ORIGINAL ARTICLE

Impact of COVID-19 lockdown on the water quality of the Damodar River, a tributary of the Ganga River in West Bengal

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Abstract

The COVID-19 (SARS-CoV-2) pandemic is wreaking havoc on the planet, yet control of waste materials comforted the ecosystem during the lockdown restricting human activities. Damodar is the most important tributary of the lower Ganga River in West Bengal. It flows through an industrially developed, agriculturally flourished populated area. Different methods are applied to identify the changing pattern of water quality during the lockdown. BOD graph shows an increase in pollution levels in residential areas but a sharp decline in coliform levels in urban residential sites. The National Sanitation Foundation Water Quality Index (NSFWQI) shows the same pattern of water quality throughout the course. Irrigation suitability of water is examined using sodium percentage (%Na), sodium absorption ratio (SAR), potential salinity (PS), magnesium absorption ratio (MAR), and Kelly's ratio (KR). Mujhermana (received maximum pollutants from industries and residential areas) station shows a decrease in ions concentration and subsequent improvement in agriculture water quality during the COVID-19 period. According to Kelly's ratio, the water at this sample site is unfit for agricultural use; however, the water quality improved and became acceptable for cultivation during the lockdown period. Cluster analysis is used to understand the similar pollution concentration of eleven sampling stations in different periods. Mujhermana site makes a separate cluster due to its high pollution load compared to other sampling sites before the COVID-19. But during the lockdown period, this site was clustered with the most petite contaminated sites.

Keywords Organic pollution · Water quality index (NSFWQI) · Irrigation water quality · Cluster analysis · Damodar River

Introduction

Severe acute respiratory syndrome was named SARS-CoV-2 or coronavirus or, in short, COVID-19 spread worldwide and was declared a pandemic. As the name suggests, this illness targets the respiratory system. On December 31, 2019, China reported the first 'cluster of cases of pneumonia' (Archived: WHO Timeline—COVID-19) in Wuhan, Hubei province. 'On March 11, 2019,' WHO declared COVID-19 a pandemic. India's first case was found in Kerala on January 27, 2020 (Andrews et al. 2020). Two months after the first case,

on March 22, 2020, India faced a 14-h voluntary lockdown called 'Janata Curfew' (COVID-19 India timeline: Looking back at pandemic-induced lockdown and how the country is coping with the crisis | India News, The Indian Express). India had to be sealed off to stop COVID-19 from spreading to this large nation. During that period, India and all over the world faced lockdown. India declared the first lockdown on March 25, 2020, till April 14, 2020. Lockdown was extended until May 3, 2020; a further extension was announced for another two weeks, and the last extension was until May 31, 2020. Industries had permission to restart the industries from May 1, 2020 (NDMA(MHA) Issues Guideline on Restarting Manufacturing Industries after the Lockdown Period Field, 2020). During this lockdown phase, many economic activities were stopped except for essential services and companies like pharmaceuticals, oil, and gas exploration/refinery, packaging materials, mining activities, power plants, IT hardware, fertilizers, and steel/ferroalloys. During the lockdown, fisheries, animal husbandry, and agricultural activities were also functional. During the second lockdown, some

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industries were opened but still it may had less pollution since production level decreases among the industries across the world due to very low demand of products (Coronavirus outbreak and lockdown impact weighs on steel industry | Business Standard News (business-standard.com)). So, the pollution from the industries may be cut down to some extent, but not entirely. Hotels, restaurants, and other recreational activities were stopped following the order of the government.

Lockdown adversely affects common people, but nature reboots herself due to some absence of human pressure. Not only in India, water and air quality improved worldwide. Important rivers of India show an improved water quality during the lockdown period (CPCB 2020b). Heavy metal concentration in the Ganga River decreases by about 50% during lockdown (Khan et al. 2021). Another study on the Gomti River shows no significant improvement in water quality (Khan et al. 2021), and water quality in the Bagmati River was improved during the lockdown phase (Pant et al. 2021). So, it is hard to say, water quality improved during the lockdown phase for all rivers. The water quality of each river stretch is controlled by its surrounding land-use pattern, government regulation on sewage control, presence of STPs, etc.

Damodar River is one of the important tributaries of the Ganga River in West Bengal. Many large-scale industries like iron and steel, cement, and thermal power stations are situated along this river. Damodar is a highly polluted (category-I) river (CPCB 2017). Damodar River basin is characterized by large-scale industries, densely populated and developed urban areas, enriching mining sites, and fertile agricultural land. Maximum large-scale industries along this river fall into the red category (most polluted). This basin contains many densely populated cities like Kulti, Asansol, Durgapur, Burdwan, etc. Human activities were also restricted during the lockdown period. So, this study emphasizes water quality assessment in a restricted human intervention during the lockdown. It tries to detect any positive effect of lockdown on the river water quality. Different methods are applied to check the suitability of water usage for agriculture (as this region is also an agriculturally developed region) and daily use.

## Materials and methods

Study area

Damodar River originates in Jharkhand, flows through the state of Jharkhand and West Bengal (WB), and finally meets Hoogly River (renamed Ganga in West Bengal). The river is 260.48 km in West Bengal, between 22°27' and 23°49' north and 86°48' and 87°55' east, through the Purba

(East) Paschim (West) Bardhaman, some areas of Bankura, Purulia, Hoogly and Howrah districts with an average slope of 2.34° (Fig. 1). The region is highly industrialized in the middle and upper course. This river basin constitutes sandstone, shales in Gondwana formation, lateritic formation in the tertiary period, and alluvial geological formation (Mondal et al. 2018).

