activities on the environment and allow nature to heal itself. While several artificial intelligence methods are available to forecast the potential effect of the COVID-19 pandemic on emission rates and many other factors (Jain et al. 2021), these are currently beyond the kind of analysis presented in this paper.

The rest of the paper has been organized as follows: "Related work" section presents the related work in the context of pollution during COVID. "Main contributions" section puts forward the main contributions of this research article. "Lockdown restrictions in India during COVID-19 pandemic" section discusses several restrictions imposed during different lockdowns phases. "Impact of COVID-19 imposed a lockdown on industrial production" section presents the impact of lockdowns on industrial production. The apparent reduction in industrial growth led to variations in

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[3] Regan, Helen. "21 of the world's 30 cities with the worst air pollution are in India". CNN. Retrieved 2020–02-26.

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air quality viz. highlighted and discussed in "Subsequent impact on air quality amidst COVID-19" subsection, and water quality, viz. highlighted and discussed in "Subsequent impact on water quality amidst COVID-19" subsection. "Reflections" section propounds observations and viewpoints on the health of air and water amidst the pandemic. "Conclusion" section concludes the paper.

Related work

Several studies have reported the improvement in environmental conditions due to the worldwide imposed lockdown. Major cities have witnessed a dip in air pollution and water pollution because of restricted human activities (Chauhan and Singh 2020). There has been a substantial improvement in environment's health globally (Lal et al. 2020). For different particulate matters, PMs have lessened in their steep increase (Le et al. 2020). Analyzing and reporting particular countries or bodies of water for pollutant parameters have been one of the main fields of science. Scientists have made a major contribution throughout the world during the post-locking period. Several studies have analyzed the impact on air during this period. A study conducted in Dantas et al. (2020) discusses the impact of the measures on the air quality of a city in Brazil during the partial lockdown as well as weeks prior to the virus outbreak. Authors in Li et al. (2020) suggested a reorganization of the energy and industrial strategy for a sustainable air pollution plan. Comprehensive analysis has also been performed for the Air Quality Index variation amidst COVID-19 in countries like Brazil, China, the USA, Italy, and France (Balasubramaniam et al. 2020).

Similarly, for the water bodies, the report (Braga et al. 2020) inferred increased water transparency in the Venice Lagoon due to reduced human activity. Water quality assessment of river Ganga and Chilika Lagoon has been presented in Chander et al. (2019). Authors in Yunus et al. (2020) concluded the positive impact on lake water quality is due to direct or indirect human activities during COVID-19 restrictions. Both satellite imagery and ground observation data (Kylili et al. 2020) have served as tool-based resources to report such analysis. A study (Garg et al. 2020) has presented these positive changes in water pollution levels through remote sensing data (both image and attributed data). Such observations can be manifested to propose smart algorithms (Kovacova et al. 2019) and further assure sustainable industrial technical progress (Milward et al. 2019).

Deriving the associations and interrelationships between the restrictions imposed during the lockdown and its various effects is a hot topic these days. Existing works that try to link pollution and the changes in the environment's quality during lockdown include (He et al. 2020). The authors discuss the short-term impacts of COVID-19 and the lockdown imposed on the urban population of China. They also show heterogeneous effects of lockdown on air quality like climatic conditions, G.D.P., population, and traffic. Another paper (Muhammad et al. 2020) discusses the impacts of COVID-19 on various countries throughout the world. They compare the effects on air pollution and link it to mobility during lockdowns since more than half of the world was under some form of lockdown during that period. Tobias et al. (Tobías et al. 2020) try to show the air quality changes during the lockdown period in Barcelona, Spain, during the Sars-Cov-2 pandemic. The authors state that the concentrations of NO_2 and B.C. (black carbon) were reduced to half during the windy and warm climate of Barcelona during the lockdown period. They also state that only a slight decrease is observed in PM10 concentrations. In (Masum and Pal 2020), the authors tried to analyze the trends shown by various air pollutants considered while measuring AQI during the lockdown period in Bangladesh. In (Patel et al. 2020), the authors study the effect of lockdown on river Yamuna's water quality by analyzing the measured parameters and using satellite image-derived indices. Such times of crisis also necessitate the need for sustainable policy-making and strategy development. In this regard, (Jeffreys and Xu 2018) examines coal-related environmental and health crises, and in pushing an authoritarian government to change policies to maintain social and political stability. Public communication and participation play a significant role in carving out decisions concerning environmental policies (Walker 2007). To the best of our understanding, there is not an extensive coverage of assessment of a large landscape like India that has varied climatic and environmental conditions.

Main contributions

The main contributions of the conducted assessment are as follows:

a) Air quality and water quality are measured, and the difference is observed and visualized by comparing them during the pre-lockdown time and during the lockdown to demonstrate the environmental impact of restrictions. These were then related to industrial waste, which is the main source of emissions for various contaminants, and the effect on the atmosphere of closing the factories was examined.

b) We discuss the multifold impact of COVID-19 on the environment. The restrictions imposed due to preventive strategies and lockdowns by the government helped in purifying the environment both directly (by limiting human mobility) and indirectly (by closing down factories that are a significant source of pollution).

c) Explanatory plots depict diverse variations of water and air quality changes observed over multiple lockdown phases. The water quality of the country's main rivers is evaluated via the data published as one of the significant impacts of lockdown by the different state governments. Such significant effects have demonstrated that the waterways on the brink of being a drain saw water quality change. A comparison with the water quality is rendered in the pre-lockdown period and during the lockdown process.

Lockdown restrictions in India during COVID-19 pandemic

The Indian government enforced a national shutdown on 24 March that saw an increasing number of cases. Although the number of incidents has been deficient compared to other nations, the lockdown decision was made quickly. The shutdown created specific difficulties for both citizens and the government when addressing the demands of 1.3 billion people was very complicated. People associated with critical services were allowed to travel outside their homes, thus limiting the entire Indian population's movement. All facilities and shops were closed, except grocery stores, supermarkets, hospitals, banks, and other vital services. Figure 1 indicates the various stages of lockdowns in India.

With the declaration of successive lockdowns, such relaxations were granted in phases according to the conditions assessed. Next to all, facilities and factories are shut down during phase 1. Citizens were arrested for violating lockdown norms. People rushed to stock the necessary products in certain areas. During phase 2, the lockdown areas were classified as three zones: "red" indicating highly infectious zones, "orange" indicating some infection, and "green" with zero infections. Certain relaxations were given allowing agricultural businesses; small retail shops were allowed to open to half the staff, cargo vehicles were allowed to move. In every scenario, it was made clear that social distancing norms must be followed. In phase 3, the country was categorized into red, orange, and green zones. Red zones were those with high COVID-19, orange zones with comparatively fewer cases, and green with no cases in the past 21 days. The movement was permitted in green zones with only 50% capacity in buses. In phase 4, some additional relaxations were given. States were given authority to demarcate the red, orange, and green zones. The red zone was further divided into containment and buffer zones. Any kind of movement was not allowed in the containment zones. States were given authority to decide further roadmaps to deal with COVID-19 disease. The lockdown may not be fruitful for economic growth (Dev and Sengupta 2020; Singh and Neog 2020) but has been beneficial in decreasing pollution levels across the country.

Impact of COVID-19 imposed a lockdown on industrial production

The imposition of a countrywide lockdown aimed at stopping the speed of the dissemination of deadly COVID-19, but, sadly, it also delivered a fatal blow to the already slowdown Indian manufacturing sector, placing it at a complete halt. Figure 2 shows that during the months when the lockdown was implemented between April and May, the industrial output's monthly sectoral index had a substantial decline. After that, a small rise in manufacturing can be seen in different industries due to some relaxations. A decrease in industrial production rejuvenated the health of water bodies and resulted in an improvement in air quality. Table 1 explains the effects of several industries on the environment.

Except for the sectors that manufacture essential goods such as food and beverages, pharmaceuticals, and others, all businesses have undergone a substantial decrease in productivity. Lower production in most sectors means lower freshwater use and more inadequate drainage of toxic effluents into river beds and soil, leading to healthier rivers and better air quality indices (ref. "Main contributions" section and "Lockdown restrictions in India during COVID-19 pandemic" section).

