Eco-restoration of river water quality during COVID-19 lockdown in the industrial belt of eastern India

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Abstract
The sudden lockdown recovers the health of the total environment particularly air and water while the country’s economic growth and socio-cultural tempo of people have been completely hampered due to the COVID-19 pandemic. Most of the industries within the catchment area of river Damodar have been closed; as a result, significant changes have been reflected throughout the stretch of river Damodar. The main objective of the study is to analyze the impact of lockdown on the water quality of river Damodar. A total of 55 samples was collected from eleven different confluence sites of nallas with the main river channel during and pre-lockdown period. The relevant methods like WQI, TSI, Pearson’s correlation coefficient, and “t” test have been applied to evaluate the physical, chemical, and biological status of river water. The result of “t” test indicated that there are significant differences (α = 0.05) of each parameter between pre and during lockdown. Water quality index (WQI) is used for analysis of drinking water quality suitability followed by BIS. The values of WQI showed “very poor” (S1, S2, S3, S6, S7, and S11) to “unfit for drinking” (S4, S5, S8, S9, and S10) of river water during pre-monsoon season. The nutrient enrichment status of the river was analyzed by Trophic State Index (TSI) method and it shows the “High” eutrophic condition with a heavy concentration of algal blooms in almost an entire stretch. During lockdown, nutrient supplies like TN and TP have been reduced and is designated as “Low” (S1, S2) to “Moderate” (S3 to S11) eutrophic condition of middle stretch of Damodar. This research output of river Damodar will definitely assist to policy makers for sustainable environmental management despite the dilemma between development and conservation.

Keywords Lockdown · Eutrophic condition · Water quality index · Trophic state index · Sustainable management
Introduction

Economic development of the twenty-first century has suddenly been obstructed by the COVID-19 global pandemic. This virus mainly transmits through coughing, sneezing, saliva, and spit of the affected person to another person. At the end of March 2020, over one million positive cases and 50,000 deaths have been reported from different corners of the globe (DuTheil et al. 2020; Han et al. 2020; Isaiaf 2020). Simultaneously, eighteen million people were affected by the deadly Coronavirus within the 1st week of August 2020. World Health Organization (WHO) declared this pandemic as an International Emergency of Public Health (Kambalagere 2020; Sohrabi et al. 2020). Scientists of all over the world are continuously trying to find out its antidote or vaccine but desirable results are still elusive. Therefore, to reduce the rapid transmission of COVID-19, maintenance of social distance and face mask is the only way during this critical time. Probably the first time in the world’s history, many affected countries have declared “lockdown” or shutdown of their public, educational, industrial, and business sectors to reduce the transmission of coronavirus. Sudden declaration of lockdown very badly harmed the economic sector while the health of the total environment has been improved due to limited anthropogenic actions (Beine et al. 2020; Ray et al. 2020; Huang et al. 2020; Bera et al. 2020). Several studies on environmental quality have been conducted in different parts of the world, and it showed that the ecological restoration has been significantly retrieved (Ma et al. 2020; Yongjian et al. 2020; Sharma et al. 2020a; Gautam and Hens 2020; Bera et al. 2020).

In India, an assessment on the water quality of river Ganga showed that the water quality has been improved by 40% to 50% during the lockdown period (CPCB 2020; Mani 2020). Many relevant studies have also been conducted on the quality of surface water bodies in different sites of India, and it demonstrated that the water parameters like pH, DO, BOD, and TC have been notably enhanced (Dhar et al. 2020; Chakraborty et al. 2020b; Mukherjee et al. 2020). Water quality is the assessment of an individual as well as all the parameters is associated with it. The influence of every individual parameter to the overall quality and the total influence of all parameters collectively determine the state of water quality for its definite use. Water quality index (WQI) is a very effective tool to select adequate treatment techniques (Rana et al. 2018). Similarly, it determines the physical, chemical, and biological parameters of the water (Vasistha and Ganguly 2020a, 2020b). Here, WQI comprises of sub-indices allotted to each parameter as per its importance and all together of sub-indices expressed in a single value which is indicating water quality (Sharma et al. 2020b). The WQI method is widely used by many researchers for the assessment of water quality in different parts of the world (Swami and Tyagi 2000; Kanakiya et al. 2015; Dwivedi and Pathak 2007; Mukherjee et al. 2012; Selvam et al. 2014; Hou et al. 2016). Quality of water is also indicated by the health as well as the growth of plants and aquatic animals in the aquatic ecosystem or environment. Subsequently, Trophic State Index (TSI) is a numerical expression of the trophic status of the water body. It was first developed by Carlson (1977) and further modified by Burns et al. (2005) by adding total nitrogen (TN) parameter along with chlorophyll a (Chl a), depth of Secchi disc (SD), and total phosphorus (TP) parameters. TSI was determined by many researchers for evaluation of aquatic health (Guildford and Hecky 2000; Lathrop 2009; Canfield Jr and Hoyer 2009; Vincent et al. 2010).

