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Assessment of water quality of River Ganga during COVID-19 lockdown

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ABSTRACT

We have done a qualitative and quantitative analysis of Ganga River water in two areas namely Palta and Diamond Harbour, in the state of West Bengal, India. Anthropogenic activity is very high in these regions. Restriction of human activity near river basins due to the prolonged COVID-19 lockdown has brought remarkable changes in the environment. A comparison of the pre-lockdown period and the lockdown period was done. The study covered the years from March 2019 to May 2020. Results demonstrate improvement in surface water quality of River Ganga, during the lockdown period as there was less anthropogenic activity. The water quality test revealed that turbidity has reduced to <94% during the lockdown. River Ganga was one of the polluted rivers, unfit for a bath but physicochemical properties like turbidity, total suspended solids, and total dissolved solids have improved enormously during the lockdown. The chemical oxygen demand, biochemical oxygen demand has changed from 12 and 3 mg/L to <6 and 1.2 mg/L, respectively. Consecutively, dissolved oxygen level has increased from 6 to 12 mg/L. Low total coliform and fecal coliform counts indicated improvement in the bacteriological quality of water. The results of the present investigation establish a significant improvement in water quality.

Keywords: COVID-19; Lockdown; Water pollution; Total suspended solids; Total dissolved solids; Turbidity; Chemical oxygen demand; Biochemical oxygen demand; Dissolved oxygen; Total coliform; Fecal coliform; River Ganga

1. Introduction

Industries, vehicle movement, and human activities suddenly halted in the present times and possibly for the first time in our record of past decades as a measure of the COVID-19 outbreak. The increased industrialization and anthropogenic activities polluted the atmosphere and hydrosphere in the last two decades [1]. In recent times industries have stopped completely and anthropogenic activities have been shut off for a month or more in West Bengal, India [2]. As an outcome of industrialization, environmental pollution had seriously raised to a limit that was detrimental to human health. The most obvious consequence of it was the deterioration of water quality [3].

The regions of West Bengal have been facing problems with Ganga River water pollution for a long time. River Ganga in West Bengal is the major source to suffice human water demands both for drinking and domestic purpose. However, its pollution and toxicity make it even unfit for a bath. In West Bengal, India the idols of God after their worship is immersed in the river Ganga. Though the most sacred river, it has been polluted for decades with idols, puja articles, flowers, food offerings, metal polish, plastic sheets, cosmetic items, and polythene bags [4]. These items were directly thrown into the river water. Industrial wastes, agricultural wastes, biomedical wastes, and sewage disposals are also added to the Ganga River often without treatment, which contributes to the pollution

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load. Cattle shed, animal carcasses, human remains, and day to day activity near the bank of river Ganga has degraded the water quality [5–8].

The water environment has been severely polluted because of rapid urbanization, industrialization, and over-exploitation during the last few decades [5,9]. The industrial effluents are also released into the nearby stream of this river often without treatment. The COVID-19 lockdown period has stopped all the major industrial sources of pollution that affect aquatic systems [3]. Industrial waste-water, untreated sewer water disposal, crude oil, heavy metals, and plastics disposal into the river have completely stopped [6,10]. Therefore, the level of pollution is expected to be reduced. Recently, news media reported that the Ganges, a severely polluted river in India, turns cleaner at several places during the nationwide lockdown period that started on 22nd March 2020. To minimize the health burden due to water pollution the Central government and the State government of West Bengal, have imposed several regulatory measures extended as per international guidelines of the World Health Organization (WHO) for preventing water pollution [11,12].

The current research paper made a first attempt to deal with water quality assessment in West Bengal, India. The focus of the study is to view the effect of lockdown on water pollution: (a) the primary objective of the present study is to assess water, qualitatively and quantitatively before lockdown and during the prolonged lockdown in West Bengal, India (a measure implemented by the Government to restrict COVID-19 spread) and (b) all the results were statistically analyzed and a co-relation of the water quality parameters with the lock-down was drawn sharply. The *p*-value was determined to statistically draw a significance of the variables with our hypothesis.

We have made an effort to study the water pollution in mainly two districts of River Ganga in West Bengal, India. The samples were randomly drawn from the subpopulations of: (1) 24 Parganas North-Palta ghat: 22°47′30″ N 88°21′6″ E and (2) 24 Parganas South-Hoogly ghat: 22°11′34.91″ N, 88°11′4.78″ E, for quality assessments. A detailed study was done by considering the data set of water test parameters for the last 5 y from March 2016 to May 2020. A pre- and post-lockdown comparison of water quality was analyzed from March 2019 to May 2020 as shown in the map below in Fig. 1.

2. Methodology

2.1. Physicochemical, biochemical, and bacteriological assessment of water quality

In vitro test for water quality analysis was conducted at the School of Water Resources Engineering (SWRE), Jadavpur University (JU) during the lockdown period and before the lockdown period as a routine practice for quality monitoring of water. The water quality of river Ganga was analyzed from March 2019 to May 2020 following the standard protocols of Indian standards: 10500 [13–17]. The sample size of 200 was considered for the study. Random sampling was done for the present study. Physicochemical, biochemical, and bacteriological parameters were mainly assessed *in vitro*. The reports of routine water quality analysis tested *in vitro* at the SWRE, Jadavpur University in past 5 y from 2016 to 2019 were also taken under consideration for statistical analysis and inference of the present study. Physicochemical, chemical, and biochemical parameters like pH, total dissolved solids (TDS, mg/L), total suspended solids (TSS, mg/L), turbidity (nephelometric turbidity units (NTU)), hardness (mg/L), nitrate (mg/L), chemical oxygen demand (COD, mg/L), dissolved oxygen (DO, mg/L), and biological oxygen demand (BOD, mg/L) were analyzed for the study. Bacteriological tests for detection of total coliform (TC) and fecal coliform (FC) were carried out following Most Probable Number (MPN) technique. The count was taken as MPN/100 mL [15–17]. Statistical analysis was done to sharply co-relate the changes in water quality of River Ganga with the lockdown. A comparative study was done by considering the last 5 y test reports, annual water quality test reports (pre-lockdown), and the recent test reports (lockdown) of Ganga River water performed *in vitro* at SWRE, JU.