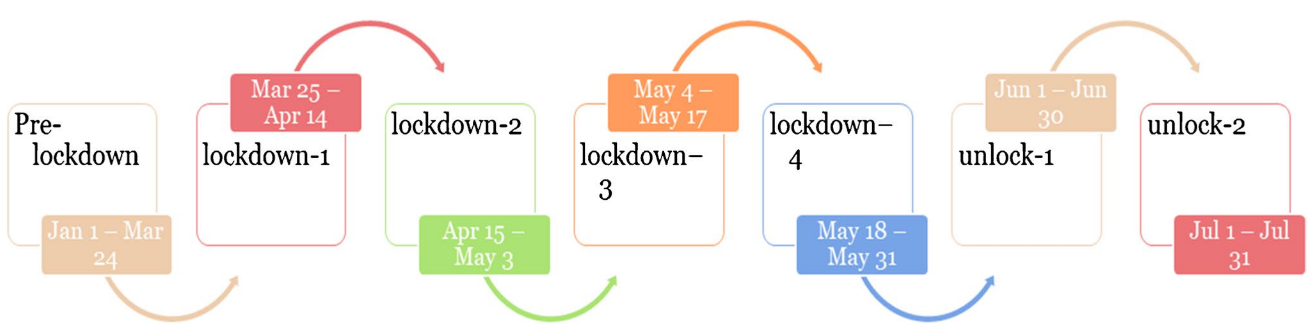


Fig. 1 Timeline showing different stages of lockdowns

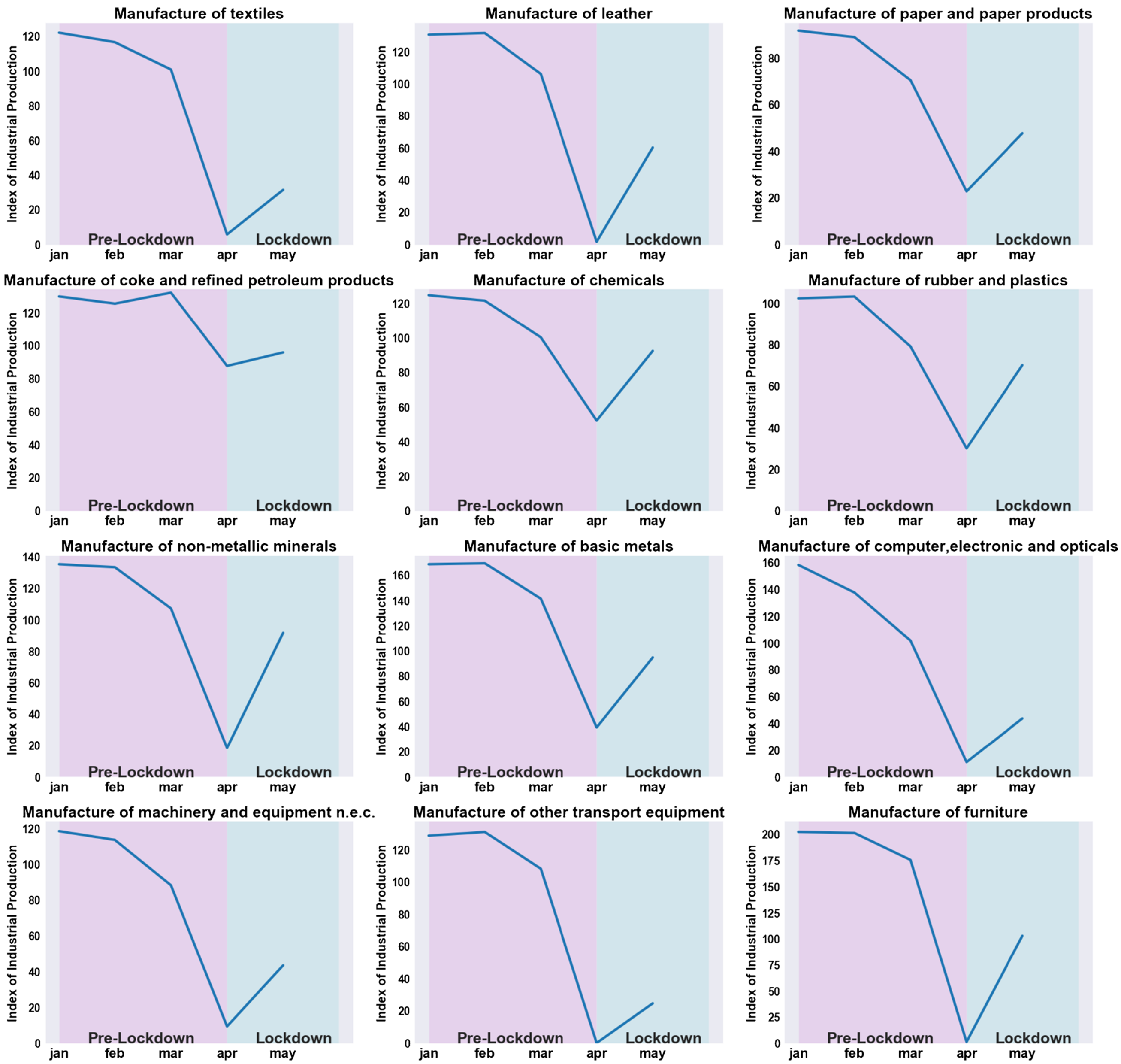


Fig. 2 Monthly sectoral indices of industrial production during the pre-lockdown and lockdown period (http://mospi.nic.in/iip#)

Subsequent impact on air quality amidst COVID-19

The Air Quality Index is a ranking that offers a verdict on the safety or condition of the air in an area over some time. Such AQI scores are further divided into six groups based on the impact on the wellbeing of the masses living in the region, as shown in Table 2. It allows the public to identify risks to their health and to prevent possible health hazards.

To calculate the AQI score, usually, the pollutants taken into consideration are as follows (Xiao et al. 2018):

- Particulate matter (PM 2.5 and PM 10): These contaminants consist of solid particles (like dust) and water droplets that can be discharged directly or produced when other contaminants react with each other. Such particles differ greatly in size and are thus classified into two groups: fine particles, where the particles' size is 2.5 µm or less is measured using PM 2.5, and coarse particles, where the particle size is between 2.5 and 10 µm and is measured in PM 10. Major sources of particulate matter include motor vehicles, forest fires, agricultural combustion, industrial processes, crushing, or grinding operations. Such particles can penetrate the lungs and cause

Table 1 Industries along with their pollutants emitted

Industry	Function/items produced	Pollutants released in the environment
Textile industry	Design and production of yarn, cloth, and clothing	Dust and lint, oil fumes, acid vapor, solvent mists, and boiler exhaust (Toprak and Anis 2017)
Leather industry	Leather garments, leather clothing, leather footwear	Toxic chemicals and acidic effluents concentrated with heavy metals like chromium, cadmium, lead, arsenic
Paper industry	Produce paper and paper products from wood	Chlorine, hypochlorite, chlorine dioxide, hydrogen peroxide, sulfite, and oxygen
Coke and petroleum industry	Refined petroleum products from crude oil	Volatile organic compounds, nitrogen oxides, sulfur oxides, hydrocarbons, inorganic salts, and heavy metals (Jafarinejad 2016)
Chemical industry	Industrial chemicals	Toxic compounds like oxides, sulfites, nitrites, phenols
Plastic and rubber industry	Plastic and rubber products include the manufacturing of N95 masks, P.P.E. kits, and COVID-19 test kits	Tetramethyl thiuram disulfide, diammonium phosphate, vapors of low molecular weight organic compounds (carbon disulfide and amines) or inorganic compounds (hydrogen sulfide) (Jagadale et al. 2015)
Metallic and non-metallic minerals industry	Produce products from metallic and non-metallic minerals	The release of toxic metals and non-metallic organic and inorganic matter
Electronic industry	Design, manufacture, and assemble electronic products	Dioxins, furans, heavy metals, polyaromatic hydrocarbons, and polychlorinated biphenyl (Awasthi et al. 2016)
Automobile industry	Design, development, and manufacturing of motor vehicles	Volatile organic compounds used as paint solvents and lead used for automobile batteries (Li et al. 2016)

Table 2 AQI categories

Color	Air Quality Categories	Value of AQI	Description/ Quality Parameter
Green	Good	0 - 50	Air quality is satisfactory. Little or no risk
Yellow	Moderate	51 - 100	Air quality is acceptable. Reasonable health concerns for people who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive People	101- 150	No risk for the general public. Members of sensitive groups may experience health effects.
Red	Unhealthy	151 - 200	Moderate risk for the general public. Members of sensitive groups may experience more severe health effects.
Purple	Very Unhealthy	201 - 300	Health alert for everyone.
Maroon	Hazardous	301+	Health warnings of emergency conditions.

severe health issues (Peng et al. 2009). Several PMs interfere with human lungs differently, causing multiple lung and heart diseases (Nakao et al. 2018; Yongjian et al. 2020). Figure 3 shows the variation of these particulate matters (PM 2.5 and PM 10) in India's various cities, i.e., Bengaluru, Bhopal, Delhi, Kolkata, Mumbai, Shillong, and Thiruvananthapuram. As it is clear from the graph, most cities see a considerable drop of PM 2.5 and PM 10 values after the imposition of lockdown. Due to the lockdown restrictions, a considerable decrease in the traffic

