



Variations in the Yamuna River Water Quality During the COVID-19 Lockdowns

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The COVID-19 pandemic that emerged in Wuhan city of China in December 2019 has adversely impacted the health and the economy, society, and other significant spheres of the human environment. The pandemic has severely impacted economic activities, especially the industrial production, transportation, tourism, and hoteling industries. The present study analyses the impact of varying severity of lockdowns of economic activities during various phases of the pandemic on the water quality of the Yamuna river on parameters like pH values, biological oxygen demand, chemical oxygen demand, dissolved oxygen, total suspended solids, and electrical conductivity. The study has found a significant improvement in water quality parameters with closing economic activities during lockdowns. The average levels of concentration of these parameters of water quality were quite low during the lockdown period at 7.26 (pH value), 31.32, 136.07, 7.93, 30.33 mg/L, and 1500.24 μ S/cm compared to pre lockdown periods levels at 7.53 (pH), 39.62, 116.52, 6.1, 57.2 mg/L and 1743.01 μ S/cm for biological oxygen demand, chemical oxygen demand, dissolved oxygen, total suspended solids, and electrical conductivity, respectively. In addition, the study has found a strong significant positive correlation between COD with BOD and TSS during the lockdown period. The major findings from the present study could be instrumental in making environmentally sustainable policies for the country's economic development. There is also a huge scope of scaling up of the study at the national level to analyze the health of the rivers in the backdrop of lockdowns.

Keywords: COVID-19 lockdowns, water quality parameters, lockdown, yamuna river, correlation

INTRODUCTION

COVID-19 pandemic started with the detection of a novel coronavirus in Wuhan City in late December 2019 China. The pandemic has been found to have impacted every aspect of human life, health, social and economic (Arora et al., 2020; Conforti et al., 2020; Sohrabi et al., 2020; Travaglio et al., 2020; Wu et al., 2020). The World Health Organization (WHO) declared the outbreak a Public Health Emergency of International Concern on January 30 2020, named the novel Coronavirus disease COVID-19 on February 11, 2020, and finally declared it a pandemic on March 11, 2020

(Rothan and Byrareddy, 2020; WHO, 2020; Singh et al., 2021a). As of January 10, 2022, the confirmed cases of the COVID-19 pandemic have surpassed 308 million, with over 5.5 million deaths and about 260 million instances of recovery, leaving around 42 million active cases globally (Worldometers, 2021). The evolving nature of the COVID-19 pandemic due to the continuous emergence of new variants of varying severity and infectivity has multifariously complicated the economic impact estimation (Bachman, 2020; Sarkis et al., 2020).

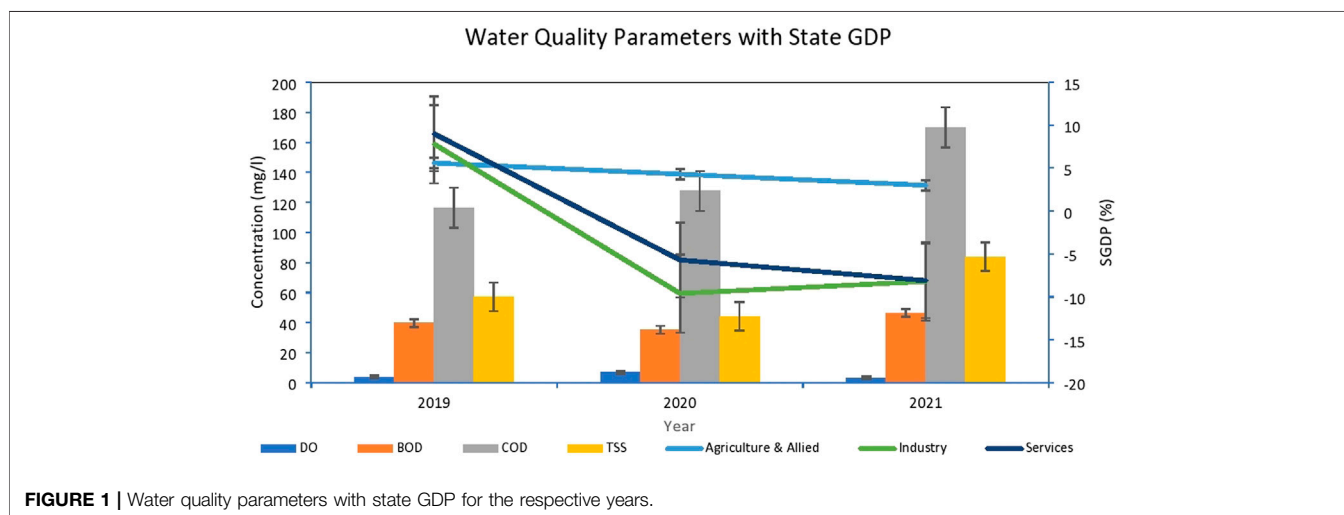
Countries across the globe have implemented nationwide lockdowns with restrictive measures, coercing people to work from home (whenever possible) and observing social distancing to avoid the unhindered escalation of the pandemic (Singh et al., 2021b). However, it must be noted that in several studies, the lockdowns which negatively impacted the economy have led to sudden revival and restoration of the physical environment and its various components like air and water (Beine et al., 2020; Huang et al., 2020; Ma et al., 2020; Bera et al., 2020; Ray et al., 2020; Sharma et al., 2020; Yongjian et al., 2020; Singh et al., 2021a; Singh and Kumar, 2021; Singh et al., 2022). In addition, several studies have attempted to estimate the economic effects of the pandemic across countries, such as Wiener Zeitung, 2020 (5–11%) for Australia, Ministry of Finance of Finland, 2020 (4%) for Finland, Rapport Cazeneuve, 2020 (2.4%) for France, (Ministry of Transport and Local Government, 2020 (1.1%) for Iceland, ANCI, 2020 (21%), respectively.