Industrial, urban, agricultural, and mining areas are essential land-use types in this river basin. Municipalities like Kulti, Burdwan, Raniganj, Jamuria, and Municipal corporations like Asansol and Durgapur are situated along the main river channel. Asansol–Kulti township extends along the upper reach of the Damodar River (DCO 2011) at about 36 km. Barakar, Dishergarh, Asansol, and IISCO are the four sampling stations located along this section of the river. Durgapur Municipal Corporation (DCO 2011) extended about 16.5 km along the river and included two sampling stations, Durgapur and Mujhermana. Narainpur, Raniganj, Andal US, and Andal DS are four sampling stations between IISCO and Durgapur. The last sampling station, Burdwan, is situated in the lower Damodar channel in Burdwan municipality.

The river receives several discharges from industries and municipalities, mainly in the upper and middle course up to the Burdwan sampling station. Barakar site receives outlets from Kulti industrial and residential areas. Only 30% of Kulti municipality's population contributes about 94,143 KLD as per the 2011 census (CPCB 2020a). Dishergarh site receives water from a tributary near the state of Jharkhand. Asansol and IISCO stations are located near congested urbanized and large-scale industrial clusters. Sewage from Asansol municipal corporation (AMC) is about 563,917 KLD, and from Raniganj municipality is 129,441 KLD (CPCB 2020a). Narainpur site receives a drainage outlet from the Asansol residential area. Raniganj, Andal US, and Andal DS stations receive sewages from residential areas. Andal block contributes about 186,915 KLD sewage to the Damodar River (CPCB 2020a). Durgapur and Mujhermana stations are highly congested industrial and residential areas. Treated and untreated effluents from industries and municipalities in the Durgapur region drain into Tamla Nala (drain), finally joining the Damodar River (Mukhopadhyay and Mukherjee 2013) in Mujhermana. Damodar receives 396,570 KLD sewage from Durgapur municipal corporation (70%) (CPCB 2020a). Burdwan site is in the lower reach of the Damodar River near the Burdwan municipality. Multiple outlets from industries and cities fall into the river (Fig. 2).

In the summer, the river discharge is minimal, and sometimes it reaches zero (Bhattacharyya 2011). It is a braided river, and the channel is fragmented in different sites. So due to very lean discharge except for monsoon season, satellite image analysis could not be possible in this river. So only field-based measured parameters are used to analyze
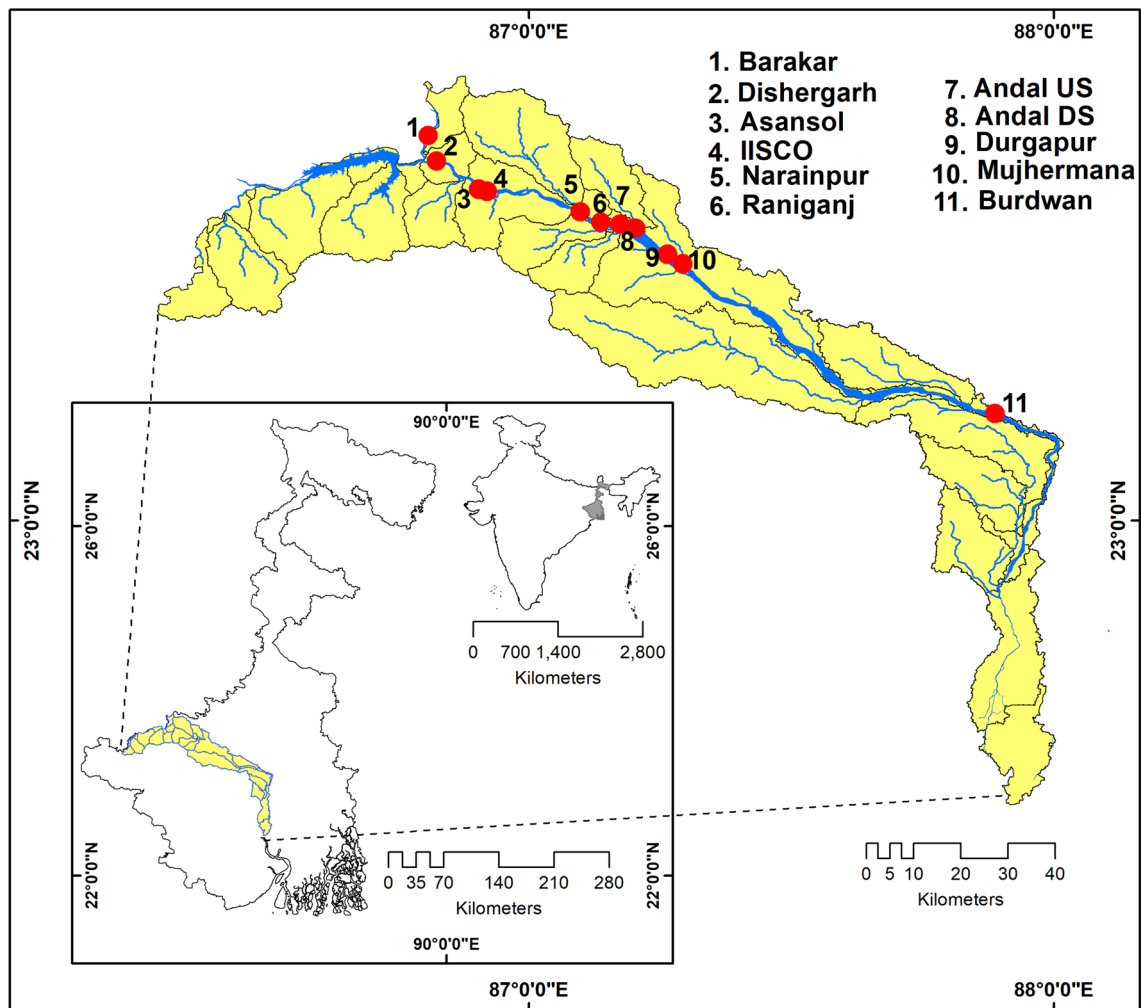
Fig. 1 Location map of the study area showing the distribution of sampling stations

the change in water quality. Because each sample point has a unique land-use pattern, the estimation of total contamination of the river is less precise, so the water quality for each station is presented separately.