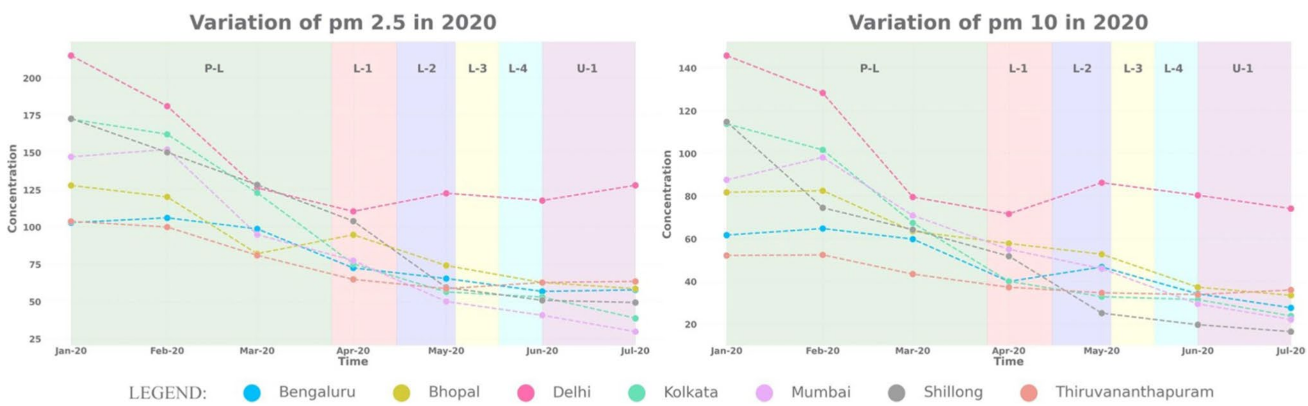


Fig. 3 Graphs showing the variation of particulate matter in several cities of India during different stages of lockdown. (*P-L: pre-lockdown, L-1: lockdown-1, L-2: lockdown-2, L-3: lockdown-3, L-4: lockdown-4, U-1: unlock-1)

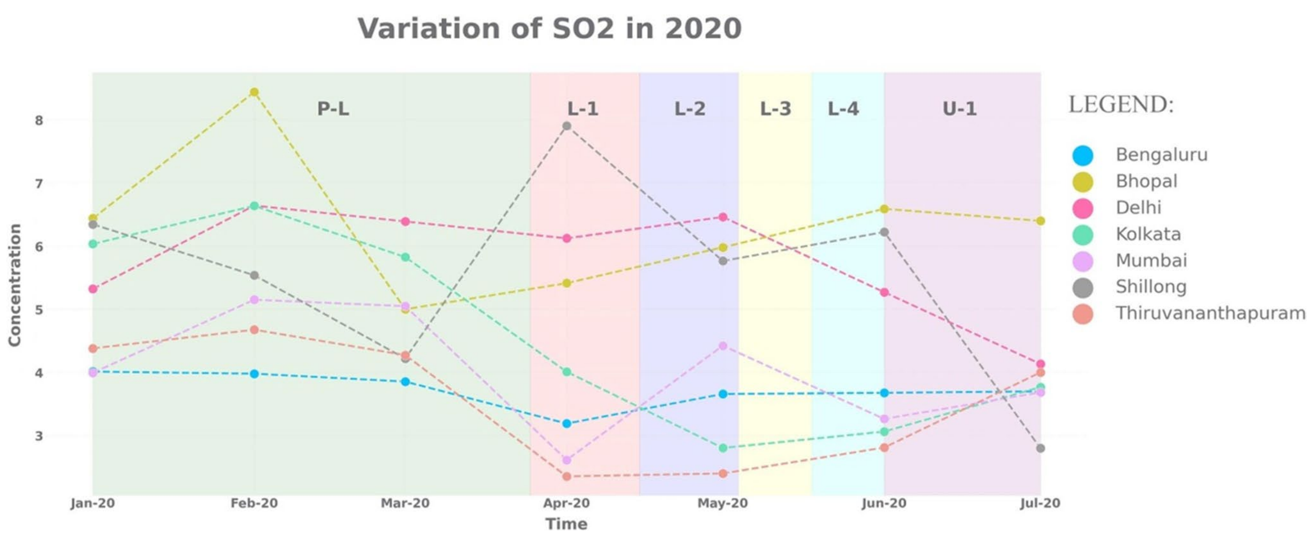


Fig. 4 Graphs showing the variation of SO2 in several Indian cities during different stages of lockdown. (key: P-L: pre-lockdown, L-1: lockdown-1, L-2: lockdown-2, L-3: lockdown-3, L-4: lockdown-4, U-1: unlock-1)

and production of industries can be seen, which were the major sources contributing to the growth of particulate matter in the air, resulting in a decrease in the quantity of these pollutants.

• Sulfur dioxide (SO2): Sulfur dioxide is an inert gas that tastes like burnt matches. These contaminants are highly reactive and lead to acid rain. Human activities such as the combustion of sulfur-based fuels such as oil and coal for manufacturing or the production of sulfur-based materials in manufacturing are the major contributors to the presence of SO2. Emissions from motor vehicles also produce SO2 (McManus et al. 1988). Exposure to SO2 causes coughing, wheezing, and breathlessness, and long-term exposure can cause respiratory diseases like aggravating asthma (Lippmann 1985). Most of the cities except Shillong see a decrease in the concentration of SO2, as seen from Fig. 4 during the lockdown period.

• Nitrogen dioxide (NO2): This gas has a nasty smell, which induces a decline in immunity against lung infections when it consumes the lungs' lining, contributing to respiratory issues. NO2 is used as a symbol for a wider group of nitrogen oxides (NOx). Lightning bolts can spontaneously produce nitrogen dioxide, but a significant contribution is made from pollution from automobiles, power plants, other manufacturing industries, and food processing. Oxides of nitrogen also contribute to acid rain and photochemical smog (Brimblecombe and Stedman 1982). A significant drop in the emission of NO2 in the air can be observed due to a decline in the number of cars involved during the lockdown. Reduction in the produc-

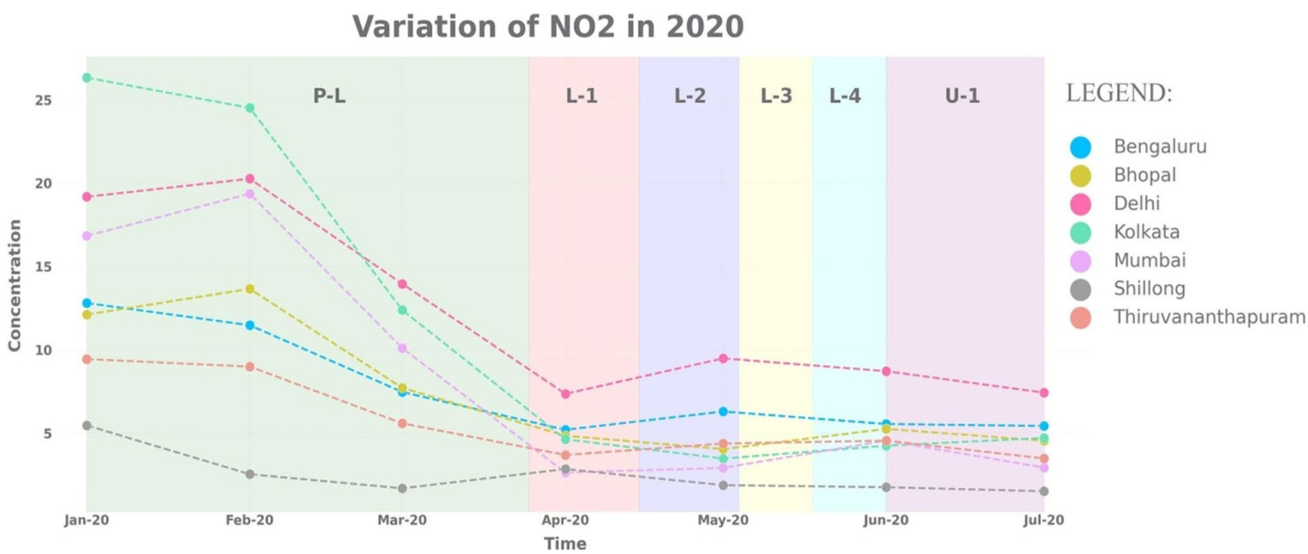


Fig. 5 Graphs showing the variation of NO2 in several cities of India during different stages of lockdown. (key: P-L: pre-lockdown, L-1: lockdown-1, L-2: lockdown-2, L-3: lockdown-3, L-4: lockdown-4, U-1: unlock-1)