While negative effects of economic growth on the environment are well established, it is quite intriguing that even high levels of pollution can hinder economic growth and inflict catastrophic costs in terms of lives and property (Lei Ding et al., 2015). The understanding of the complex relationship between economic development and environmental degradation is further obfuscated and fragmented by disciplinary biases. Cracolici et al. (2010) claimed that only a few countries had managed to achieve simultaneous favorable environmental health and high levels of economic development. Gross Domestic Production (GDP) per capita ignores the considerations of the impact of a polluted environment on

human lives and provides a very narrow and limited measure of well-being (Hobijn and Franses 2001; Neumayer 2003; Marchante and Ortega 2006).

A report released by the World Bank indicated a significant relationship between a reduction in economic growth, losing between 0.5 and 2.0 percent of economic growth, and polluted rivers (Desbureaux et al., 2019). The relationship between economic growth and water pollution has been explored quite extensively (Grossman and Krueger, 1995; Shen, 2006; Diao, Zeng, Tam, and Tam, 2009; Lee, Chiu, and Sun, 2010; Jayanthakumaran and Liu, 2012; Choi et al., 2015). In this backdrop, the complete shutdown of economic activities under the COVID-19 pandemic has had two massive environmental impacts. First, it has dramatically improved the air and water quality and reduced our material consumption, water usage, and waste production. Second, the environment underwent a partial and limited self-revival. This phase helped me better understand the magnitude of the contribution of even the non-industrial sources of pollution to the environment, especially water and air (Singh et al., 2014; Singh et al., 2016; Hader et al., 2020; Singh et al., 2021b,c). The improvement in the river water quality has been reported worldwide, including in India (Dhar et al., 2020; Mitra et al., 2020).

Recent studies claimed that the water quality and quantity in many rivers have consequently improved in a short span of time during the lockdown period, especially in river Ganga, India, 2020 (Dutta et al., 2020; Shukla et al., 2021). Similar to river water quality, domestic and non-domestic water sectors were also affected across the major economic sectors during the COVID-19 (Cooley et al., 2020; Balamurugan et al., 2021). However, few studies reported a variation in demand for domestic and non-domestic water consumption during the COVID-19 (Daijiworld, 2020; Sivakumar, 2021). A report released by the World Bank indicated a significant relationship between a reduction in economic growth, losing between 0.5 and 2.0 percent of economic growth, and polluted rivers (Desbureaux et al., 2019). However, a study conducted in Pakistan revealed that the use of technology and renewable energy may help boost economic development and reduce environmental pollution



(Abid et al., 2020). Furthermore, technology indicated a significant positive association between green growth, and ISO 14001 (Abid et al., 2021).

Improved water quality has been reported on beaches of Bangladesh, Maldives, Malaysia, Indonesia, and Thailand (Kundu, 2020; Rahman et al., 2020) mainly due to a significant reduction in pollution load from major sources of water pollution in the rivers, such as industrial water waste disposal, crude oil, heavy metals, and plastic during the lockdown period (Ghildyal et al., 2020; Hader et al., 2020; Manuel and Zambrano, 2020). The pH level and values of electric conductivity (EC), Biological oxygen demand (BOD), and chemical oxygen demand (COD) have been reported to have declined by about 1–10%, 33–66%, 45–90%, and 33–82% across monitoring stations in the world during the lockdown period as compared to pre lockdown period (Cripps, 2020; Zambrano-Monserrate et al., 2020). Cooper (2020) conducted a study on the textile sector around the globe and reported that the total industrial water consumption massively declined during the lockdown period. A similar finding was reported in the case of the river Ganges, a highly polluted river in India, which witnessed a drastic reduction in pollutant load during the lockdown period (Mani, 2020). Despite the showing an improvement in water quality parameters in COVID-19, few studies claimed that environmental pollution load reported an increase in water bodies which were attributed to pharmaceuticals and plastic pollution (Gwenzi et al., 2022).

It is pertinent to study the effects of the COVID-19 lockdowns on the water quality of rivers in the short and long terms. The Yamuna River in National Capital Region is considered one of the most polluted rivers in India and the world due to the rapid increase in industrialization, urbanization, and high-density population growth (Upadhyay et al., 2011; Sharma et al., 2020). Due to very high levels of water pollution in this river, it is interesting to study the impact of lockdowns on the water quality of this river which passes through the northern industrial region of India. In the present study, the concentrations of pH, EC, DO, BOD, SS, and COD have been measured at monitoring sites on the bank of the Yamuna river. The water quality parameters were compared between the pre lockdown (previous year), during the lockdown, and post lockdown period. The study is unique as similar studies on the interaction of economic activities and water pollution in the catchment of the Yamuna river are lacking. The present investigation focuses mainly on evaluating the relationship between economic activities and water quality parameters during the COVID-19 pandemic on the upper stream of the Yamuna river in Haryana.

2 MATERIALS AND METHODS

2.1 Study Area

The Yamuna river is the major tributary of the Ganga river. It is also considered a sacred river in India. It originates from the Yamunotri glacier near Bandar Punch (38°59'N 78°27'E) in the Mussoorie (lower range of the Himalayas) at an elevation of about 6,387 m above mean sea level (MSL) in the Uttarkashi district (Sharma and Kansal, 2011). The Yamuna River has a vast catchment area of 366,223 km². The Yamuna enters Haryana

near the Kalesar forest in the district of Yamuna Nagar and flows through the districts of Karnal, Panipat, Sonapat, and Faridabad before it enters the National Capital Region of Delhi. The major contributory industries to the water pollution in the Yamuna river are pulp and paper, sugar, tannery, steel plant distillers, textiles, leather, rubber, chemicals, glass, pharmaceuticals, and oil refineries, food, and discharge of polluted water from thermal power plants. The current study focuses on the analysis of water quality parameters of the Yamuna river in the state of Haryana only.

2.1.1 Conceptual Framework of the Water Quality Index

Water quality assessments gauge has categories in different categories according to suitability for a specific purpose (bathing, industrial or domestic purposes) which is adversely affected by any pollutants within it (Bagchi and Bussa, 2011). Several studies have developed methods for measuring water quality (Tyagi et al., 2013). The different measured variables are standardized and converted into a composite number that best denotes the suitability of the use of a particular water sample (Kumar and Dua, 2009). In addition, various agencies such as European Community, World Health Organization, Central Pollution Control Board (CPCB), and Indian Standard Specifications for drinking water have formulated their own respective standards regarding the permissible limits of measured parameters for rating a sample as different categories for specific use (Sargaonkar and Deshpande, 2003; Bharti and Katyal, 2011; Rout, 2017).