2.2. Statistical analysis

Statistical analysis of water quality was performed in SPSS version 25. Two statistical data sets (pre-lockdown and lockdown) of all the variables were compared in both cases. The mean values of paired samples (before lockdown and lockdown) were compared and correlation was established by Student's paired "*t*" tests. The significance of the test results at $p < 0.05$ was statistically analyzed.

3. Results

Turbidity is a measure to ascertain the degree to which the water loses its transparency due to the presence of suspended particulates. pH in water is an important indicator of water that is changing chemically. The level of TDS and TSS affects the overall quality of water. BOD and COD are critical in wastewater used to determine the organic wastes in the water while TC and FC in water indicate water contamination through fecal matter. The water quality assessment of surface water (river Ganga) after lockdown has been summarized in Table 2. Figs. 2a–5 explain trend line of variables of 24 Parganas north and 24 Parganas south, from spring to summer (Mar, April, and May) in the last 5 y. Figs. 6a–11 illustrate the difference between the observed and predicted values of physicochemical, biochemical, and bacteriological parameters at 24 Parganas South and 24 Parganas North (before COVID 19 outbreak period to COVID-19 outbreak until May' 2020). The dendrograms from Fig. 12a to 14 demonstrate the variation of all the variables among two different study sites at Hooghly Ghat-Diamond harbor of 24 Parganas South and Palta Ghat-Palta of 24 Parganas North, in the lower Gangetic delta, West Bengal, showing both pre-COVID-19 outbreak and outbreak lockdown phase (*= $p < 0.05$). Chemical nutrients in Ganga River water directly indicate water pollution from agricultural and wastewater, availability of such nutrients also supports the growth of pathogenic bacteria. Table 1 infers the trendline analysis of some important chemical parameters of water

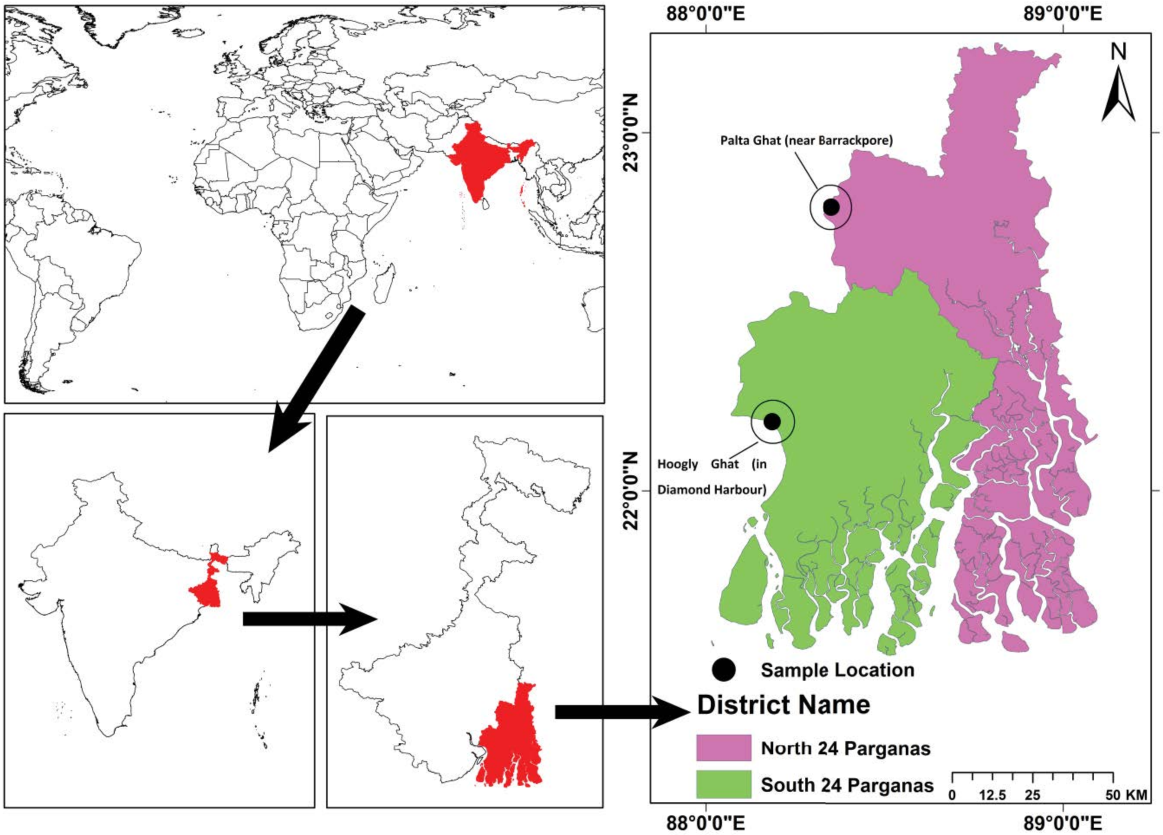

Fig. 1. Study area and sampling locations of two sites for water quality analysis (i) 24 Parganas (North), Palta Ghat (near Barrackpore) and (ii) 24 Parganas South, Hoogly Ghat (in Diamond harbor).

quality monitoring such as NO_2, NH_3, and total phosphorus. Table 2 shows the significance of the overall study.