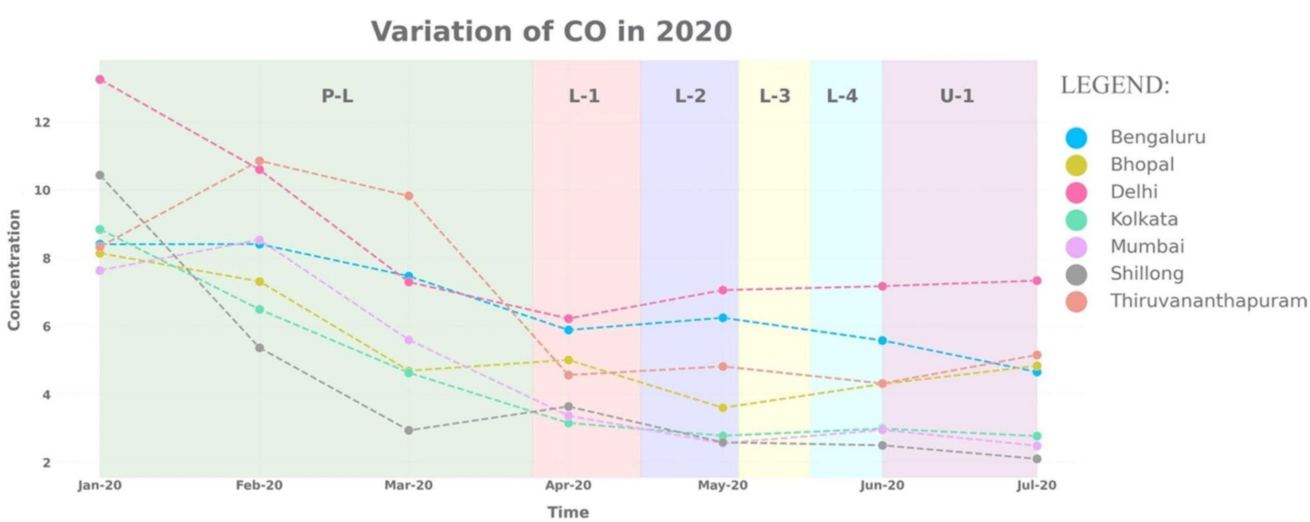


Fig. 6 Graphs showing the variation of C.O. in several Indian cities during different stages of lockdown. (key: P-L: pre-lockdown, L-1: lockdown-1, L-2: lockdown-2, L-3: lockdown-3, L-4: lockdown-4, U-1: unlock-1)

tion from industry also contributes toward the decrease in NO2 in the air. Figure 5 depicts the mentioned observations.

• Carbon monoxide (CO): It is colorless, odorless gas. The primary cause of carbon monoxide is incomplete fuel combustion, mainly in vehicles, manufacturing processes, and wildfires. CO has a higher bonding ability to hemoglobin than oxygen. Therefore, when they enter the bloodstream, they interact with hemoglobin rather than oxygen and thus reduce oxygen to different parts of the body. Therefore, exposure to an increased amount of CO can lead to several health problems. (Levy 2015). A downward trend can be seen from the graph in Fig. 6 after the lockdown is imposed due to a reduction in the number of vehicles used and the industry's closure. A slight increase in the concentration can be seen after lockdown-2 due to some restrictions being lifted up.

- Ground level ozone (O3): Unlike stratospheric ozone, which is beneficial because it protects humans from direct radiation, ground-level ozone

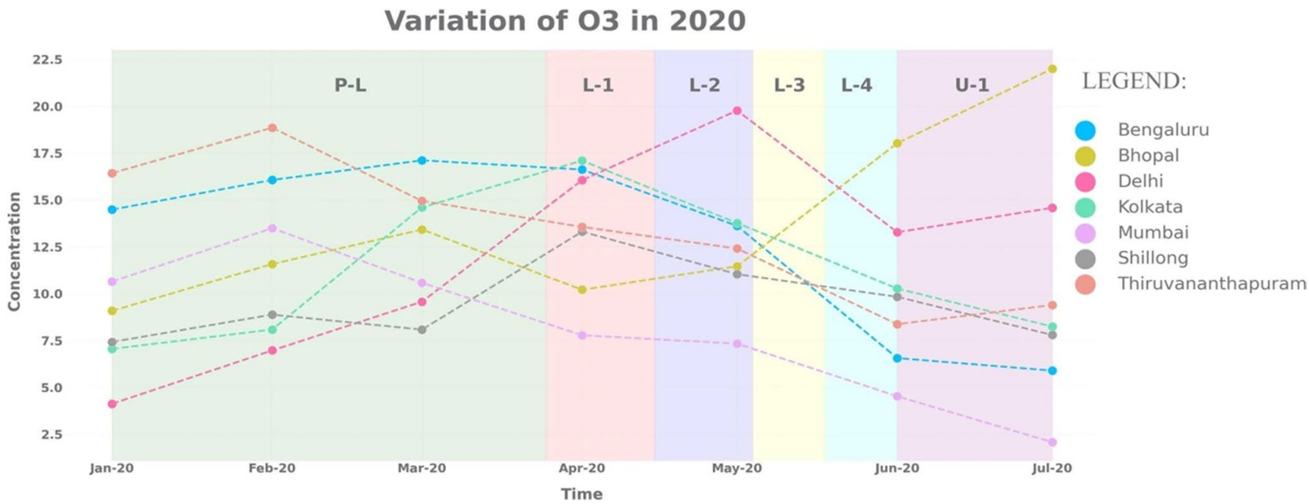


Fig. 7 Graphs showing the variation of O3 in several Indian cities during different stages of lockdown. (key: P-L: pre-lockdown, L-1: lockdown-1, L-2: lockdown-2, L-3: lockdown-3, L-4: lockdown-4, U-1: unlock-1)

Table 3 Indicators for water index quality

Indicators	Quality aspect parameter
Biological oxygen demand (B.O.D.)	Oxygen content for microorganisms
Chemical oxygen demand (C.O.D.)	Oxygen content for organic matter oxidation
Dissolved oxygen (D.O.)	Oxygen present per litre of the water sample
Total dissolved solids (T.D.S.)	Amount of inorganic salts and soluble organic matter
Ammonia	Ammonia (NH3) or its soluble form ammonium (NH4 +)
Temperature	Solubility of solids in water, metabolic activities of aquatic life
pH	Acidity and basicity of the water body
Hardness as CaCO3	Amount of soluble divalent or multivalent metals
Total coliform	General pointer of sanitary conditions in the water body

causes serious health issues such as asthma, emphysema, and chronic bronchitis as individuals are largely exposed. Such chemicals are produced as contaminants from different sources, such as power plants, refineries, and automobiles reacting chemically with sunlight. Just exposure to a small amount of ozone can cause severe long-term illnesses. As shown in Fig. 7, there is no consistent pattern in the variability of O3 levels in the different lockdown stages. While some cities like Bengaluru, Mumbai, and Thiruvananthapuram see a slight decrease in ozone concentration at ground level when the lockdown is implemented, other considered cities show an increasing in O3 levels during the lockdown possibly due to the “vanishing ozone weekday/weekend effect” (Wolff et al. 2013).

The above visualizations were plotted based on data collection from Air Quality Worldwide COVID-19 dataset. These plots provide a strong indication of the progress of AQI in different cities of India. Some cities see a major change in air quality, shifting from the “Very Unhealthy” AQI category to the “Good” category.

Subsequent impact on water quality amidst COVID-19

The water quality of water bodies depends on several interrelated factors. In rivers, due to water movement, water responds physically or chemically to minerals in rock and soil. These are also not naturally found without degradation and therefore contain many soluble inorganic and organic compounds. Along with this, there is a suspension of insoluble particles. These impurities vary in type and concentration from location to location and time of year. These are also influenced by factors such as geological, topological, and climatic. Thus, the water quality index, which monitors a range of variables, such as biological oxygen demand, dissolved oxygen, total dissolved solids, is used to test the water’s purity to see if the water is appropriate for marine life or is suitable for human use. Table 3 highlights some of these indicators.