2.2 Data Collection

The variations in the water quality of the Yamuna river have been analyzed for the pre-lockdown, lockdown, and post-lockdown periods. The study has used secondary data due to lockdown-related restrictions. The data was directly procured from the “Haryana Pollution Control Board” department from November 1, 2019, to January 10, 2021 (<https://hspcb.gov.in/yamuna>). The pandemic duration has been classified into three periods: pre lockdown, during the lockdown, and post lockdown.

The data for water quality was obtained between November 1, 2019, to March 23, 2020, which was referred to as the “pre-lockdown period” while the time between March 25 to May 31, 2020, was referred to as the “during lockdown”, and the “post-lockdown” period refers to the time between June 1, 2020, to January 10, 2021. In the present study water quality data for the corresponding year, 2019 were compared with the years, 2020 and 2021. Water quality data has been procured from 13 different monitoring stations in Haryana state namely Gharaunda Drain before the meeting (Village Ali Asgarpur), Gharaunda Drain after the meeting (Village Ali Asgarpur), Drain No. 2 before meeting Panipat drain (near village Dadola), Panipat Drain (Village Sewah), Drain No.2 after meeting discharge of Panipat drain (village Simla, Gujran), Drain No. 2 after meeting Gharanunda drain at G.T. Road (Panipat), River Yamuna before meeting (Village Sanjoli), river Yamuna (village Khojkipur), Nohra

TABLE 1 | A comparative study of variation of environmental water quality parameters in different cities across the world during the pandemic.

Study area	River	Study period	Key findings	Reference
Haryana (India)	Yamuna	Nov 2019-January 2021	the average water quality concentration was 7.26 (pH value), 31.32, 136.07, 7.93, 30.33 mg/L, and 1500.24 μ S/cm for BOD, COD, DO, TSS, and EC during the lockdown periods, respectively.	Present Study
Uttarakhand, Uttar Pradesh (India)	Ganga	25 March–14 April 2020	the temporal change study showed that reflectance in each visible NIR region has reduced, which might be attributed to a reduction in turbidity in the water of the river.	Garg et al. (2020)
Tamil Nadu (India)	Tuticorin	25 th March to 30 May 2020	The significant reductions (>50%) in metals were noticed probably owing to trick wastewater discharge from metal base industries, seafood- base industries, and thermal power plants during the lockdown period.	Selvam et al. (2020)
Tamil Nadu (India)	Kosasthalaiyar, Cooum, and Adyar	-	SPM concentration decreased by 15.48 and 37.50% in the Chennai and Ennore ports, respectively, due to minimal vessel movement and cargo handling concentration decreased by 15.48 and 37.50% in the Chennai and Ennore ports, due to minimal vessel movement and cargo handling	Vijay Prakash et al. (2021)
Lucknow, Uttar Pradesh (India)	Gomati	January -July 2020	The DO levels fell across ~69% and ~88% of the sites during the lockdown and post-lockdown periods, respectively. Moreover, there was an increase in the BOD5 levels across ~69% and 75% of the sites during the lockdown and post-lockdown periods, respectively	Khan et al. (2021)
Lucknow, Uttar Pradesh (India)	Gomati	June 2020	The concentration of all the six heavy metals (As, Cd, Cr, Fe, Mn, and Pb) clearly shows a significant reduction, highlighting the impact of the closure of agricultural, industrial, and commercial activities.	Khan et al. (2021)
Uttar Pradesh (India)	Ganga	January–May 2020	An increase in the dissolved oxygen (DO) by about 23% from 6.5 to 8ppm in 2019 and 2020, respectively, during the same period of lockdown, along with a decrease of about 25% in biological oxygen demand (BOD) from 4 to 3 ppm, during the same periods, respectively	Lokhandwala & Gautam
Uttarakhand, Uttar Pradesh, West Bengal (India)	Ganga	March–May 2020	A 55% decline in turbidity at that site during the lockdown was attributed to the abrupt halt in pilgrimage activities.	Muduli et al. (2021)
Kerala (India)	Vembanad Lake	January March 2020	A decrease of about 15.9% in suspended particulate matter (SPM) due to the COVID-19 lockdown	Yunus et al. (2020)
Ahmedabad (India)	Sabarmati River	February–May 2020	the average SPM has significantly decreased by about 36.48% when compared with the pre-lockdown period, and a drop of 16.79% was observed from the previous year's average SPM	Aman et al. (2020)
Hyderabad (India)	Lake Hussain Sagar	March and April for the years 2015–2020	The results show notable changes in SR values and FUJ due to lockdown compared to before lockdown and after unlock, suggesting a significant reduction in lake water pollution. In addition, the historical variations within April indicate that the pollution levels are least in the year 2020.	Wagh et al. (2020)
Delhi (India)	Yamuna	January–April 2020	The water quality index indicated an improvement of 37% during the lockdown period. However, compared to the pre-lockdown period, the BOD and COD values declined by over 40.83 and 39.25%.	Patel et al. (2020)
Nepal	Bagmati		Compared to the pre-lockdown, the level of DO was increased by 1.5 times, whereas the BOD and COD were decreased by 1.5 and 1.9 times, respectively, during the post-lockdown, indicating the improvement of the quality of water.	Pant et al. (2021)

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TABLE 1 | (Continued) A comparative study of variation of environmental water quality parameters in different cities across the world during the pandemic.