Sampling design

In this study, pollution data are collected from West Bengal Pollution Control Board (WBPCB) under the Central Pollution Control Board (CPCB) of India. The first lockdown was announced on March 25, 2020. The months of April and May were chosen as the months of lockdown. April 2019 is considered a pre-COVID month and is used for comparative analysis with April and May 2020. Eleven sampling points are selected near the urban and industrial centers. The lockdown month of April 2020 is indexed as lockdown 1, and May 2020 is indexed as lockdown 2 for all plots.

Samples are taken from the approximate depth of 0.5 m, and all samples are tested based on the APHA methods.

Twenty-seven parameters are analyzed to determine the water quality. Boron, phenolphthalein alkalinity, and total Kjeldahl nitrogen are three parameters that are either absent or below the detection limit. So, these are excluded from the study. The other measured parameters like ammonia-N (Ammonia), biological oxygen demand (BOD), calcium, chloride, chemical oxygen demand (COD), conductivity (Cond), dissolved oxygen (DO), fecal coliform (F.Coliform), fluoride, magnesium, nitrate–N (Nitrate), pH, phosphate, potassium, sodium, sulfate, temperature °C (Temp.), total alkalinity (Alkalinity), total coliform (T.Coliform), total dissolved solids (TDS), total fixed solid (TFS), total hardness (Hardness), total suspended solids (TSS), and turbidity are used for the comparative study of water quality.
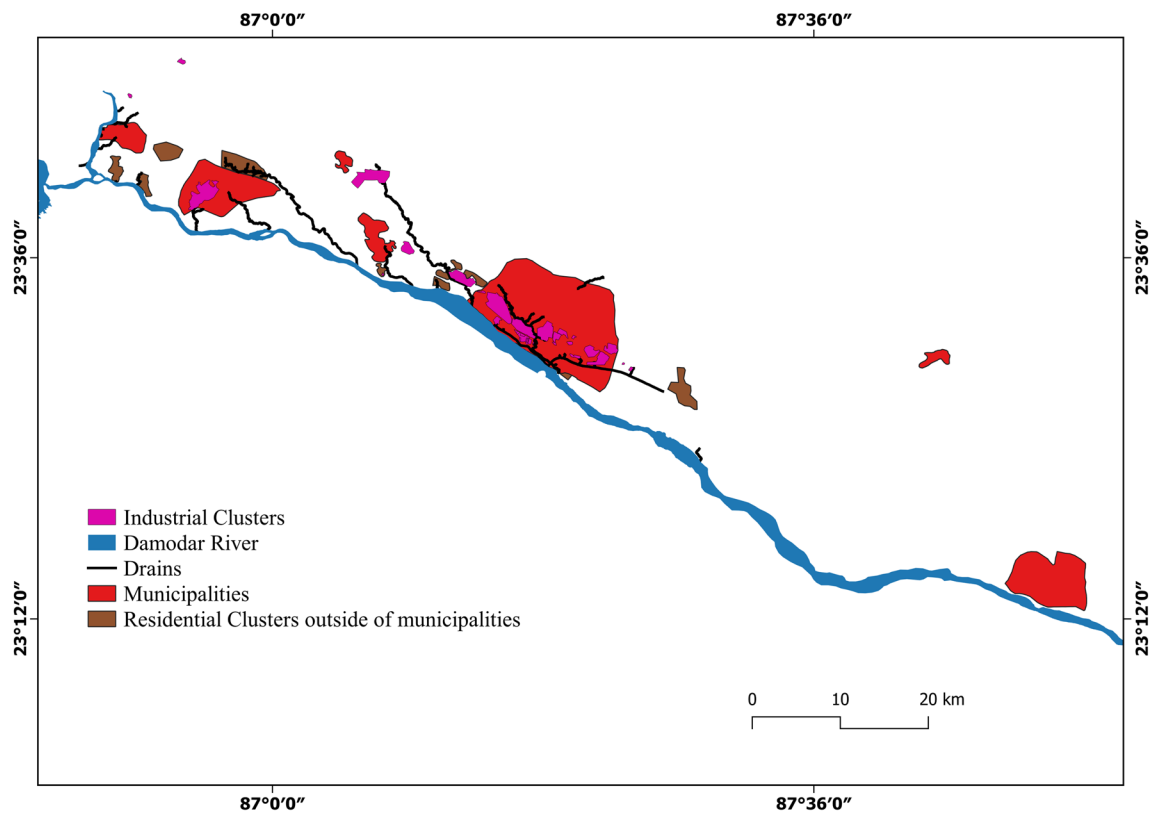
Fig. 2 Outlets form Industries and Residential areas join into Damodar River

National Sanitation Foundation Water Quality Index (NSFWQI)