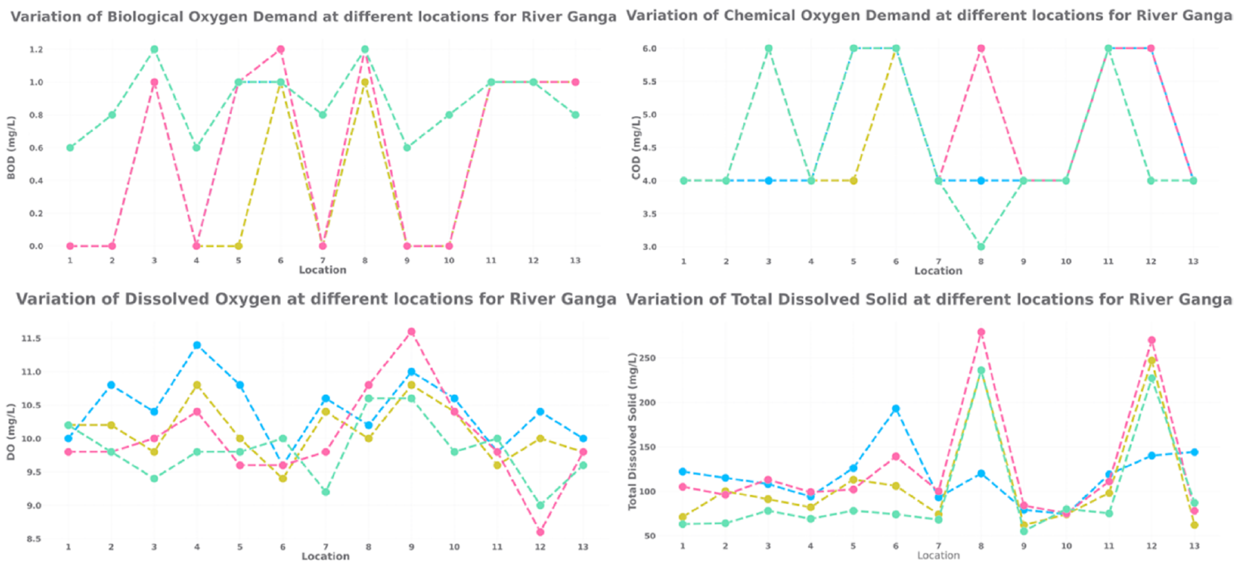
Impact on Indian river-health

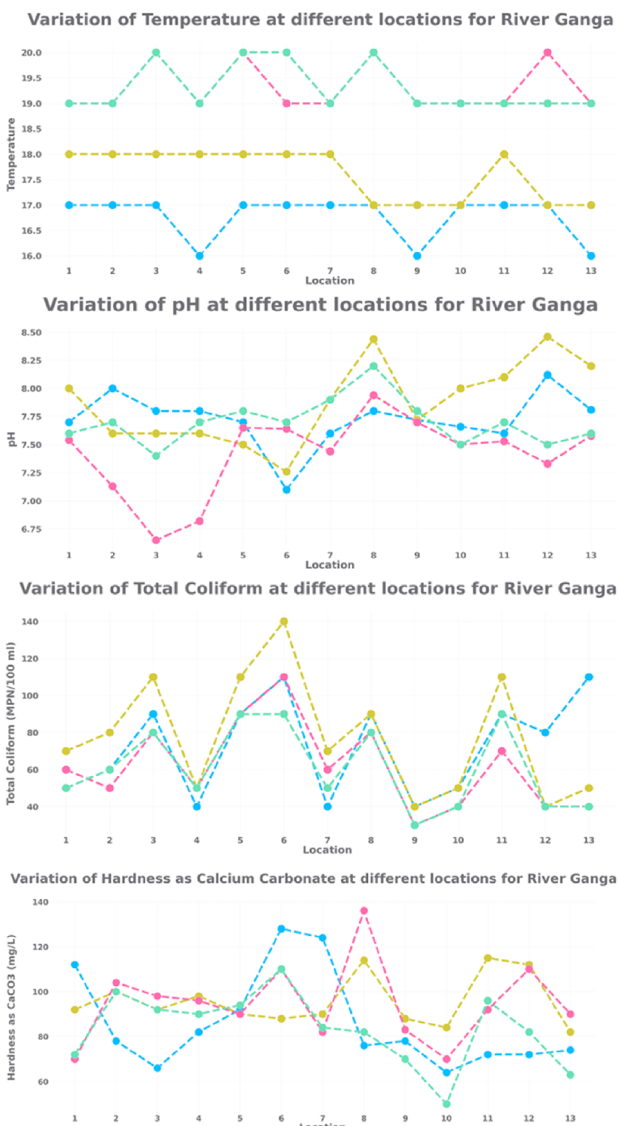
As a nation, India has sustainable water resources and six major rivers along with their tributaries that cater to its significant domestic, industrial, and agricultural demands. Increased demand from a rising population, combined with economic activity, puts a strain on already strained water supplies. Hence, providing measures and enforcing policies that help maintain water quality and its biological content is a dire need of many environmentalists, ecologists, and policymakers working for this common goal (Kliestik et al. 2018). Significant changes in policy and reforms have been suggested worldwide after witnessing the positive impacts of this lockdown on air and water bodies that need mass awareness concerning the economy and social impacts (Graessley et al. 2019). In 2018, the Central Pollution Control Board (CPCB), India's Nodal Pollution Monitoring Agency, reported over 351 contaminated rivers across India, most of which are located along with large urban/industrial areas (Bhattacharya et al. 2021). Therefore, industrial pollution has been recognized as one of the primary causes of water resource pollution and needs certain action point changes (Khursheed et al. 2020), especially wastewater management (Bivins et al. 2020). Therefore, it is presented in the following sub-sections—the variations in pollution levels for six major Indian rivers.

i. River Ganga
The closure of industries and the reduction of effluent released in Ganga have helped reduce the level of pollution to a high level. Samples of water were taken from different areas, and their B.O.D., C.O.D., D.O. alkalinity were analyzed. Figure 8 indicates that the B.O.D. and C.O.D. volumes decreased from March to April. In the lockdown period, the D.O. levels were raised relative to the months before lockdown. The pH at various sites can be found at about 7.5, which is a good sign. The hardness of water was recorded, and the lowering of hardness were observed during April and May. The level of total dissolved solids fell down at different locations. It is evident from Fig. 8 that total coliform's value at various locations decreased to a great extent. With the closing of industries, the release of toxic substances in the river Ganga was significantly reduced. Reducing human actions, such as washing and community bathing, helped Ganga restore its purity and lowered the contamination level to a very high degree. The plots above verify that the water quality improved during the lockdown period.

ii. River Yamuna
The Yamuna is the Ganga River's longest and second largest tributary that flows through northern India. The Yamuna streams are approximately 1400 km in length across seven states where industrial units discharge their effluents into it. More than 300 industrial discharge units were released into the Yamuna, between Haryana's Panipat and Delhi alone. Yamuna's water quality is a grave concern for officials. Instead, unregulated water and toxic waste disposal have turned it into a terrible situation. Yet, the enforcement of a lockdown that led to industry shutdown has proven to be a significant changeover. After the lockdown was implemented in April, it can be clearly seen that the level of pollution has fallen considerably. Figure 9 shows that the pH value, which is approximately 7.5, is similar to the optimal pH value needed for river water. Lower values of B.O.D. compared to the months before lockdown as seen from Fig. 9 give a clear indication toward the improved quality of Yamuna.

iii. River Sabarmati
Sabarmati is one of the major rivers flowing through west India. It was one of the country's most polluted rivers, but the lockdown enforced by India's government helped Sabarmati slash pollution levels. According to the data released by the Gujarat Pollution Control Board, ammonia, which is a major cause of eutrophication, water shows a decline in its percentage, which is a positive sign. There has been a significant drop in the levels of the B.O.D. and C.O.D. levels, which demonstrates that the river has been able to clean itself organically with the closure of factories. Dissolved oxygen, which allows marine life to survive, has seen a positive pattern, and a rise in D.O. can be seen if we compare the pre-lockdown data and during the lockdown time. T.D.S. of water samples taken from different locations reveals that its level was below 1000 mg/L, which is very small relative to the pre-lockdown time. This is a positive sign for the Sabarmati River as the T.D.S. for the freshwater is less than 1000 mg/L.
Plots in Fig. 10 indicate that, with factory closures and the decrease in the release of untreated toxic effluents in the Sabarmati River during the lockdown period, the Sabarmati River has managed to minimize pollution rates. When the disposal of untreated sewage in the river has led to a loss in purity and an unacceptable rise in toxicity, it demonstrated a positive growth with the increase in oxygen levels in the water. It thus proved advantageous for marine life and the quality of the flow, according to the criteria evaluated. Due to the lockdown, water quality has improved and has moved to category "A" from category "B" according to GPCB data.





Location No.	Name of Monitoring Location
1	River Ganga D/s at Harki Pouri Haridwar
2	Upper Ganga Canal D/s Harki Pauri, (Harki Pauri Haridwar at Rishikul Bridge), Haridwar
3	Upper Ganga Canal D/S Roorkee, Haridwar, Uttarakhand
4	Ganga Canal at Dam Koti, Haridwar (Upper River Ganga Canal at Harki Pauri)
5	Ganga at Haridwar U/S Bindhughat, Dudhiyavan, Haridwar, Uttarakhand
6	Ganga at Haridwar D/S Balakumari Mandir, Ajeetpur, Haridwar
7	Ganga Canal at Lal Ta Rao Bridge, Haridwar (Upper Ganga Canal), Haridwar
8	River Ganga after confluence of River Song near Satyanarayan Temple D/S Raiwala, Dehradun
9	River Ganga at Rishikesh U/S Lakshmanjhula, Swargashram U/S of Rishikesh
10	Ganga at D/S of Rishikesh, Near Pashulok, Uttarakhand
11	River Ganga D/S Bishanpur Kundi, Haridwar, Uttarakhand
12	River Ganga D/S Lakkarghat O P, Haridwar
13	River Ganga D/S Swargaashram-1, Haridwar

LEGEND: Jan Feb Mar Apr

Fig. 8 Variation in different parameters of water of river Ganga during pre-lockdown and lockdown period