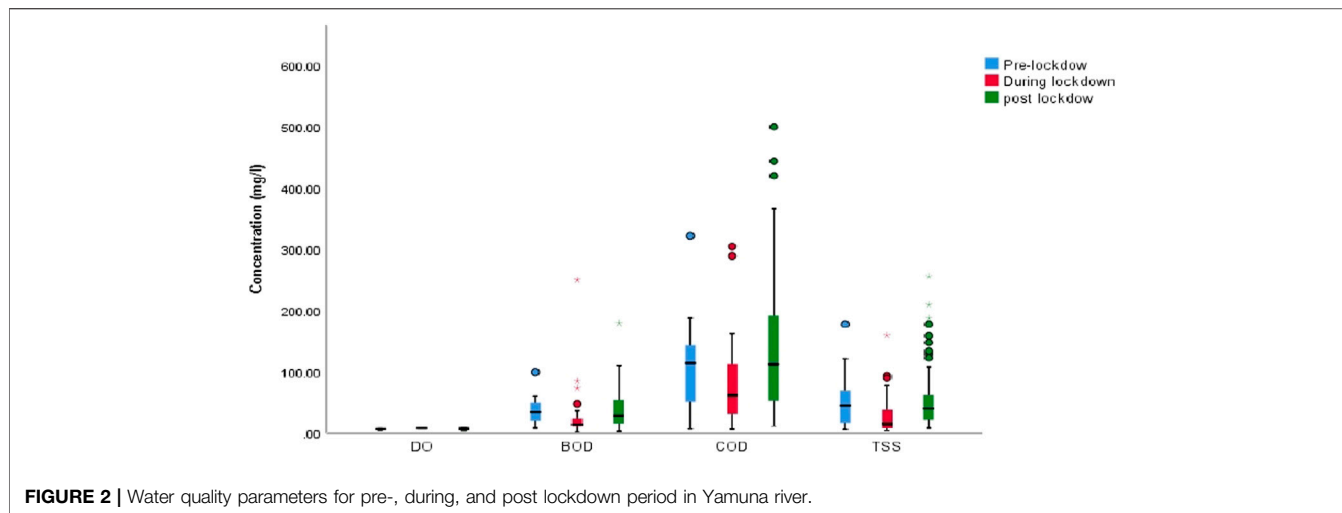
Study area	River	Study period	Key findings	Reference
Malaysia	Putrajaya Lake	February–March 2020	there is a significant increase in the WQI Class I, from 24% in February 2020 to 94% during the month of March 2020.	Najah et al. (2021)
Italy	Venice lagoon	January–February 2020	The retrievals of TSM imply a remarkable reduction of the turbidity during the lockdown due to the COVID-19 pandemic and capture the high values of TSM during the flood condition.	Niroumand-Jadidi et al. (2020)
Southern Jiangsu (China)	Beijing-Hangzhou Grand Canal	January–April 2020	The water quality parameters and intensities of fluorescent components decreased to a low level due to the collective shutdown of all industries during the pandemic.	Shen et al. (2021)
Landon	Thames	-	The tributaries to the River Thames are more vulnerable than the Thames themselves to potential changes that may have occurred under the COVID-19 anti-contagion measures, highlighting rivers' critical role in diluting effluent.	Dobson et al. (2021)
Northwest Turkey (Turkey)	Meric-Ergene River basin	January to June 2020	The heavy metal pollution index and heavy metal evaluation index values indicated a significant improvement in the water quality of almost all the stations during the lockdown period. Also, hazard index values for children and adults were reduced by 60 and 94%, respectively.	Tokatli and Varola, (2021)
Morocco	Bokhalef River		The improved water quality at the discharge mouth into the Atlantic Ocean to be significantly improved mainly due to the COVID-19 lockdown, and hence cease of industrial activities, increasing the quality class from class D onward up to class A.	Cherif et al. (2020)
China	Groundwater		Drainage channel number-1 results showed that E. coli (positive), coliform count (22.75–48.66 /100 ml), and BOD (8–25.75 mg/L) remained above the permissible limit of the World Health Organization (WHO). Besides, drainage channel number 2 results exposed that E. coli (positive), coliform count (17.7–47 /100 ml), and BOD (6.25–21.5 mg/ L) were not within the permissible limit of WHO.	Hou et al. (2021)

Drain (Village Kakoda), NWMP station (Delhi Parallel Branch), NWMP station (Village Khojkipur) River Yamuna. Data for water quality parameters have been obtained from thirteen representatives for each monitoring station.

The present study analyzed the data ($n = 113$) for 15 water quality monitoring stations in Haryana to evaluate the variability in the concentration levels of water quality parameters during the pandemic period. The parameters used for this research are pH value, dissolved oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solid (TSS), and Electrical Conductivity (EC). According to the Bureau of Indian Standard (IS 2296:1992), recommended by CPCB (Central Pollution Control Board), a table was made depicting the quality of surface water (**Supplementary Table S1**). Haryana's economic activities data were taken from Economic Survey, Haryana, 2020.

2.3 Statistical Data Analysis

To understand the changes in the individual water parameters between the pre- lockdown, during the lockdown, and post lockdown periods, statistical analysis was performed using the hypothesis testing (t-test) tool from SPSS version 26.0 (SPSS Inc., Chicago, IL, United States). Using MS-Excel Statistical attributes, trend analysis and box-whisker plots were computed and visualized (Kumar et al., 2014; Kumar et al., 2015). The Decimal Point Normalization (also sometimes referred to as the Floating-Point Number) technique is among the most frequently used normalization techniques (Nardo et al., 2009) and was employed to rank the drains during the pre-lockdown and lockdown periods based on the resulting additive aggregation (arithmetic mean) scores (Tate, 2012). In this normalization method, the maximum number of decimal points to be moved is dependent on the maximum values of the attribute data (Han et al., 2011; Punia et al., 2015), and the data attributes are transformed by simply moving the decimal points of the original data (Kumar et al., 2014a).



3 RESULTS AND DISCUSSION

3.1 Relationship Between Economic Growth and Water Quality

The economic impact of the COVID-19 is supposed to vary across the countries depending upon the structural strengths of individual economies, although all the countries would face an economic decline. In the current study, Haryana’s Gross State Value Added (GSVA), a state of India, grew at 8.0% in 2019–20, whereas it declined by 5.2% for 2020–21 (Government of Haryana, 2021). The decline was main contributed by a major decline in GVA of the Industrial Sector (−9.6%) and the Services Sector (−5.7%) for the year 2020–21 (Supplementary Table S1).