4. Discussion

The data evaluated from two different sampling sites have revealed a significant variation of physicochemical, biochemical, bacteriological, and chemical quality of River Ganga water between the pre-COVID-19 and COVID-19 lockdown phases. Trend line analysis of physicochemical parameters (TDS, TSS, and turbidity), biochemical parameters (BOD, COD, and DO), and bacteriological parameters (TC, FC) of both 24 Parganas North-Palta and 24 Parganas South-Diamond harbor, from spring to summer (March, April, and May) revealed sharp changes in the concentration of the variables (shown in Figs. 2–5) TDS, TSS, turbidity, BOD, COD, TC, and FC reduced remarkably during the lockdown phase as shown in Figs. 2–5. Chemical parameters like ammoniacal nitrogen, total nitrogen, and total phosphorus also reduced in concentration during this phase as shown in Table 1. The percentage of dissolved oxygen (DO) has increased during the month of COVID-19 lockdowns than the pre-lockdown phase as represented in Figs. 8b and 9b. In Fig. 9a where the COD was found to be in a high range of 26.46 mg/L, it reduced considerably to 2.6 mg/L, BOD was observed in a maximum range of 6.7–6 mg/L which reduced to the below-detected level in the Diamond harbor region as represented in Fig. 9a. These types of variations have not been seen in the last year (2019). The lockdown (March 2020–May 2020) had a good impact on the improvement of water quality. Year-wise trends of physicochemical, biochemical, and bacteriological variation at two stations in Palta and Diamond harbor have shown decreasing trends for all parameters except for DO represented in Figs. 6a–12b. During the COVID-19 lockdown period a sharp decrease of TSS – 91.35%, TDS – 48.5%, turbidity – 94.75%, BOD – 43.8%, COD – 43.5%, nitrate – 91.24%, and TC, FC < 99% was observed at Palta station (24 Parganas North). In Diamond harbor station (24 Parganas South) the decrease of TSS – 33.1%, TDS – 92.1%, turbidity – 94.75%, BOD – 95.3%, COD – 74.11%, nitrate 96%, TC < 96.3%, and FC < 97.6% were observed. During the lockdown phase, the DO level increased in similar trends markedly by 94.57% at Palta and 95.47% at Diamond harbor as shown in Table 2, Figs. 8b and 9b. Notably, only a significant difference in turbidity, nitrate, DO, TC, and FC has been observed among two different stations (Palta and Diamond harbor Hoogly Ghat) during the COVID-19 lockdown period, shown in Figs. 12a and b, 13a and b, and 14. However, the variation in TDS and TSS was slightly different among the two stations. In Table 1 a trendline analysis has been presented that reveals a net decrease in a load of total nitrogen, ammoniacal nitrogen, and total phosphorus from the two stations due to limited industrial and agricultural run-off, a declining trend in phosphate concentration was observed.

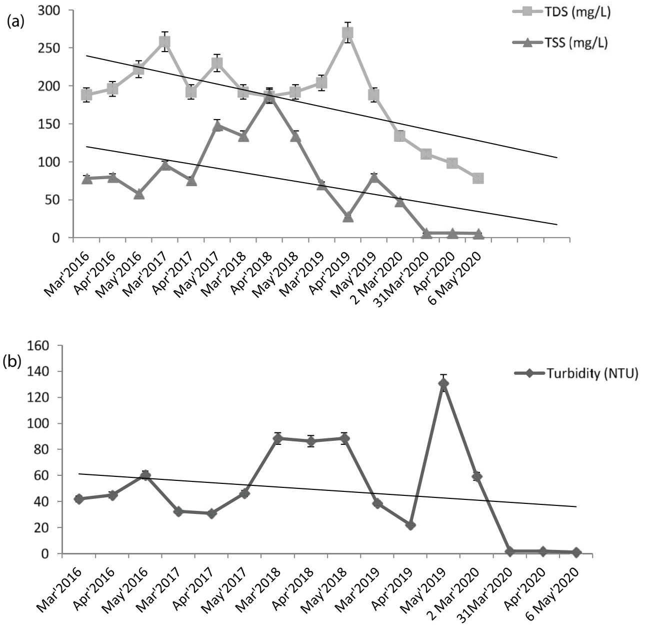

Fig. 2. Trendline of physicochemical parameters: (a) TDS and TSS (mg/L) and (b) turbidity (NTU) of 24 Parganas North-Palta, from spring to summer (March, April, and May) in last 5 y.

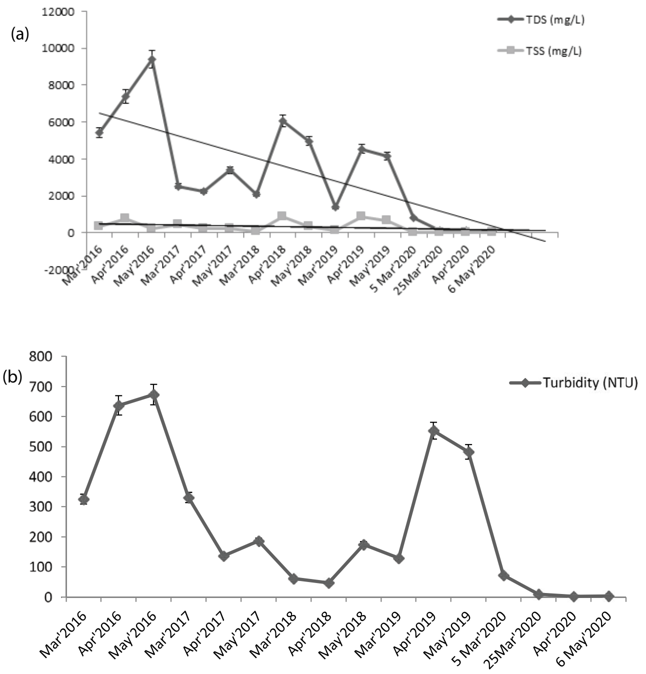

Fig. 3. Trendline of physicochemical parameters: (a) TDS and TSS (mg/L) and (b) turbidity (NTU) of 24 Parganas South-Diamond harbor, from spring to summer (March, April, and May) in last 5 y.