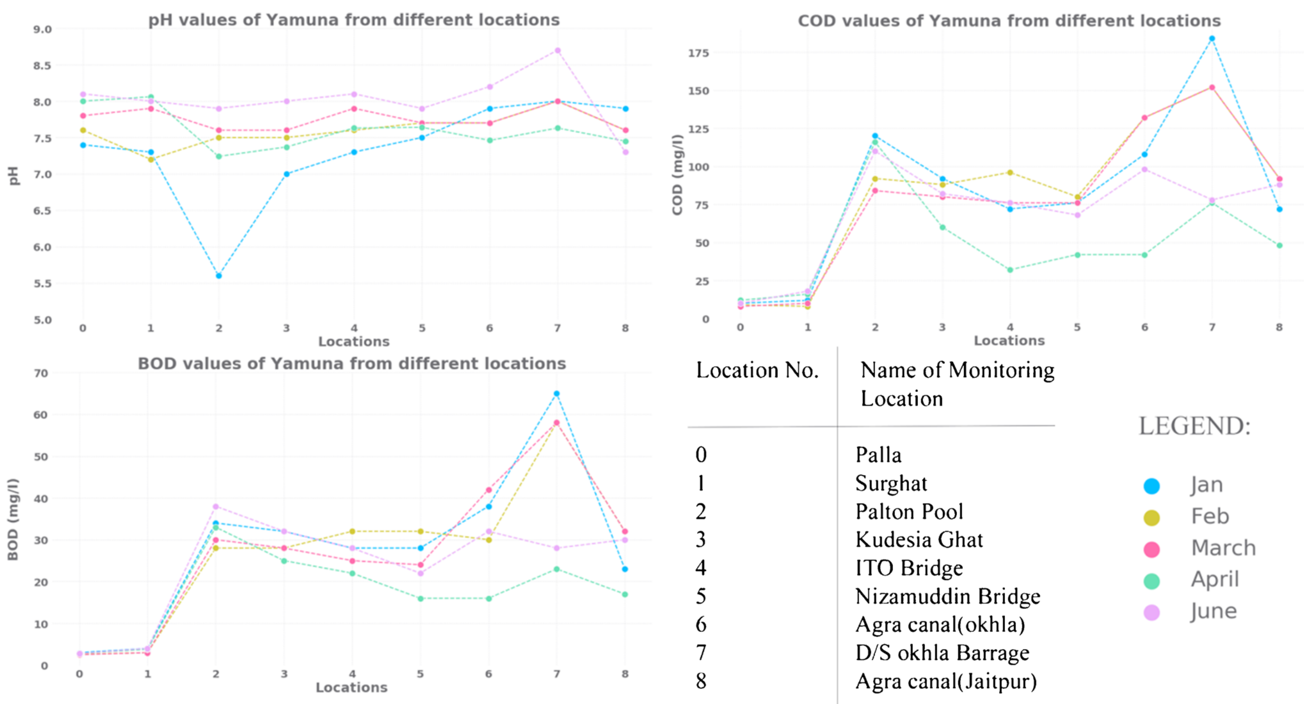


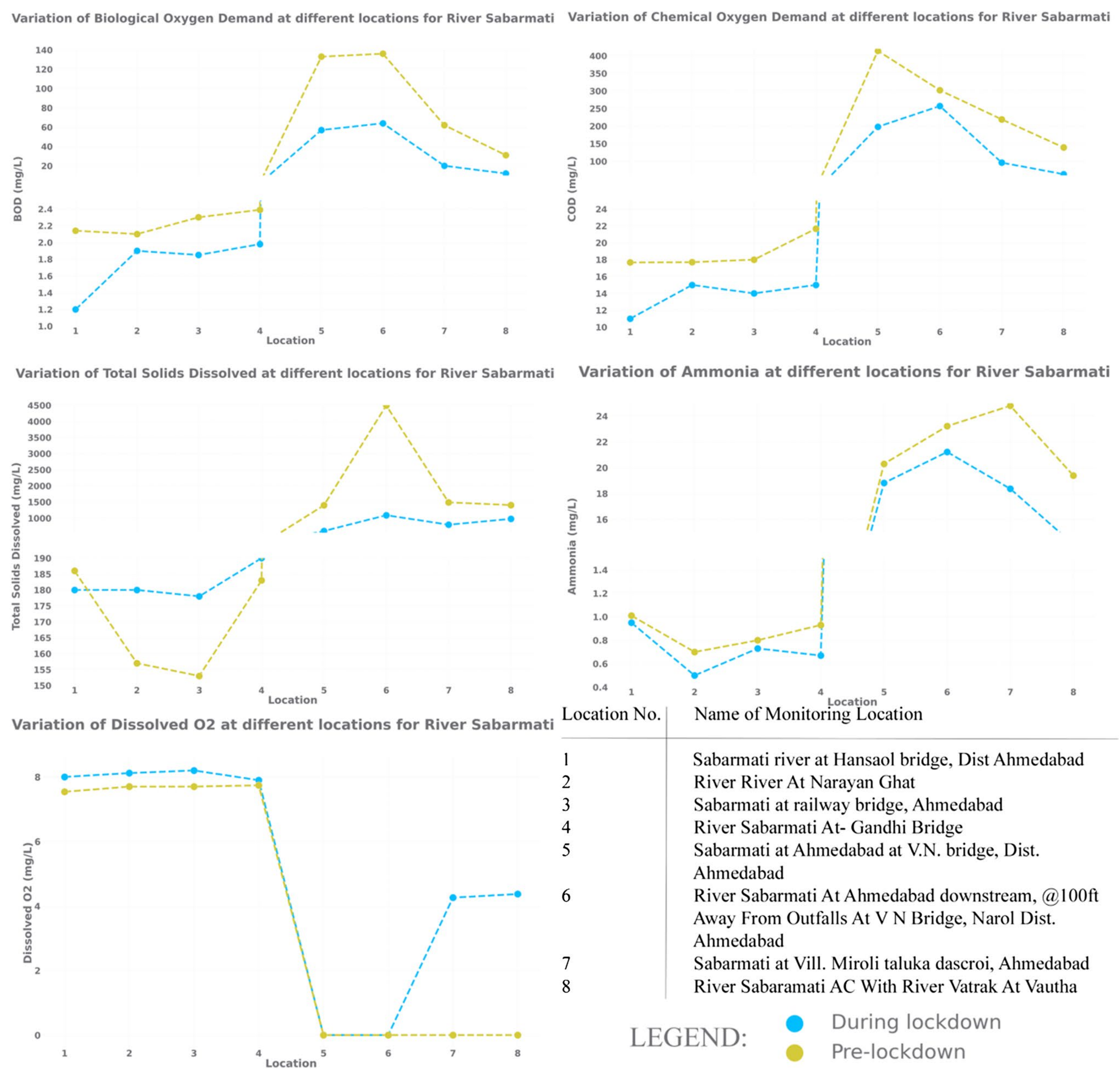
Fig. 9 Variation in different parameters of water of river Yamuna during pre-lockdown and lockdown period

iv. River Narmada

River Narmada, also called Rewa in the local areas of Madhya Pradesh and Gujarat, is one of India's sacred rivers and rises from Amarkantak Plateau in Central India. Given India's third largest river, it has been increasingly poisoned in recent years. Large amounts of untreated sewage generated in the villages and towns and chemical effluents pumped into the river brought the river toward the deathbed. However, the lockdown imposed by COVID-19 gave Narmada a new breath of life by imposing restrictions on significant pollution sources in the Narmada River. During the lockdown, the release of industrial waste and sewage drastically reduced, resulting in a decrease in T.D.S. in many areas, as shown in Fig. 11. Due to the natural healing of the river itself when no new waste is being dumped into the river, B.O.D. and C.O.D. levels also decreased. Ammonia rates also indicate a dramatic decline relative to values during the pre-lockdown time at many testing stations. D.O. levels do not improve because microorganisms that may have used up the oxygen stored in the water spontaneously decompose already accumulated waste. A temperature change due to climatic changes also reduces the D.O. present in water. Overall, river Narmada's output grew during the lockdown period from category "B" to category "A", as shown in the graph in Fig. 11.

v. River Tapi

Tapi, or Tapti, is one of the major rivers in central India near Multai in Madhya Pradesh. This river has sacred significance as well and is named after the goddess Tapati. This river is also known as Narmada's sister and is central India's second largest flowing west river. Tapi River was polluted by storing the waste discharged from factories and discarding untreated sewage in the wetlands. The incorporation of crop runoff in the river is another cause of emissions at Tapi. Thanks to the freeze after the COVID-19 pandemic; contamination rates in the Tapi River have begun to dwindle. There was a small increase in the performance of the B.O.D., which was still at a reasonable stage, although the C.O.D. also improved considerably. D.O. maintains the same average of around seven mg/L during the pre-lockdown and lockdown periods. During the lockdown time, significant improvements were observed in T.D.S. rates, particularly in the region near ONGC Bridge at Surat, a hub for numerous manufacturing industries and power plants. Owing to the lockdown enforcement, river Tapi's water quality has seen decent improvement, as shown in Fig. 12.