On the other hand, the water quality parameters such as TSS, BOD, and COD have been observed to have improved in the year 2020 during the lockdown period compared to the corresponding period in 2019 (Figure 1). This improvement in the water quality parameters of the Yamuna river can be partly attributed to the reduction in the discharge of industrial effluent during the lockdown period. It can be highlighted here that the discharge from industries was the primary source of pollution in the Yamuna river water as compared to other sources like domestic and agricultural activities. Post lockdown, the water quality of the Yamuna river was observed to have again declined with the resumption of industrial and other environmentally harmful activities. A comparative studies Table 1 has been presented for the relationship between economic growth and

water quality parameters during the pandemic period across the world.

3.2 Water Quality in the Pre-, During, and Post Lockdown Periods

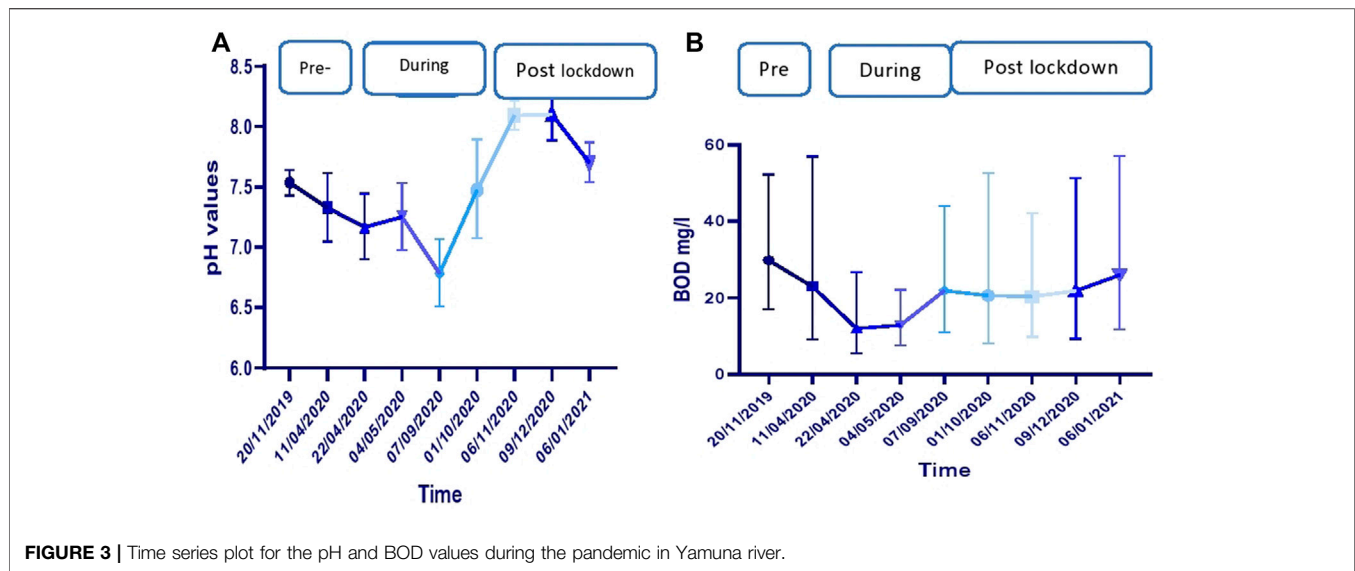
In developing countries like India, water pollution is a common phenomenon where industrial and domestic wastes are dumped directly into the rivers without proper treatment (Yunnus et al., 2020). As a result, India’s water bodies, especially the Yamuna river, have poor water quality. Moreover, most rivers and streams flowing by the major industrial sites have turned into sewer canals, making their rejuvenation and treatment very difficult. In this study, we have also evaluated the varying impacts of different phases of the lockdowns, pre-lockdown, during, and post lockdowns on the water quality of the Yamuna river. (Figure 2). The minimum, maximum, and mean values of Physico-chemical variables examined in this study are shown in Table 2. It can be mentioned here that several studies have underlined the positive impact of the lockdowns on river water qualities in many rivers for a relatively short period of few months, especially in the Ganga and the Yamuna rivers (Jain, 2015; Dutta et al., 2020; Singhal and Matto, 2020; Somani et al., 2020; Shukla et al., 2021).

3.3 Yamuna River’s pH Level

The average values of pH of the Yamuna river water were found to be 7.53, 7.26, and 7.64 for pre-lockdown, during the lockdown,

TABLE 2 | Mean, maximum and minimum values of water quality variables determined in the pre-lockdown, during the lockdown, and post-lockdown periods.

Parameter	Pre-lockdown			During-lockdown			Post-lockdown		
	average	max	min	average	max	min	average	max	min
pH	7.53	7.77	7.27	7.26	7.80	6.59	7.64	7.80	6.59
TSS	57.2	178.00	6.00	30.33	160.00	5.00	60.40	256.00	8.00
BOD	39.62	100.00	8.00	31.32	250.00	1.30	40.50	180.00	2.80
COD	116.52	322.00	6.80	136.07	784.00	6.40	148.69	724.00	8.80
Conductivity	1743.01	3310.00	8.10	1500.24	3020.00	7.10	1467.39	3290.00	7.20



and post-lockdown periods, respectively. The maximum pH values were reported to be 7.77, 7.80, and 7.81 during these three time periods (**Figure 3A**). Moreover, the pH values for all the monitoring stations were the lowest during the lockdown period. The pH values of the Yamuna river water were observed to be alkaline in nature which varied between 7.2 and 7.8 from the pre- to post-lockdown period. In the post-lockdown period, the increase in pH values was probably due to an increase in the inflow of organic waste products from the resumption of anthropogenic activities. The highest pH value (8.33) among the monitoring stations was observed at drain No. 2 at village sanjoli and the lowest (6.44) at village Khojkipur during the lockdown period. The present study indicated that the values of pH were correlated with primary water quality criteria for bathing water and designated usable water quality (https://cpcb.nic.in/wqm/Primary_Water_Quality_Criteria.pdf). During the lockdown period, the pH values were observed lower than the threshold limit (6.5–8.5) at all the monitoring stations across the designated stretch of the Yamuna river. Therefore, an alkaline pH was observed during the lockdown period. According to Yashvardhini et al. (2020), an alkaline pH indicates that industrial wastes are composed of various components which could promote acidity.