Students "*t*" (paired "*t*" test) was used as a statistical tool to compare mean values of physicochemical parameters (TDS, TSS, turbidity, and nitrate), biochemical parameters (COD, BOD, and DO), and bacteriological parameters (TC and FC). In both the stations, calculated mean values

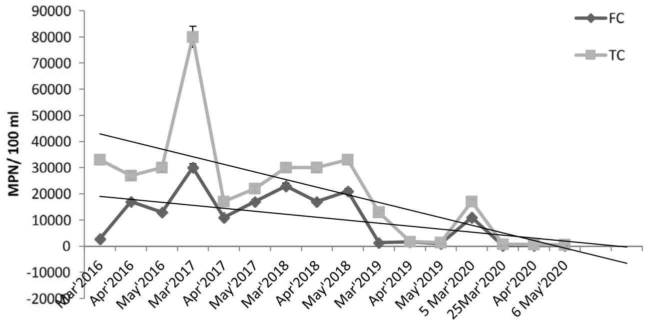

Fig. 4. Trendline of bacteriological parameters of 24 Parganas North-Palta, from spring to summer (March, April, and May) in last 5 y.

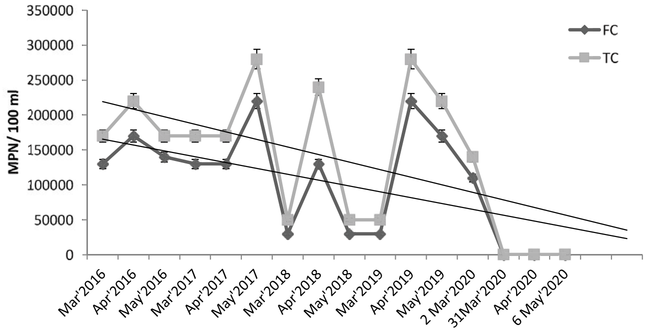

Fig. 5. Trendline of bacteriological parameters of 24 Parganas South-Diamond harbor, from spring to summer (March, April, and May) in last 5 y.

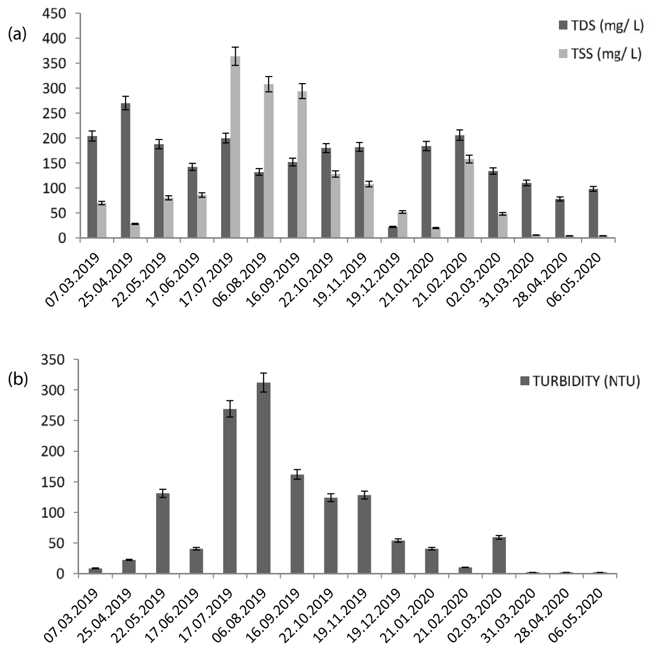

Fig. 6. Difference between the observed and predicted values of physicochemical parameters like (a) TDS (mg/L) and TSS (mg/L) and (b) turbidity (NTU) at 24 Parganas North-Palta Ghat (Palta), from last year to COVID-19 outbreak period until May 2020.

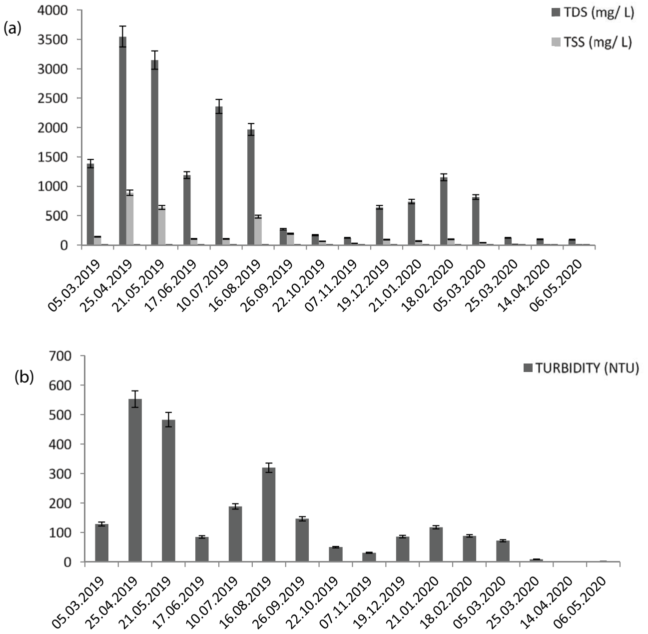

Fig. 7. Difference between the observed and predicted values of physicochemical parameters like (a) TDS (mg/L) and TSS (mg/L), turbidity (NTU) and (b) turbidity (NTU) at 24 Parganas South-Hoogly Ghat (Diamond harbor) from last year to the COVID-19 Outbreak period until May 2020.