The water quality index (WQI) is a method that calculates a single value considering multiple parameters to determine the overall water quality. Different WQIs are available to analyze the water quality. Among the other indexes, WQI from the National Sanitation Foundation (NSFWQI) (Abdel-Fattah et al. 2020; Darvishi et al. 2016; Hoseinzadeh et al. 2015; Jahin et al. 2020; Matta et al. 2020; Misaghi et al. 2017) has been used in this study. This index includes the BOD, DO, fecal coliform, nitrate (related to the decomposition of materials or pollution from organic sources), pH, phosphate, temperature, turbidity (includes physical, chemical, and biological parameters), and total solids. WQI can be calculated with a single observation data. CCME-WQI is also a renowned water quality index used in the same study area (Maity et al. 2022), but it requires a minimum of three datasets for the result accuracy. The Q value is calculated from the conversion curve for each parameter generated by 142 members of a panel in the USA (Table S1). Pre-assigned weights are given for each parameter multiplied by the Q value (generated by 143 members based on the importance of the parameter) (Wills and Irvine 1996), and summing all

the resultant multiplication gives the NSFWQI value (Table: S1).

$$\text{NSFWQI} = \sum_{i=1}^{n} w_i q_i$$

where q_i represents the subindex (Q value) value from the assigned curve, ranging from 0 to 100, and w_i is the pre-assigned weightage for each variable.

The water quality is divided into five classes (Table: S2) and considered very bad (0–25), bad (26–50), medium (51–70), good (71–90), and excellent (91–100) (Hamdan et al. 2018).

The water quality index is calculated and plotted using R software.

Irrigation water quality analysis

The above-discussed WQI does not include the different salts like calcium, magnesium, sodium, chloride, and potassium. But the salt concentration in water significantly affects plants' health and agriculture production. Various methods are adopted like sodium absorption ratio (SAR), sodium percentage (%Na), potential salinity (PS), magnesium

Table 1 Standards of different methods to measure the suitability of water for irrigation

Classification scheme	Range	Categories
Electrical conductivity (EC) in µs/cm	< 250	Excellent/low salinity water (C1)
	250–750	Good/medium salinity water (C2)
	750–2250	Permissible/high salinity water (C3)
	> 2250	Unsuitable/very high salinity water (C4)
Sodium percentage (% Na)	< 20	Excellent
	20–40	Good
	40–60	Permissible
	60–80	Doubtful
	> 80	Unsuitable
Sodium absorption ratio (SAR)	< 10	Excellent/low sodium water (S1)
	10–18	Good/medium sodium water (S2)
	18–26	Doubtful/high sodium water (S3)
	> 26	Unsuitable/very high sodium water (S4)
Potential salinity in meq/l	< 5	Excellent to good
	5–10	Good to injurious
	> 10	Injurious to unsatisfactory
Magnesium absorption ratio (MAR) in percentage	< 50	Acceptable
	> 50	Non-acceptable
Kelly's ratio (KR)	< 1	Suitable
	> 1	Unsuitable

absorption ratio (MAR), and Kelly's ratio to analyze the agricultural suitability of water (Table 1).

Salinity hazard

Plants cannot take up water through roots in excess soil solution due to high osmotic pressure (Zaman et al. 2018). EC and TDS are two parameters used to measure the salinity in water. Depending on the level of EC (Table 1), water can be classified into different salinity hazards (Nishanthiny et al. 2010; Tiri et al. 2020). This category is developed depending on the EC of irrigation and saturated soil extract (Regional Salinity Laboratory (US) 1954). A higher concentration of salts in water increases the salinity hazard for agriculture.

Sodium/alkaline hazard

Principal cations (calcium, magnesium, and sodium) and anions (carbonate, bicarbonate, sulfate, chloride, and nitrate) are naturally present in the soil. Still, increased sodium proportion in the soil causes a high alkali hazard. Conversely, a predominance of calcium and magnesium causes low alkali hazards. Sodium hazard calculates the relative balance of sodium with other ions. Sodium percentage (%Na) and sodium absorption ratio (SAR) reveal the sodium hazard and suitability for agriculture use. Excess sodium in water reduces the soil permeability (Nishanthiny et al. 2010), leaf

burn, leaf scorch, and dead tissue outside the leaf (Nagaraju et al. 2014; Zaman et al. 2018).

Divalent cations generally exchange with clay minerals, and displacement of calcium and magnesium by sodium ions can be possible if the sodium percentage is higher than 50. Sodium percentage calculates the percentage of sodium in total cations (concentrations are expressed in milliequivalent per liter) (Hem 1970).

$$\text{Na}\% = \frac{\text{Na}^+}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+} \times 100$$

SAR is calculated in the form of sodium ratio to calcium and magnesium. SAR calculates the effect of exchangeable sodium on soil (Regional Salinity Laboratory (US) 1954).

$$\text{SAR} = \frac{\text{Na}^+}{\sqrt{\frac{\text{Ca}^{2+} + \text{Mg}^{2+}}{2}}}$$

where all cations are expressed in milliequivalents/liter

Potential salinity

Chloride and sulfate salts are highly soluble to produce saline soil, whereas Ca is precipitated as Ca-MgSO$_4$ and CaSO$_4$ (Doneen 1975). So, the salinity index is calculated by adding chloride and half of sulfate (Ogunfowokan et al. 2013; Tiri et al. 2020).