3.4 Yamuna River's Biological Oxygen Demand Level

Biological Oxygen demand (COD) indicates the amount of dissolved organic matter and is an indicator of water pollution. The present study has found a drastic decline in BOD values during the lockdown period compared to pre-lockdown and post-lockdown periods. The mean values of BOD were found to be 39.62, 30.33, and 40.50 mg/L for pre-, during, and post lockdown periods, respectively (**Figure 3B**). Furthermore, reduction in the BOD levels during the lockdown period was reported by Dutta et al. (2020).

One of the significant factors behind the decline in BOD levels in the Yamuna river water is the closure of industries during the lockdown period. Another study on the Yamuna River water quality reported that the average BOD values increased by 7.09% during the same period and indicated quite a significant impact of domestic sewage load on the BOD levels in the river water. Khan et al. (2021) have also reported an increase in the average values of BOD by 19.44% in the post lockdown period. The findings of the present study indicate that values of BOD declined by 30.32% during the lockdown and increased by 39.5% during the post lockdown period, as also reported by Khan et al. (2021).

Moreover, another study conducted on the Ganges River water quality indicated a reduction of BOD values by 35–40% during the lockdown period due to the closure of automobile workshops, floating population, saree dyeing units, reduction in cremation, closure of hotels, and restaurants, and check on dumping of solid wastes into the river water. Besides, due to the shutdown of lift canals, the flow of the river water also surged (Time of India, 2020). Chauhan et al. (2020) reported that before the lockdown, the BOD ranged between 1.24 mg/L to 5.56 mg/L, whereas during the lockdown period, it ranged between 1.05 mg/L to 4.32 mg/L in the surface waters (river and canal) of Rajasthan. A similar result was reported in another study where BOD levels declined by 9.46, 24.25, and 5.59% in the Gomti, the Hindan, and the Ganges rivers, respectively (Ghildyal et al., 2020).

3.5 Yamuna River's Chemical Oxygen Demand Level

Chemical Oxygen demand (COD) indicates the amount of dissolved susceptible matter and is an indicator of water pollution. The major sources of COD are industries and wastewater treatment plants which were halted during the lockdown period. An increase in the level of COD severely affects dissolved oxygen, which adversely affects aquatic life (Yashvardhini et al., 2020). The present study has found the

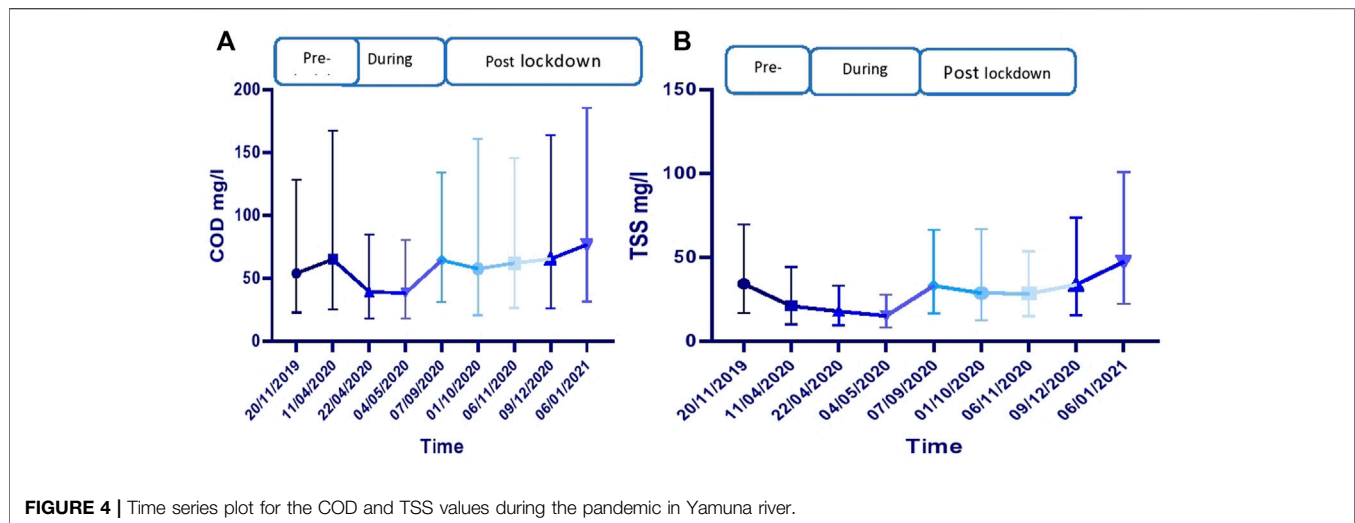


FIGURE 4 | Time series plot for the COD and TSS values during the pandemic in Yamuna river.

average values of COD to be 116.52, 136.07, and 148.69 mg/L, for pre-lockdown, during the lockdown, and post-lockdown periods, respectively. Similar results were reported by Yashvardhini et al. (2020). The maximum values of COD were 322.00, 784.00, and 724.00 mg/L for the pre-lockdown, during the lockdown, and post-lockdown periods respectively in the upper stream of Yamuna river (Figure 4A).

COD concentration declined during the lockdown period compared to pre- and post-lockdown periods. The high values of COD could be because of the rise of discharge of the untreated and moderately treated wastewater from the municipal sewage and a slower speed of dissolution in the pre-lockdown and post-lockdown periods. A study, conducted on the Ganges River during the pre-lockdown period reported the values of COD in the range between 6.14 and 17.7 mg/L, which was much lower than the current study (Dutta et al., 2020). The low levels of COD in the Ganges river indicated a complete stoppage in the flow of industrial pollutants owing to the complete lockdown, which significantly increased the water quality during the lockdown period. As a result of a halt in industrial activities and stoppage of discharge of pollutants and polluted water in the river, the Yamuna River's water quality has significantly improved during the lockdown period (Times of India, 2022). A study in Rajasthan indicated a general decrease in COD between 7.0 and 41.0 mg/L during the lockdown period in rivers and canals of the state (Chauhan et al., 2020). Another study conducted on COD levels in the Yamuna river water reported that the COD levels declined by 24% during the lockdown period (Ghildyal et al., 2020).