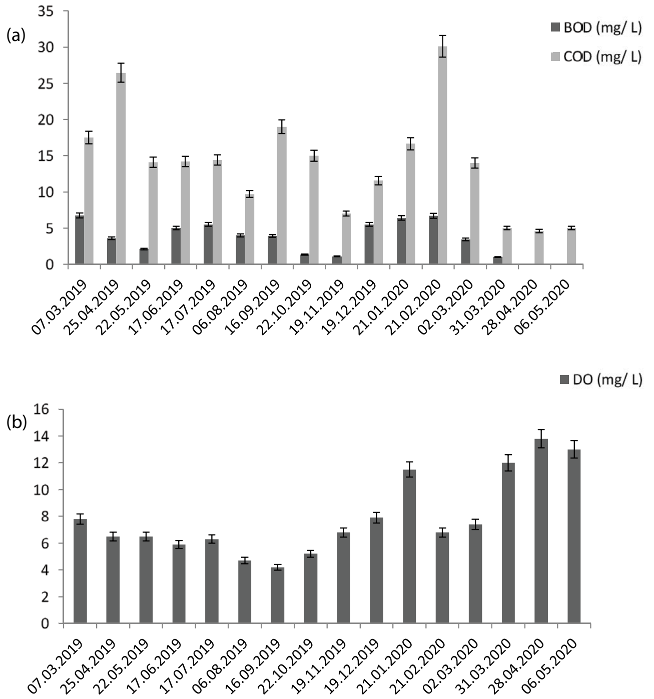

Fig. 8. Difference between the observed and predicted values of biochemical parameters like (a) BOD (mg/L) and COD (mg/L) and (b) DO (mg/L) at 24 Parganas North-Palta Ghat (Palta) from last year to COVID-19 outbreak period until May 2020.

were higher than tabulated or predicted mean values (arithmetic mean if no lockdown would have occurred during this period), represented in Figs. 12a and b, 13a and b, 14, and Table 2. This signifies that the p-values of all these parameters were significant at ($p < 0.05$) indicating improvement in water quality marking a significant increase in DO and decreases in other parameters like TSS, TDS, turbidity, nitrate, COD, BOD, TC, and FC in both the regions of Palta and Diamond harbor.

5. Conclusion

Water pollution mandates action. The river Ganga pollution sources are bodily wastes, animal droppings, agricultural run-off, and sewage which add nitrogen sources in water. Nitrogen is an essential element for all organisms. Like other enteric bacteria, *Escherichia coli* are able to use a lot of organic nitrogen-containing compounds as sole nitrogen sources. Ammonium is considered the preferred nitrogen source, as it supports the highest growth rate [18]. The lockdown phase of the Ganga River is not only appearing more pristine but is actually much cleaner with a substantial reduction in the sources of nitrogen and ammonia which prefers the persistence of bacteria in water. However, due to the minimal availability of these nutrients, the nitrogen-reducing bacteria and the indicator of water pollution *E. coli* reduced remarkably, as is apparent during the lockdown period of March to May 2020. The content of fecal coliform (FC) and total coliform (TC) bacteria found in feces, animal droppings, and agriculture run-off was totally restricted in the river water in March 2020 at least in the two sampling locations

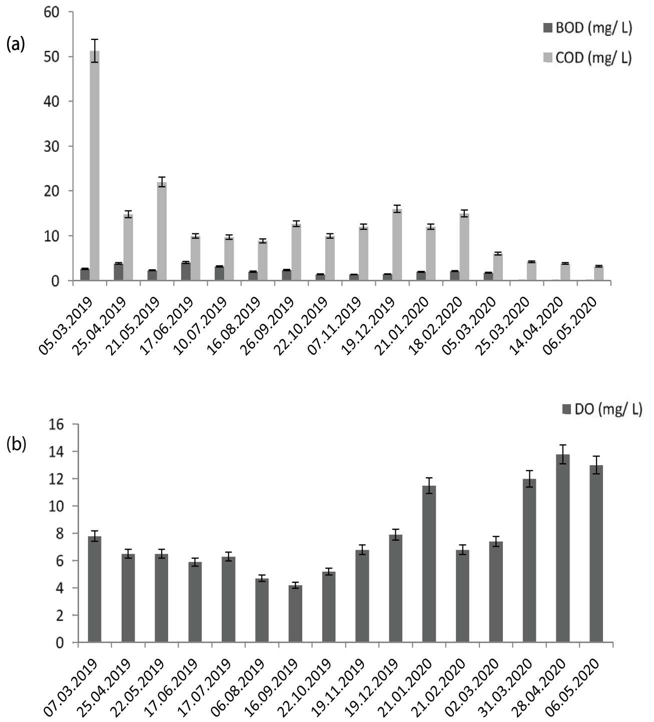

Fig. 9. Difference between the observed and predicted values of biochemical parameters like (a) BOD (mg/L) and COD (mg/L) and (b) DO (mg/L) at 24 Parganas South-Hoogly Ghat (Diamond harbor) from last year to COVID-19 Outbreak period until May 2020.