$$\text{PS} = \text{Cl}^- + \frac{\text{SO}_4^{2-}}{2} \text{ (where concentrations are in meq/lit.)}$$
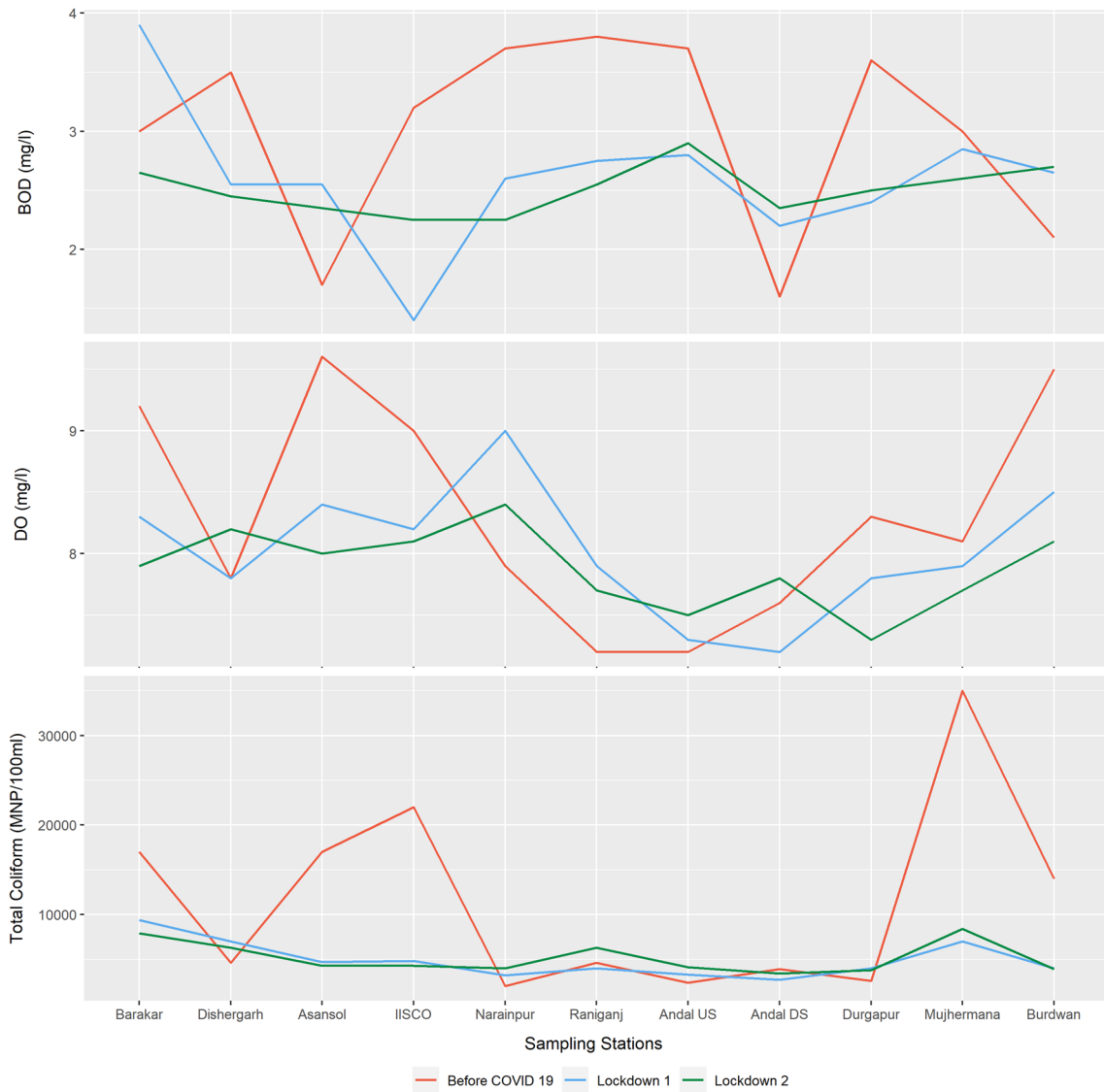
Fig. 3 Comparative study of BOD, DO and total coliform before and during lockdown
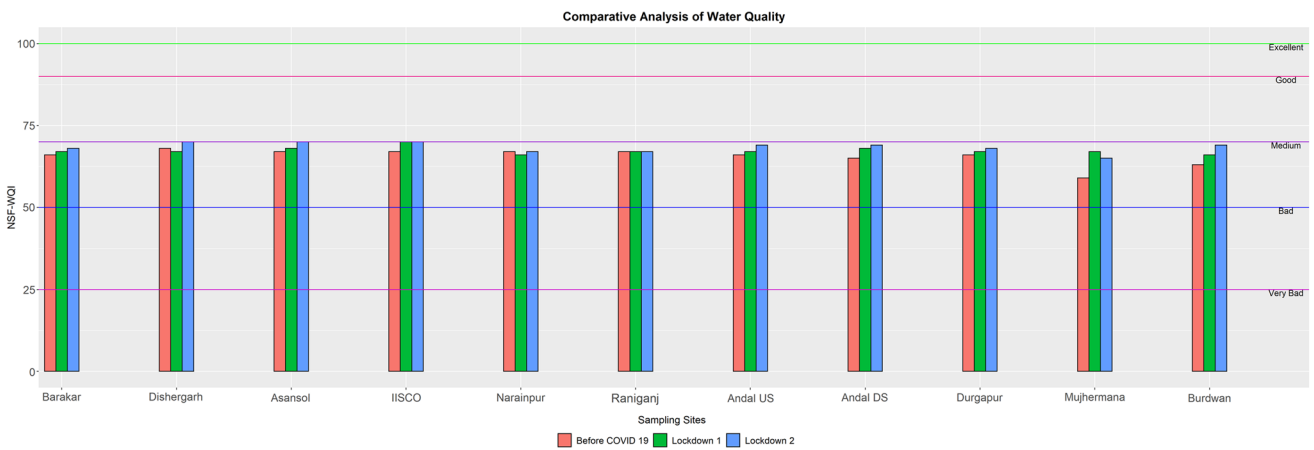