3.6 Yamuna River's Dissolved Oxygen Level

Dissolved oxygen (DO) indicates oxygen availability in the water, which is opposite to biological oxygen demand (BOD). The higher value of DO refers to better water quality which is necessary for water bodies in order to sustain aquatic life. The average concentrations of DO in the Yamuna river water were observed to be 6.1, 7.93, and 6.12 mg/L for pre-lockdown, during the lockdown, and post-lockdown periods, respectively. The

maximum values were found to be 7.4, 8.4, 9.0 mg/L, whereas the minimum was 4.3, 7.1, 3.6 mg/L for the same periods. Similar values were reported in another study during the lockdown phase from 0 to 8.1 mg/l with a mean value of 3.2 mg/L (Yashvardhini et al., 2020). The drastic improvement in DO values during the lockdown period indicated a significant reduction in the effluent from the industrial and agricultural activities, accounting for the rejuvenation of the DO levels during the same period.

A study conducted in the Damodar river reported the DO levels in the range of 4.2–5.67 mg/L with an average value of 4.85 ± 0.49 mg/L for the pre-lockdown period, and 6.15–815 mg/L with an average value of 7.31 ± 0.59 mg/L for the during lockdown period (Chakraborty et al., 2021). Several studies reported a drastic improvement in DO levels in river waters and thus improved water quality of the Yamuna River during the lockdown period where the values of dissolved oxygen (DO) were found to be in a range from 2.3 to 4.8 mg/L, which can be considered significant as compared to the previous year, 2019 (CPCB 2020; UPPCB 2020; Khan et al., 2021). A study conducted in the Ganga River reported a slight decrease in DO levels at all the monitoring sites in contrast to the present study, due to a significant increase in the turbidity and suspended solids which were contributed by heavy rain spells (60%) during the lockdown period (Dutta et al., 2020).

3.7 Total Suspended Solid Level in Yamuna River

The present study has found the average value of TSS to be 57.2, 30.33, and 60.40 mg/L for the pre-lockdown, the during the lockdown, and post-lockdown periods, respectively. The values of TSS varied from 6.0 to 178.0, 5.0 to 160.0, and 8.0–256.0 mg/L during these three time periods, respectively (Figure 4B). In the Damodar river, India, a study reported TDS values ranging from 665.6 to 806.4 mg/L and 480–563.2 mg/L for three comparable time periods (Chakraborty et al., 2021). TSS results indicated a sharp decline of 29.33% during the lockdown compared to the pre-lockdown period. A similar result was reported in the Ganga

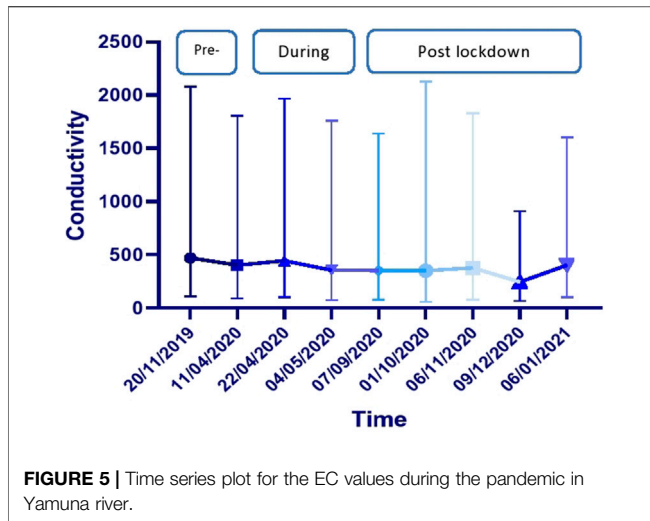


FIGURE 5 | Time series plot for the EC values during the pandemic in Yamuna river.

River where the TSS declined by 33.89% during the same period due to a decrease in industrial waste dumping (Ghildyal et al., 2020). However, the TSS value increased by 59.40% in the post-lockdown period compared to the lockdown period due to the opening of industrial and commercial activities.

3.8 Yamuna River's Electrical Conductivity Level

The average values of electrical conductivity of the Yamuna river water were detected to be 1743.01, 1500.24, and 1467.39 $\mu\text{S}/\text{cm}$ for the pre-lockdown, the during the lockdown, and the post lockdown periods, respectively. The electrical conductivity levels in the Yamuna river water varied from 8.10 to 3310.0, 7.10 to 3020.0, and 7.20 to 3290.0 $\mu\text{S}/\text{cm}$ for the pre-, during, and post-lockdown periods respectively (Figure 5). The values of EC in the Damodar river, India, were reported to be much lower than the present results, ranging from 1040 to 1260 $\mu\text{S}/\text{cm}$ and 750 to 880 $\mu\text{S}/\text{cm}$ for the during and post-lockdown periods, respectively (Chakraborty et al., 2021). In a study conducted in the rivers and canals of Rajasthan state, the electrical conductivity values ranged between 300 and 2100 $\mu\text{mho}/\text{cm}$ and 230 to 1250 $\mu\text{mho}/\text{cm}$ for the pre-lockdown and the post-lockdown periods, respectively (Chauhan et al., 2020). During the lockdown and the post-lockdown phase, the electrical conductivity has been observed to decline due to the reduction in industrial effluents' discharge into the river water. Furthermore, a decline in the electrical conductivity values implied a significant shutdown of industrial activities, which lowered the discharge rate of industrial effluents into the Yamuna River during the lockdown. In the pre-lockdown period, the higher electrical conductivity value in the pre-lockdown indicated a higher presence of chloride, phosphate, and nitrate emanating from the sewage systems flowing into the Yamuna River.

3.9 Hypothesis Testing (t-test)

We performed hypothesis testing (t-test) to understand any changes in the individual water quality parameters between the pre-lockdown and during lockdown periods. The results indicated that the t value

was more significant than the alpha value at a 0.05% significance level. It suggested a significant reduction in concentrations of water quality parameters, thus rejecting the null hypothesis. Results indicated improved water quality during the lockdown period, which can be partly attributed to a significant closure of industries in the study area. Similar results were reported in the Damodar river during the same time periods (Chakraborty et al., 2021).