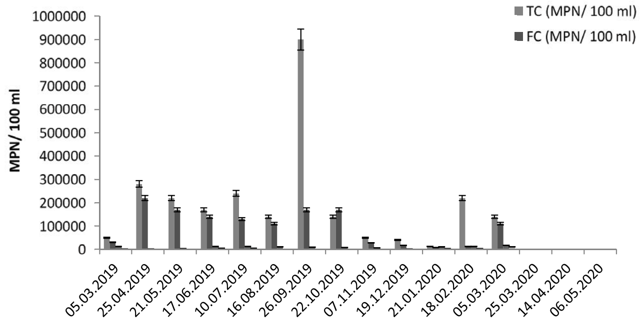

Fig. 10. Difference between the observed and predicted values of bacteriological parameters like TC (MPN/100 mL) and FC (MPN/100 mL) at 24 Parganas North-Palta Ghat (Palta) water during the COVID-19 outbreak period until May 2020.

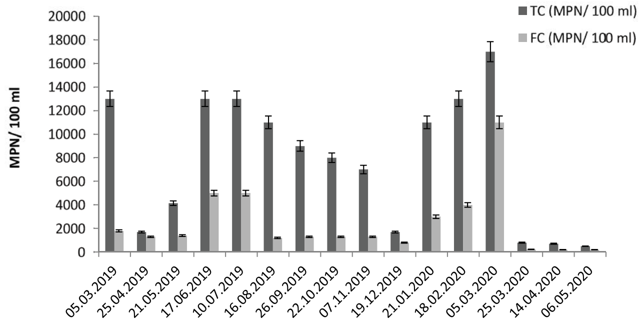

Fig. 11. Difference between the observed and predicted values of bacteriological parameters like TC (MPN/100 mL) and FC (MPN/100 mL) at 24 Parganas South-Hoogly Ghat (Diamond harbor) from last year to the COVID-19 Outbreak period until May 2020.

compared to January 2020 to February 2020 as well as March 2019.

All major polluting industries were closed during lockdown; the toxic load was off the river. Water quality improvement has been observed particularly around the industrial clusters and urban areas that was the main purpose of adding huge pollution load due to the discharge of untreated and partially treated wastewater. The contributing factor of municipal sewage generation and treatment capacities remained the same given that commissioned sewage treatment plants (STPs) were running as

Table 1
Trends in some significant chemical changes observed in water quality of the River Ganga in the sampling locations of West Bengal during the lockdown and before lockdown

Chemical Parameters	Pre-lockdown	During lockdown	Overall trend in water quality
Ammoniacal nitrogen (NH_3–N)	Diamond harbor in West Bengal recorded the highest in ammoniacal nitrogen, that is, 2 mg/L. In the Palta area, the level of ammonia was 1.2 mg/L.	Diamond harbor in West Bengal reported 1.1 mg/L and Palta reported 1.0 mg/L of ammoniacal nitrogen less than the prescribed criteria of 1.2 mg/L limit; during the first week of the lockdown. Ammoniacal nitrogen has been found below levels from 0.15 to 0.2 mg/L during the first 2 months in both Palta and Diamond harbor.	The main reason being the increased discharge of the untreated and partially treated wastewater.
Nitrate (NO_3^-)	Highest nitrate values were recorded in Diamond harbor – 11 mg/L. In Palta Basin it was 7 mg/L	Marginal changes were observed in first week of lockdown in comparison to the pre-lockdown condition. Diamond harbor recorded a decrease in nitrate concentration in the second week of the lockdown to 0.4 mg/ L. In Palta River basin nitrate level was 0.60 mg/L. During the second month of the lockdown, the nitrate level was less than 0.20 mg/L in both locations.	Due to limited industrial and agricultural run-off, a declining trend in nitrate concentration was observed.
Total phosphorous	Total phosphorus was in a limit of 3.2 mg/L or more in Diamond harbor, in Palta region, it was found to be 1.35 mg/L	Total phosphorus was 0.05 mg/L in during lock down in Diamond harbor, in Palta region, it was found to be 0.03 mg/L in the second month of lockdown.	Due to limited industrial and agricultural run-off, a decline trend in phospate concentration was observed.

Table 2
Percentage progress of Ganga river water during COVID-19 lockdown phase

Parameter	Unit	24 PARGANAS (NOTH)				24 PARGANAS (SOUTH)			
		A.M*	"t"	Sig. (2 tailed)	Percent progress (%)	A.M*	"t"	Sig. (2 tailed)	Percent Progress (%)
TSS	(mg/L)	9.33 ± 0.5	3.86	0.002	91.35	8.25 ± 1.7	2.94	0.012	33.17
TDS	(mg/L)	95.3 ± 16	5.57	0.000	48.52	105 ± 14.3	0.03	0.010	92.14
Turbidity	NTU	2.2 ± 0.1	3.80	0.003	94.75	2 ± 0.16	3.73	0.003	94.75
pH	–	7.73 ± 0.5	5.07	0.000	–	7.67 ± 0.06	–1.27	0.228	–
Temperature	°C	31.3 ± 2.3	–0.622	0.545	–	24.65 ± 1.7	2.27	0.042	–
Total hardness	(mg/L)	126.3 ± 8	0.003	0.10	27.22	110.32 ± 1.2	0.003	0.100	39.95
Nitrate	(mg/L)	0.05 ± 0.1	3.303	0.003	91.24	0.1 ± 0.0	3.303	0.003	96.00
BOD	(mg/L)	1.03 ± 0.8	7.5	0.000	43.81	BDL	9.25	0.000	95.32
COD	(mg/L)	6.46 ± 0.6	6.61	0.000	43.54	3.72 ± 0.4	3.88	0.002	74.11
DO	(mg/L)	12.9 ± 0.9	–5.35	0.000	94.57↑	11.37 ± 0.9	–20.7	0.000	95.32 ↑
TC	(MPN/100 mL)	712	3.17	0.008	99.68	634	6.75	0.000	96.35
FC	(MPN/100 mL)	271	4.95	0.000	99.86	212.25	3.48	0.005	97.66