Location No.	Name of Monitoring Location
1	Sabarmati river at Hansaol bridge, Dist Ahmedabad
2	River River At Narayan Ghat
3	Sabarmati at railway bridge, Ahmedabad
4	River Sabarmati At- Gandhi Bridge
5	Sabarmati at Ahmedabad at V.N. bridge, Dist. Ahmedabad
6	River Sabarmati At Ahmedabad downstream, @100ft Away From Outfalls At V N Bridge, Narol Dist. Ahmedabad
7	Sabarmati at Vill. Miroli taluka dascroi, Ahmedabad
8	River Sabaramati AC With River Vatrak At Vautha

Fig. 10 Variation in different parameters of water of river Sabarmati during pre-lockdown and lockdown period

vi. *River Mahi*

Mahi is one of the major western flowing interstate rivers. Mahi's water quality was still in the group A before lockdown as B.O.D. is 2 mg/L or less and D.O. is more than 6 mg/L, and it was still inapplicable requirements. Nevertheless, its water quality has increased further with the introduction of lockdowns. In specific sampling sites, the levels of ammonia have decreased, which indicates a good outcome. The B.O.D. rates at each control station have also deteriorated. C.O.D. levels were still above acceptable levels as stable relative to other waterways. There is not a variation in C.O.D. rates. D.O. levels have risen at most tracking sites, but not much rise is expected due to an increase in temperature. The T.D.S. values remained stable between 200 and 300 mg/L, which holds Mahi River water in the category of freshwater. Figure 13 indicates that the water quality previous to the lockdown was good; however, the lockdown attributable to the COVID-19 pandemic has also strengthened the condition. The river has been holding in the fit category. Therefore, the closing of factories and no further dumping in the Mahi River indicated an increase in water quality.

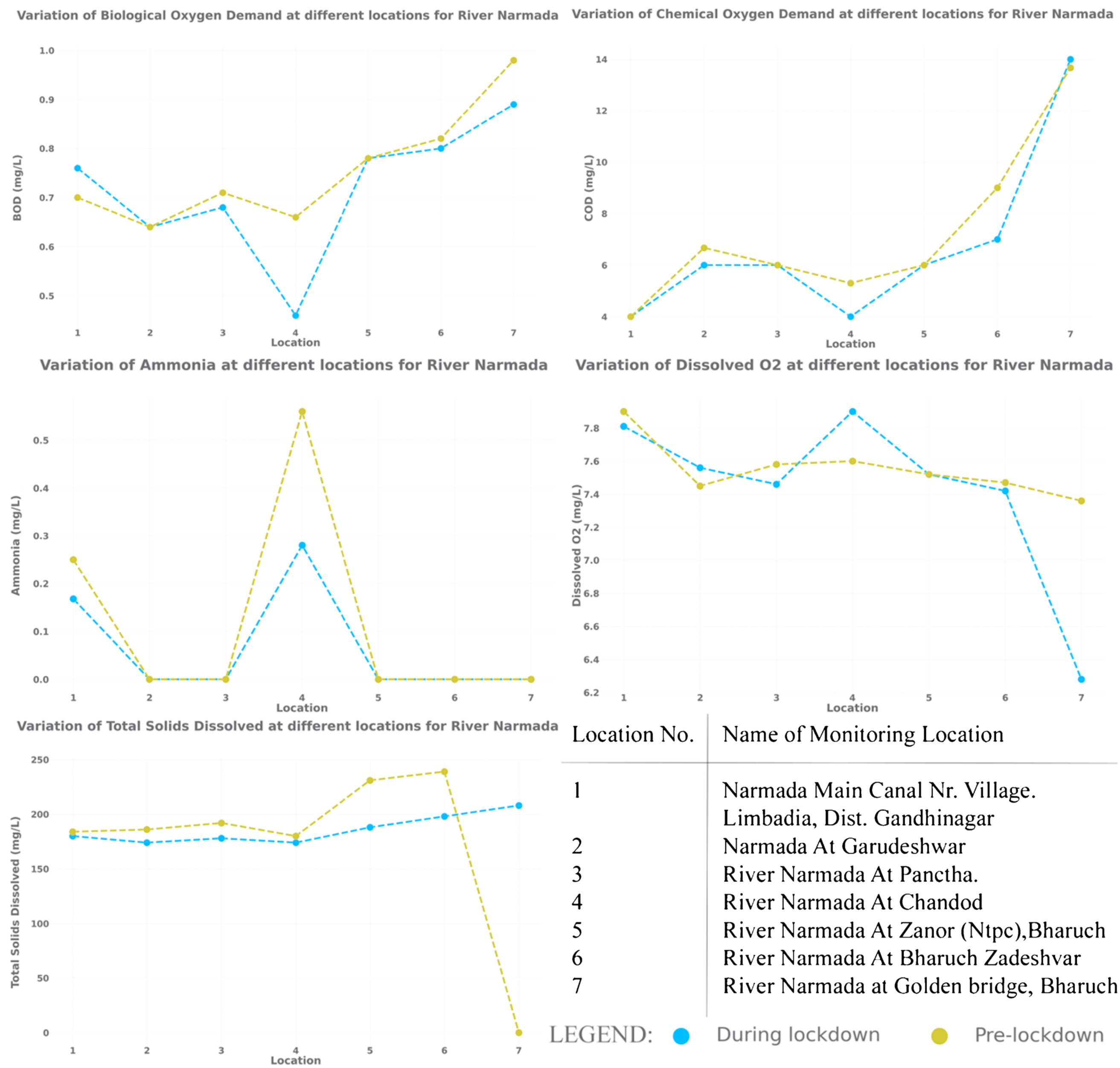


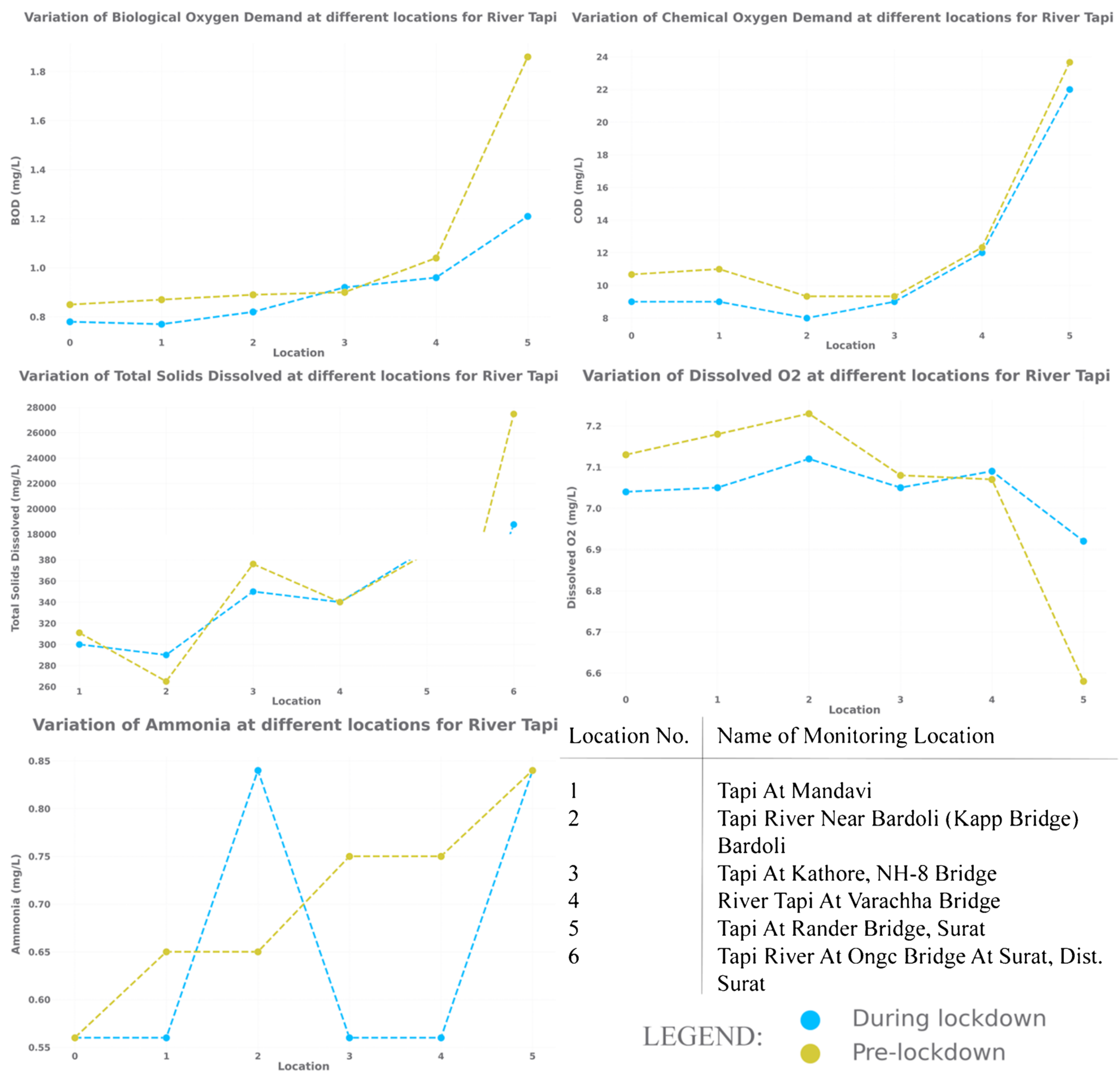
Fig. 11 Variation in different parameters of water of river Narmada during pre-lockdown and lockdown period

Most of the waterways mentioned in this paper have been seriously polluted with many hazardous chemicals from manufacturing and waste management. It has led water quality to reach the rock bottom in various parts of these rivers, and the water became inadequate for marine life and human use. The lockdown helped the rivers rebound in the near term from the envisaged demise and continued to revitalize their health. This was only possible because of the decrease of contaminants pumped into rivers from different sources due to the constraints imposed by COVID-19 lockdowns. The data used for plotting the visualization have been collected from various sources, including Gujarat Pollution Control Board[7] for rivers Narmada, Sabarmati, Tapi, and Mahi, Uttarakhand Pollution Control Board[8] for river Ganga, and Delhi Pollution Control Committee[9] for river Yamuna.