Table 3 depicted the correlation between the water quality parameters for the Yamuna river in the pre-lockdown, during the lockdown, and post-lockdown periods. A strong significant positive correlation between electrical conductivity and COD and TSS with COD was found, whereas a moderate correlation was observed between DO and COD and electrical conductivity for pre lockdown period. A strong significant positive correlation was observed between COD with BOD and TSS during the lockdown period, whereas moderate conductivity with pH, DO, BOD, COD, and TSS. A strong positive correlation was found between COD with BOD and conductivity, whereas moderate was shown between TSS with BOD and COD for the post lockdown period.

4 SUGGESTIONS AND RECOMMENDATIONS

The governments, both the Central and the State governments, have taken many steps to control pollution in the Yamuna river, for instance, the Yamuna Action Plan (YAP), whose first and second phases started in 1993 and 2004 with a total expenditure of Rs.682 crore and Rs.666.76 crore respectively. Building upon

TABLE 3 | Correlation coefficient matrix of Physico-chemical parameters for Yamuna River (Bold values indicate the strong correlation).

Pre-lockdown period						
	pH	DO	BOD	COD	TSS	Conductivity
pH	1					
DO	-0.18	1.00				
BOD	0.06	-0.14	1.00			
COD	-0.16	-0.48	0.01	1.00		
TSS	0.11	-0.53	0.04	0.73	1.00	
Conductivity	-0.16	-0.48	0.01	1.00	0.73	1.00
During Lockdown Period						
	pH	DO	BOD	COD	TSS	Conductivity
pH	1.00					
DO	0.09	1.00				
BOD	-0.64	-0.44	1.00			
COD	-0.67	-0.60	0.76	1.00		
TSS	-0.35	-0.72	0.59	0.85	1.00	
Conductivity	-0.61	-0.62	0.44	0.71	0.71	1.00
Post Lockdown Period						
	pH	DO	BOD	COD	TSS	Conductivity
pH	1.00					
DO	-0.04	1.00				
BOD	-0.11	0.37	1.00			
COD	-0.11	0.37	1.00	1.00		
TSS	-0.11	-0.10	0.69	0.69	1.00	
Conductivity	-0.18	0.36	0.78	0.78	0.65	1.00

the success and lessons learned from YAP-1 and YAP-2, the Government of India has launched Yamuna Action Plan-3 (YAP-3) at an estimated cost of Rs 1656 crore with the assistance of Japan International Cooperation Assistance (JICA). From a policy point of view, the current study suggests that more efforts are required to improve the water quality of the Yamuna river. Some of the recommendations emerging from the current study are:

- Implementation of Growth Pole Strategies of economic development where decentralization of economic activities is advocated in a more emphatic manner.
- Close-knit collaboration with multiple stakeholders, where the industrial pollution from public sector enterprises must be minimized and shared with other stakeholders as industry best practices towards sustainable industrial development.
- Improvements of current sewage treatment plants (STPs), including automated river water quality monitoring.
- Formulation and strict implementation of regulations and laws to contain water pollution. Incentivizing the industries to use high-quality equipment resulting inefficient use of resources and reducing water pollution discharge.

Despite showing a strong correlation between the variation of water quality parameters and certain economic activities during the COVID-19 in Yamuna River, the current study has the following limitations. First, the current study only accounts for certain water quality parameters where data variability can be accurately measured. We do not account for other parameters such as metals loads and socio-economic indicators; future studies can research in this direction. Secondly, the inclusion of economic data for other sectors along the Yamuna river would provide more precise results and an interesting research contribution. However, we need to strengthen the real-time monitoring of water quality data for the river to accurately estimate the improvements or reduction in river water quality monitoring across all the rivers during and after any consequential events.

5 CONCLUSION

The impacts of the COVID-19 lockdown on the water quality parameters in the Yamuna river have been analyzed in the current study. The data on water quality parameters such as pH, BOD, COD, TSS, and EC were obtained from the Haryana Pollution Control Board between November 1 2019 to January 10 2021, and economic data were used from the economic survey of Haryana, 2019–2021. Overall, the discussion highlighted the dramatic effects of COVID-19 lockdown on economic activities and water quality parameters, such as 1) a significant improvement in water quality parameters in the Yamuna river due to COVID-19 lockdown that prevented the discharge of industrial effluent in the river, 2) a change in water demand and supply patterns in industrial and commercial sections, and 3) a disruption in agricultural activities near the Yamuna river bank which changed the agricultural water usage pattern.

The water quality parameters such as TSS, BOD, and COD witnessed a significant improvement during lockdown compared to the corresponding time period in 2019. This improvement in the water quality parameters of the Yamuna river was mainly due to a reduction in the effluent discharge into the river water as a result of the sudden lockdown.

Furthermore, the average concentrations of water quality parameters were 7.26 (pH value), 31.32, 136.07, 7.93, 30.33 mg/L, and 1500.24 $\mu\text{S}/\text{cm}$ during the lockdown period, as compared to pre lockdown period values of 7.53 (pH), 39.62, 116.52, 6.1, 57.2 mg/L and 1743.01 $\mu\text{S}/\text{cm}$ for BOD, COD, DO, TSS, and EC respectively. This indicated a drastic improvement and rejuvenation of the water quality of the Yamuna river due to restrictions in industrial, commercial, agricultural, and other anthropogenic activities near the Yamuna river bank.

The study has rejected the null hypothesis and has found a statistically significant impact of the lockdown period on the water quality parameters of the Yamuna river. The findings from the current study provide relevant insight to authorities towards the necessity of stringent environmental regulations to prevent the discharge of untreated municipal and industrial water waste into the Yamuna river.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

BS: Conceptualization, environment, analysis of the results and; discussion. PR: Procurement of data, Economics, framing the introduction section, preparing suggestions. NM: Data curation, Methodology, Economic section in results and discussion and Writing review and; editing. SK: visualization of graphs and; tables. MA: recommendations, and improving the overall quality of the current draft. ZA: Analysis of the statistical results and discussion. SR: Preparing the economic table from various sources.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fenvs.2022.940640/full#supplementary-material>

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