Fig. 4 NSF-WQI for Damodar River water quality before and during lockdown

Magnesium absorption rate (MAR)

Magnesium is the most vital element to access the irrigation suitability of water. Excessive magnesium in irrigation water increases the magnesium concentration in water, reducing crop yield (González-Acevedo et al. 2016; Nagaraju et al. 2014). Magnesium concentration is calculated in the form of a magnesium absorption rate.

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100$$

Kelly's ratio (KR)

Kelly (Kelley 1963) has determined Kelly's ratio to analyze the hazardous effect of sodium. Kelly's ratio is calculated with sodium ions divided by the addition of calcium and magnesium.

$$KR = \frac{Na^+}{Ca^{2+} + Mg^{2+}}$$

Representation of irrigation water quality

Along with the above indexes, irrigation water suitability can be presented in two diagrams. USSL plot the water quality based on electric conductivity and sodium absorption ratio (Regional Salinity Laboratory (US) 1954). Curves are drawn in negative slopes, and each block represents a different water quality for irrigation purposes (Regional Salinity Laboratory (US) 1954; Wilcox 1955). After L.Wilcox, this diagram is also called the Wilcox diagram (Wilcox 1955). Conductivity represents the salinity hazard of water, and SAR represents the sodium hazard in the water. Both parameters are classified into four categories (low, medium, high, and very high) from the lower left corner to the right (*x*-axis) and upper side (*y*-axis), depending on the suitability of water for irrigation. In another diagram, irrigation water quality is plotted based on electric conductivity and % Na.

Cluster analysis

Cluster analysis is generally used for grouping sampling stations based on similar water quality of different sampling sites (Maity et al. 2022; Singh et al. 2004). Damodar River pollution is controlled by sewage from different industries, municipalities, mining areas and agricultural
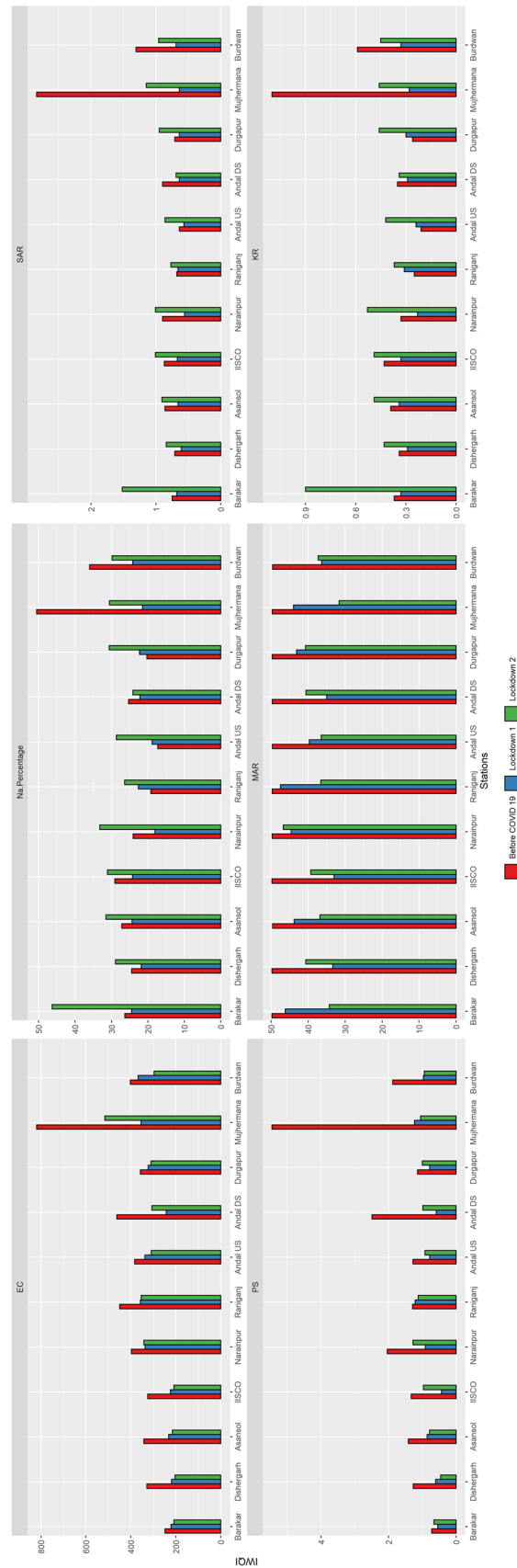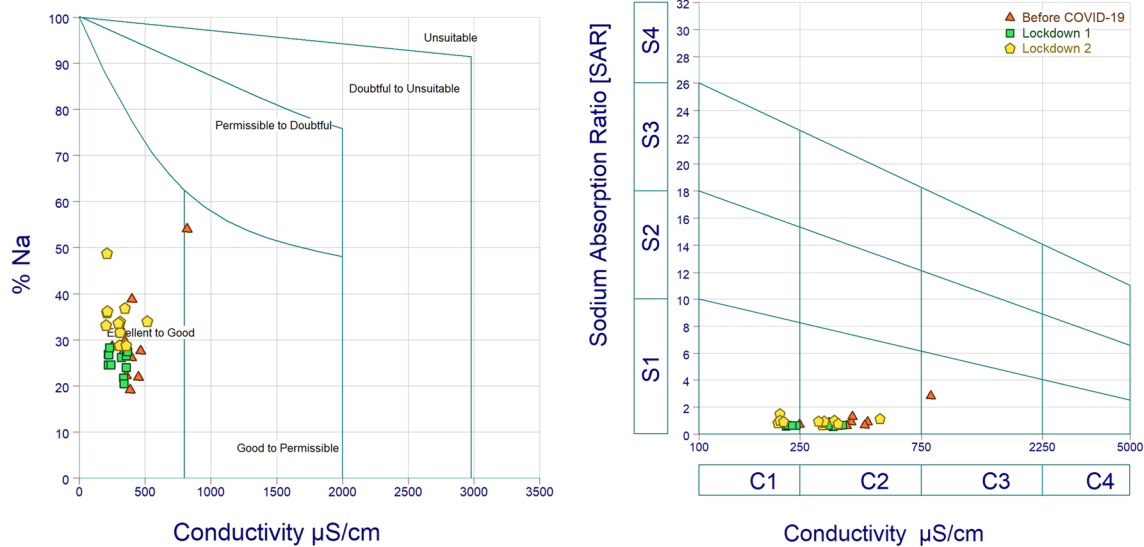