[7] https://gpcb.gujarat.gov.in/uploads/GPCB_SURFACE_WATER_QUALITY_IN_GUJARAT_DURING_COVID19_LOCKDOWN.pdf

[8] https://ueppcb.uk.gov.in/files/Water_Data_2020_2.pdf

[9] http://www.dpcc.delhigovt.nic.in/Analysis_report_RY2020.html



Location No.	Name of Monitoring Location
1	Tapi At Mandavi
2	Tapi River Near Bardoli (Kapp Bridge) Bardoli
3	Tapi At Kathore, NH-8 Bridge
4	River Tapi At Varachha Bridge
5	Tapi At Rander Bridge, Surat
6	Tapi River At Ongc Bridge At Surat, Dist. Surat

Fig. 12 Variation in different parameters of water of river Tapi during pre-lockdown and lockdown period

Reflections

The vivid practical experience of the lockdown reducing pollution levels is thought-provoking in itself. It leaves us with questionable exercises to follow—Is it an uncanny restorative act of nature? It has presented humankind with an idea to overcome the problem of pollution (Shariq et al. 2021), or at least to reduce its gravity. The pandemic and the imposed lockdown has laid down some lessons to learn and prepare for us to maintain our environmental sustainability.

In a National Geographic study[10], the author discusses how the pollution made COVID-19 more lethal and how lockdowns are clearing the air. It is also a matter of fact that pre-COVID-19 pollution has been becoming epidemic-like in India, causing severe respiratory issues and water-borne diseases. Studies also suggest that pollutants existing in the environment (air and water) can carry the novel coronavirus' genetic material presenting a grim

[10] https://www.nationalgeographic.com/science/2020/04/pollution-made-the-pandemic-worse-but-lockdowns-clean-the-sky/

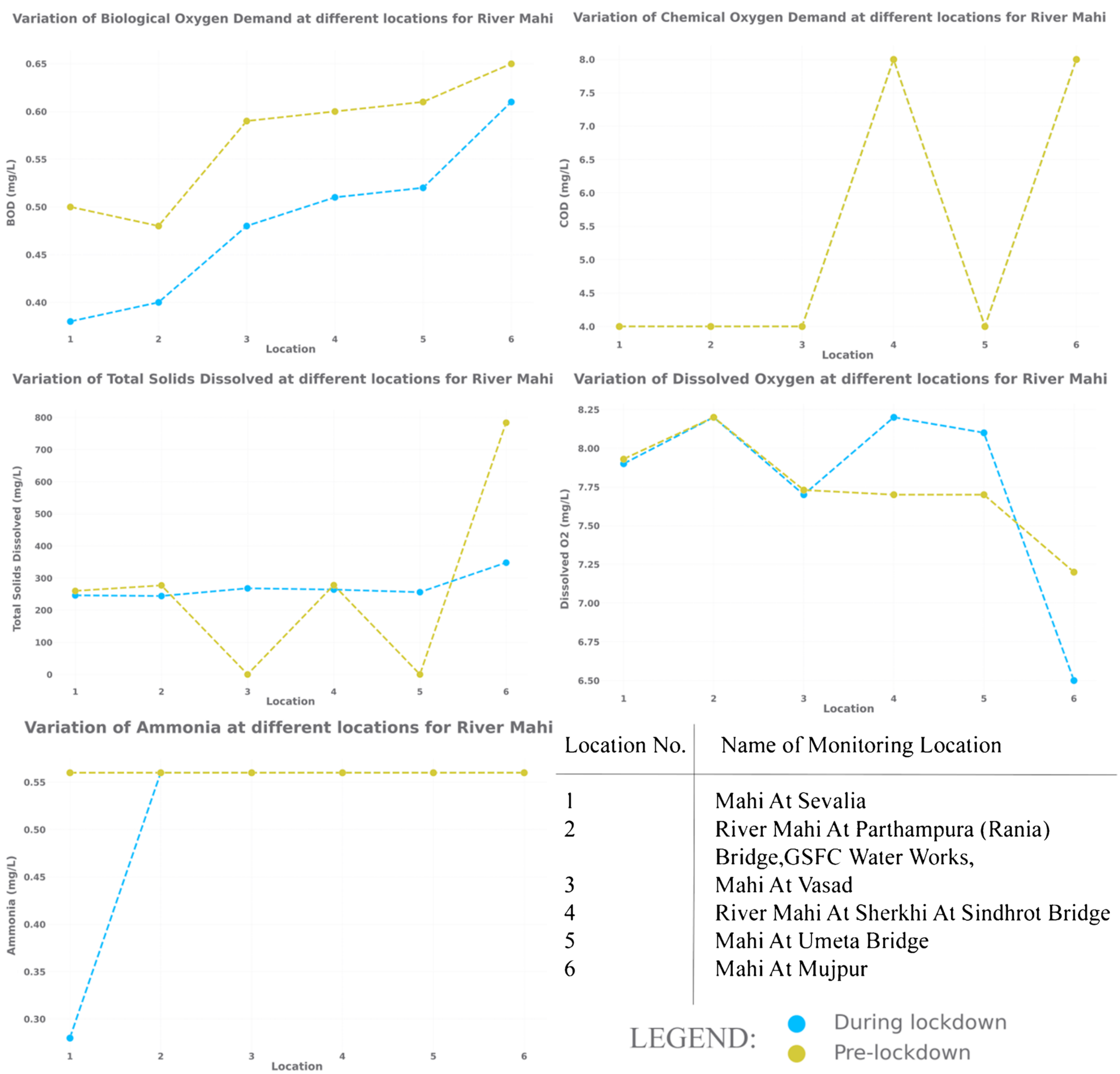


Fig. 13 Variation in different parameters of water of river Mahi during pre-lockdown and lockdown period

picture of what can be referred to as a "twindemic"[11]. Industrial waste pollution also increases susceptibility to COVID-19 and other ailments by damaging the overall health in the long-term. Nevertheless, while contaminated air inhaled and polluted water utilized in the past is still causing hurt today, the transitory experience of cleaner air and water achieved by nationwide closures may offer learning for the kind of world we want to picture after the pandemic.

[11] Kiran Pandey. "Twindemic: What we know about the link between air pollution, COVID-19". DownToEarth. Published on 9th Novemebr 2020.

Conclusion

The manuscript discussed its analysis on the research—"Are there any correlations between the periods of restriction implemented during COVID-19 and its effect on air and water quality?".

The discussions presented in this paper concluded that nevertheless the COVID-19 lockdown severely affected the global economy but also played a vital role in re-energizing the environment. This paper examines the effect of the nationwide lockdown on air and water quality specifically for Indian subcontinent via the depiction of well-suited plots and charts. Halting on industrial production as an added effect of the restrictions imposed during the lockdown has helped in reducing the emission of harmful pollutants while restoring the environment. While several industries faced complete shutdown or saw a sizable decrease in production, their effect on the environment waned, and the pollutants released into the environment declined greatly. Hence, air quality and water quality have improved significantly during this period. Levels of PM 2.5 and PM 10 have plummeted to a great extent across major cities of the country. While factors like nitrogen oxides, sulfur oxides, and carbon dioxide sank in numbers in the environment, ozone sees an increase in several cities of India. Furthermore, the water quality of various major river bodies saw a large increase in their water quality indexes. While several artificial intelligence methods are available to forecast the potential effect of the COVID-19 pandemic on emission rates and many other factors, these are currently beyond the kind of analysis presented in this paper. Nevertheless, the lockdown has certainly proved to be a blessing in disguise opening the path for future implementation of similar government policies to check air and water pollution, while also balancing the impacts on the country's economy.

Acknowledgements The authors of this paper are thankful for the data on the Index of Industrial Production made public by the Ministry of Statistics and Programme Implementation, the Government of India, and the team of the World Air Quality Index project for providing transparent and well-processed data on air quality for several cities of India. Moreover, the authors would like to extend toward Uttarakhand Pollution Control Board, Government of Uttarakhand for providing water quality data for river Ganga; Gujarat Pollution Control Board, Government of Gujarat for making available water quality data for the rivers Narmada, Sabarmati, Tapi, and Mahi; and Delhi Pollution Control Committee, Government of N.C.T Delhi for making the data for water quality of river Yamuna available.

Author contribution All authors have equally contributed toward the formation of this paper.

Declarations

Conflict of interests The authors declare no competing interests.

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