A.M = arithmetic mean with standard deviation, BDL = below detected level, TSS = total suspended solid, TDS = total dissolved solid, TC = total coliform, FC = fecal coliform, (MPN/100 ml), ↑ Indicates increase, t = student's "t" test, degree of freedom in all cases were (n–1 = 12) and Sig. = significance at $p < 0.05$

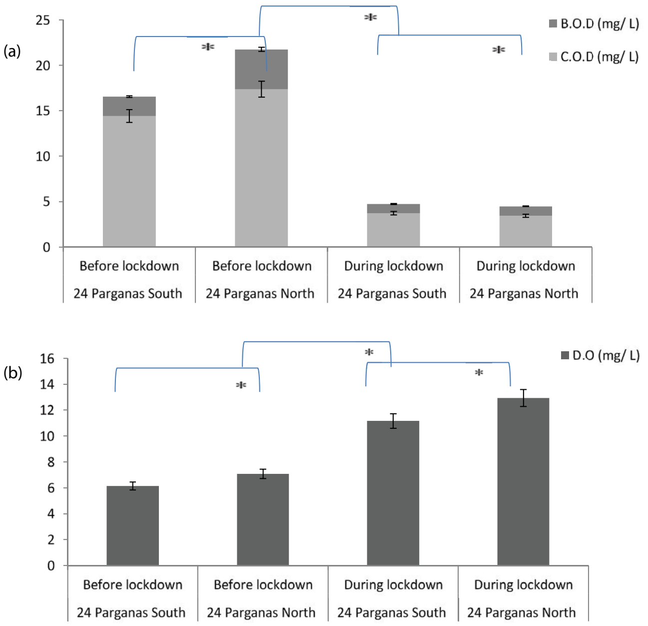

Fig. 12. Spatiotemporal variation of (a) BOD (mg/L), COD (mg/L) and (b) DO (mg/L) among two different study sites at Hooghly Ghat-Diamond harbor of 24 Parganas South and Palta Ghat-Palta of 24 Parganas North, in the lower Gangetic delta, West Bengal, showing both pre-COVID-19 outbreak and outbreak lockdown phase (*= $p < 0.05$).

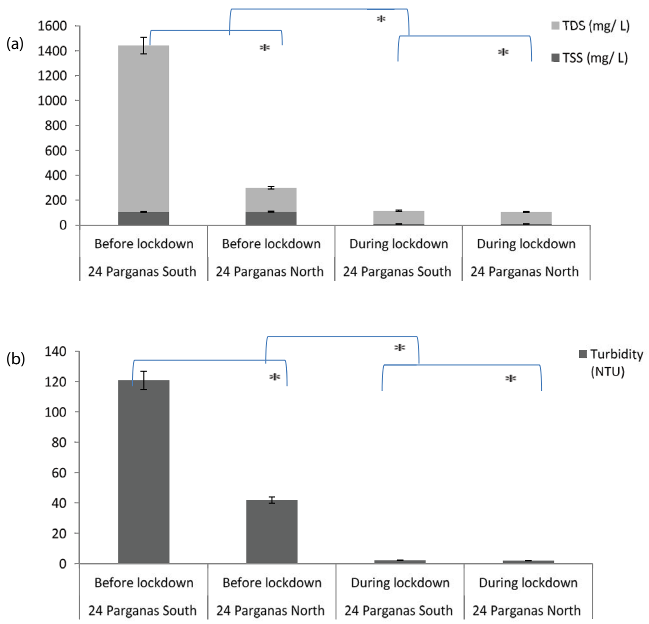

Fig. 13. Spatiotemporal variation of (a) TDS (mg/L), and TSS (mg/L) and (b) turbidity (NTU) among two different study sites at Hooghly Ghat-Diamond harbor of 24 Parganas South and Palta Ghat-Palta of 24 Parganas North, in the lower Gangetic delta, West Bengal, showing both pre-COVID-19 outbreak and outbreak lockdown phase (*= $p < 0.05$).

they used to run before the lockdown phase. As the community gathering was restricted to congregate for religious activities and fair, the local impacts of solid waste coming to the river reduced remarkably. The activities near the river banks were shortened. During the lockdown, River Ganga was free from the problems of solid waste dumping and littering along its banks by the public. The river banks along major cities improved as the public did not access the river for rituals and bathing. In the Ganga Basin, the seventh week of the lockdown period, the agriculture sector was also not withdrawing much water from the river since the time from March to May 2020 as it was a harvesting

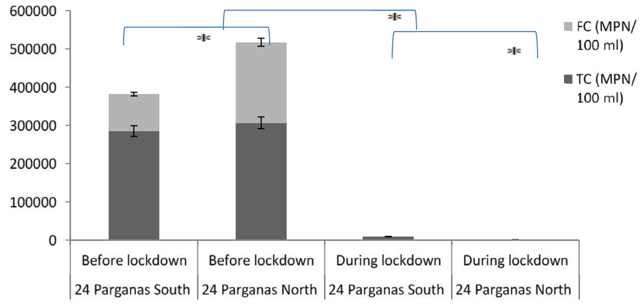

Fig. 14. Spatiotemporal variation of TC (MPN/100 mL) and FC (MPN/100 mL) among two different study sites at Hooghly Ghat-Diamond harbor of 24 Parganas South and Palta Ghat-Palta of 24 Parganas North, in the lower Gangetic delta, West Bengal, showing both pre-COVID-19 outbreak and outbreak lockdown phase (*= $p < 0.05$).