Fig. 5 Comparative analysis of Irrigation Water Quality Indices

Fig. 6 Wilcox diagram for Damodar River irrigation water quality

land. Land-use types possess variation in water quality, but restricted human activities minimize the effects of point sources during the lockdown. Cluster analysis is performed for grouping sampling sites based on the water quality parameters. A comparative study before and during lockdown has been conducted to show the lockdown effect on different sampling sites based on the clustering pattern. Sampling stations with similar pollution loads will cluster depending on the pollution load during pre-lockdown and lockdown. The agglomerative hierarchical method has been used for this cluster analysis.

Result and discussion

Organic pollution

BOD is one of the most critical parameters that can give a general idea about water quality. So Central Pollution Control Board (CPCB) of India used it widely to determine the water quality and categorized Indian rivers depending on the pollution load. So, the changing pattern of BOD is represented in a simple line graph (Fig. 3) to get an overall idea of river health. BOD value is higher in the Barakar, Asansol, Andal DS, and Burdwan sampling stations during lockdown months than during the pre-COVID period. A similar result is found in the Gomti River in India (Khan et al. 2021). The effect of high domestic discharges and anthropogenic activities are the responsible sources of increased BOD in the Damodar. BOD value increased in May in the IISCO station. The industries were opened on May 1, and IISCO is a sampling station near the IISCO industry (large-scale iron and steel producer). Asansol,

Andal DS, and Burdwan stations have high BOD values than during the lockdown months. BOD level is higher during lockdown than before the COVID period, mainly in the stations located in the residential area.

During lockdown months, DO level is lower in Asansol, IISCO, Andal DS, Durgapur, Mujhermana, and Burdwan sampling stations than during the pre-COVID period. The organic pollution level is higher during the COVID period due to increased domestic discharge leading to the deterioration of DO levels in the Damodar River. This river flows through the highly dense polluted area and agriculturally developed region, so the organic pollution level does not decrease. Increasing the organic pollution level is expected due to domestic discharges as all are locked in their houses.

The total coliform level sharply decreases (~ 40%) in congested urbanized areas. It results from closing hotels, restaurants, malls, etc. (Khan et al. 2021) and other sources from animal and bird farms. Dishergarh, Raniganj, Andal, and Durgapur showed the constant coliform level during and pre-COVID period.

National Sanitation Foundation Water Quality Index (NSFWQI)

It shows that water quality was medium (Fig. 4) in the study period, i.e., before and during the lockdowns. However, the WQI score increases (better quality) during the lockdown period for all stations except Dishergarh and Narainpur. Residential areas dominate these two stations, and a tributary that joins Dishergarh site receives multiple drainage outlets from residential areas (Fig. 2). But
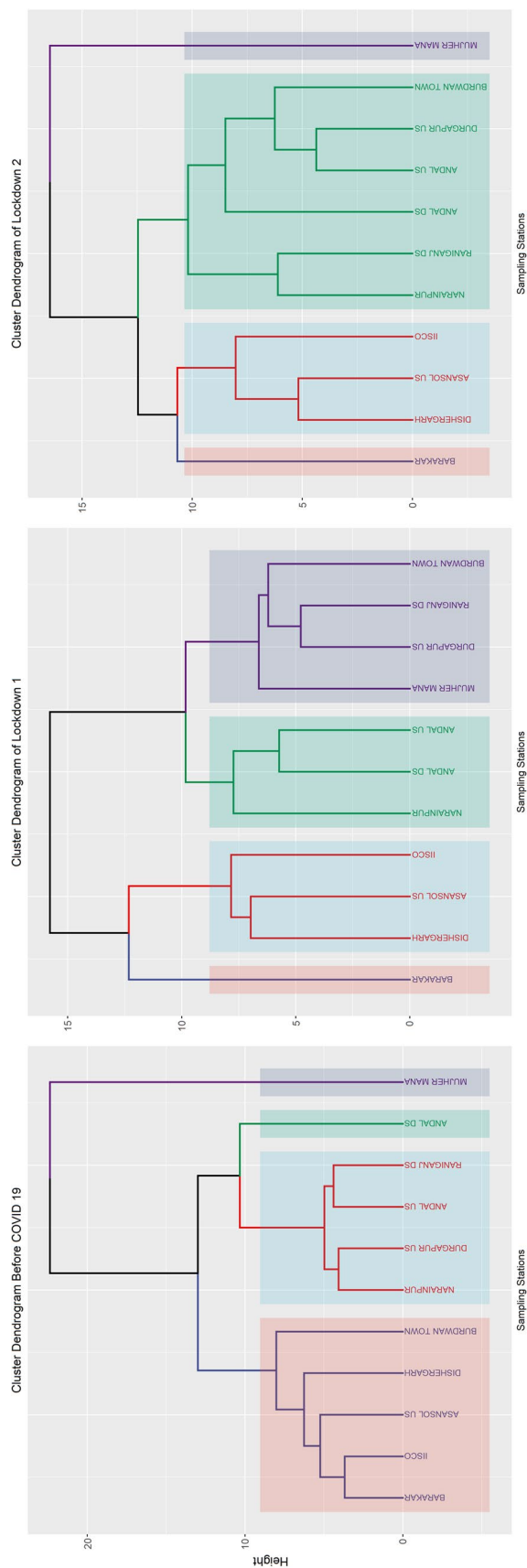
Fig. 7 Comparative Cluster analysis of the sampling sites

water quality of Mujhermana station (which receives pollutants from the Durgapur Industrial cluster, municipality) improved significantly during the lockdown period.

During the lockdown, the residential areas show an increase in pollution levels in either BOD or WQI. The station that receives maximum pollution load shows improvement by a benchmark during the lockdown phase and again a slight decrease in water quality by May 2020, when industries got permission to open.

Irrigation water quality

Water quality indexes do not include the positive and negative ions. These indices primarily focus on parameters that examine the biological component of pollution. So different methods to determine the irrigation water quality also incorporate the characteristics of ions in water. Figure 5 summarizes the result of all indexes. Water in Mujhermana station is high saline in electric conductivity (EC), good to injurious for potential salinity, and unsuitable for agriculture in Kelly's ratio. Water quality improved during the lockdown period in April. In May, it increased further but still less than in the pre-lockdown period. % Na, SAR, and KR increased for the maximum stations in the lockdown period but remained in the same category. It may be due to the rise in sodium in the lockdown period.

Figure 6 represents the conductivity concerning % Na and SAR. Both diagrams show water can be easily used for irrigation purposes, but the water quality improved during the lockdown. The distinct site in both graphs is the Mujhermana station, the most polluted one.

Cluster analysis

Cluster analysis (Fig. 7) has been used to group the stations into different clusters depending on all the variables. Cluster analysis is used before COVID-19, the first month of lockdown, and the second month of lockdown. Clusters are numbered from cluster 1 to cluster 4 from left to right for all the clusters. From the above discussion, we can say that Mujhermana is the most polluted site, especially before lockdown, and it makes a separate cluster 4. Pollution increases from cluster 1 to cluster 4 (Maity et al. 2022). The pollution was much lower in April 2020 (lockdown 1) than before COVID-19. There has been a minor increase in pollution level in May 2020 (lockdown 2) than April 2020 but still much less than before COVID-19. The Mujhermana station, the most polluted one, showed a separate cluster before COVID-19 and separated in May 2020 as the industries got permission to open. The Mujhermana did not form a separate cluster in lockdown 1. It creates a cluster with Burdwan, which falls in the least polluted cluster before lockdown. In lockdown 2, sites in clusters 1 and 2 remain the same as in lockdown

1, but site distribution in clusters 3 and 4 changes due to the slight modification in economic activities from lockdown 1 to lockdown 2.

Conclusion

The study evaluates the changes in water quality during the lockdown period. Pollution content is not constant throughout the river, so station-wise comparisons have been made in this study. The pollution level in this river is highly controlled by land-use patterns that vary throughout the channel. There was a slight increase in water quality during the lockdown, although lower water quality prevails in some residential areas. The irrigation water quality analysis also shows a minor decrease in ions content. The BOD level in stations that get strong industrial outputs drops dramatically. WQI and irrigation quality show the highest improvement in water quality of the most polluted station (Mujhermana). Different industries had opened during the COVID period, so water quality did not improve to a higher level. Noticeable improvement in water quality is found near industrial sites. Coliform level decreases sharply during the lockdown period.

Along with the industries, outlets from municipalities also deteriorate the water quality level because the river travels through a highly industrial and developed area. Like air pollution, water quality did not improve up to the mark because agriculture activities, mining, some industries, and power plants were open during the lockdown period. Pollutants from households increased during this lockdown, which is one of the most determining factors in water pollution. So in some areas, the water quality deteriorates during the COVID lockdown period.

of Paschim Bardhaman under MSME (Ministry of micro, small, and medium enterprise) under Govt. Of India, West Bengal Industrial Development Corporation, and Asansol Durgapur Development Authority under Govt. of West Bengal. SRTM DEM data have been downloaded from USGS (US Geological Survey) Earth Explorer to generate river basins and channels. Google Earth Pro helps to demarcate industrial clusters and sewages. All datasets are available in the public domain.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This work is original and has not been published or submitted elsewhere for publication.

Consent to participate This paper is guided by Dr. Ramkrishna Maiti and Dr. Tarakeshwar Senapati. This paper is written with the consent of two other authors.

Consent to publish The paper is sent to publish with the consent of all authors.

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