season in West Bengal. Practically a zero industrial pollution due to complete lockdown increased the quality of water in the Ganga River near Diamond harbor and Palta basins (since the enforcement of the lockdown), especially around the industrial clusters which indicates that industrial effluents were not being adequately treated prior to it's discharged into the river. During the lockdown, the sewer dumped in the river must have undergone stringent tertiary treatment before its final dumping. It is understood from the test results that with limitation to anthropogenic activity water pollution may be restricted to a limit. Industrialization, agricultural activity, and anthropogenic activity alongside the river basins were restricted persistently during the lockdown phase, consequently achieving a great improvement in water quality standards. The lockdown phase, initiated from 22nd March 2020 completely ceased all the industrial operations and movements of water transports that ultimately upgraded the Ganga River water quality as revealed by the hike in the DO values and decrease of water pollutants. Good surface water quality makes it more accessible for use. Limited industrialization, construction work, and vehicle transport system drastically improved air quality. There was daily human activity to mass balance that resulted in less release of harmful pollutants in the water. COVID-19 lockdown of 3 months had an overall good impact on the reduction of pollutants in water bodies. Improvement in water quality has benefited ecology, the environment, society, and mankind.

With an increase in industries and urban settlements, the population load in the Ganga basin may increase in the future, expected to generate a huge demand for clear water. It is worthwhile to examine key lessons that the COVID-19 pandemic indicated for river water resources management.

References

[1] P. Yunus, Y. Masago, Y. Hijioka, COVID-19 and surface water quality: improved lake water quality during the lockdown, Sci. Total Environ., 731 (2020) 139012 (1–9), doi: 10.1016/j.scitotenv.2020.139012.

[2] S. Chakraborty, A. Mitra, P. Pramanick, S. Zaman, A. Mitra, Scanning the water quality of lower Gangetic delta during COVID-19 lockdown phase using dissolved oxygen (DO) as proxy, J. Cent. Reg. Stud., NUJS Journal of Regulatory Studies Special Edition April 2020, (2020) 61–66.

[3] S. Shovonlal, COVID-19 pandemic: impact of lockdown, contact and non-contact transmission on infection dynamics, medRxiv, Special Edition 7th April 2020, (2020) 1–6, doi: 10.1101/2020.04.04.20050328.

[4] R. Sinha Roy, I. Dube, Pollution of River Ganga in West Bengal - problems & policy initiatives, GNLU J. Law Dev. Polit., 5 (2015) 1–20.

[5] D.P. Hader, A.T. Banaszak, V.E. Villafane, M.A. Narvarte, R.A. González, E.W. Helbling, Anthropogenic pollution of aquatic ecosystems: emerging problems with global implications, Sci. Total Environ., 713 (2020) 1–10, doi: 10.1016/j.scitotenv.2020.136586.

[6] K.D. Alley, Ganga and Gandagi: interpretations of pollution and waste in Benaras, Ethnology, 33 (1994) 127–145.

[7] A. Mitra, Estuarine Pollution in the Lower Gangetic Delta, Threats and Management, Springer Nature Switzerland AG, 371.

[8] A.M. Shrestha, U.B. Shrestha, R. Sharma, M. Rupakheti, Lockdown caused by COVID-19 pandemic reduces air pollution in cities worldwide, EarthArXiv, (2020) 1–20, doi: 10.31223/osf.io/edt4j.

[9] T. Kjellstrom, M. Lodh, T. McMichael, G. Ranmuthugala, R. Shrestha, S. Kingsland, Chapter 43 - Air and Water Pollution: Burden and Strategies for Control, D.T. Jamison, J.G. Breman, A.R. Measham, G. Alleyne, M. Claeson, D.B. Evans, P. Jha, A. Mills, P. Musgrove, editors, Disease Control Priorities in Developing Countries, 2nd ed., The International Bank for Reconstruction and Development/The World Bank, Washington, DC, 2006. Available at: https://www.ncbi.nlm.nih.gov/books/NBK11769/Co-published by Oxford University Press, New York

[10] S. Saadat, D. Rawtani, C.M. Hussain, Environmental perspective of COVID-19, Sci. Total Environ., 728 (2020) 1–7, doi: 10.1016/j.scitotenv.2020.138870.

[11] WHO, Coronavirus Disease 2019 (COVID-19) Situation Report-48, World Health Organization, 2020. Available at: https://www.who.int/docs/ default-source/coronaviruse/situation-reports/20200308-sitrep-48-covid-19

[12] WHO, Water, Sanitation, Hygiene, and Waste Management for the COVID-19 Virus Interim Guidance, 2020. Available at: https://www.who.int/water_sanitation_health/news-events/wash-and-covid-19/en/

[13] P.K. Roy, D. Kumar, M. Ghosh, A. Majumder, Disinfection of water by various techniques-comparison based on experimental investigations, Desal. Water Treat., 57 (2016) 28141–28150.

[14] P.K. Roy, M. Ghosh, Chlorine resistant bacteria isolated from drinking water treatment plants in West Bengal, Desal. Water Treat., 79 (2017) 103–107.

[15] Indian Standard Drinking Water – Specification, Second Revision, IS 10500, New Delhi, India, 2012.

[16] Standard Method for the Examination of Water and Wastewater, 20th ed., American Public Health Association, Washington, DC, 2008.

[17] West Bengal Pollution Control Board, Fact Sheet Department of Environment, Government of West Bengal. Available at: http://www.wbpcb.gov.in/.

[18] W.C. van Heeswijk, H.V. Westerhoff, F.C. Boogerd, Nitrogen assimilation in *Escherichia coli*: putting molecular data into a systems perspective, Microbiol. Mol. Biol. Rev., 77 (2013) 628–695.