River Damodar is one of the most important rivers of eastern India especially in Chottanagpur plateau region where it flows through the mineral rich (iron, limestone, and dolomite) Gondwana coal seam basin. Naturally, it became an important source of water for the entire industrial belt and townships developed within the catchment area. The upper and middle stretches of river Damodar are the principal sources for disposal of wastes and industrial effluents from the vicinity of industries. These industrial effluents directly pollute the river water, and it can alter the biophysical and chemical nature of the water body. These industrial effluents or wastes include heavy metal ions, oils, greases, acids, dissolved inorganic, pesticides, polychlorinated biphenyls (PCBs), dioxins, poly-aromatic hydrocarbons (PAHs), petrochemicals, phenolic compounds, and microorganisms. The contemporary studies focused that the untreated industrial effluents and urban sewage are being discharged into the main river Damodar and its tributaries, and as a result, the quality of water has been drastically reduced (De et al. 1980; Tiwary and Abhishek 2005; George et al. 2010; Chatterjee et al.2010; Mukherjee et al. 2012; Banerjee and Gupta 2013; Pal and Maity 2018; Savichev et al. 2020; Chakraborty et al. 2020a).

Therefore, serious attention has to be given to the quality of hydro-ecosystem based on some indicators such as physical, chemical, and biotic parameters. Previously, various studies on water quality and river health have been conducted on river Damodar (Basu and Mitra 2002; Tiwary and Abhishek 2005; Chakraborty et al. 2020a; Savichev et al. 2020; Chakraborty et al. 2020a).
resources and over population. The eco-restoration of river quality during COVID-19 lockdown will bring new horizons for environmental sustainability through the amendment of untreated industrial effluents, urban sewage, and rampant water use.

**Materials and method**

**Study area**

River Damodar originates from Khamarpat hill of Palamau district of Jharkhand state of India and 563 km long river flows towards the east direction and finally joins with river Bhagirathi near the Bay of Bengal. The latitudinal and longitudinal extensions of the river Damodar are 22°15′ to 24°32′N and 84°30′ to 88°20′E. The upper and middle catchments of this river are rich in various minerals and high-quality coal deposition of the Gondwana period. Due to the high availability of mineral resources and fresh water at the middle catchment of Damodar River, mining, coal, and other industries have been gradually developed. Many medium and large urban centers have also been emerged depending on these industries. River water is the principal source for drinking, domestic, and industrial purposes in this region. Thus, the entire mineral-rich catchment is highly pressurized by various anthropogenic activities along with multi-storeyed buildings. The large scale discharge of industrial effluents (solid/liquid), toxic elements, mining activities, and urban runoff deteriorates the health of water day by day. The present study has confined within the middle catchment of about 65.37 km stretch of river Damodar (from Panchet dam 23°40′50″ N/86°44′50″ E to the border of Jharkhand and West Bengal to Durgapur barrage 23°40′50″ N/87°18′39″E) (Fig. 1). This zone is highly suitable for industrial activities and coal mining due to landscape morphology, road accessibility, and connectivity. As a result, different iron and steel plant, thermal power plant, sponge iron factory, cement factory, and chemical industries are established in this region. These industrial effluents and coal mining dusts are discharged to the main river directly or through the tributary streams or “nallas” (Fig. 2a, c).

**Sample collection and analysis**

The water samples were collected from eleven (11) locations at the confluence zone of local “nallas” or small tributary channels with river Damodar in the month of December 2019 (normal condition) and June 2020, i.e., during the unlock period to evaluate the variation of water quality at the same locations. The stratified random sampling technique was carried out. Here, a stratified sampling technique has been applied due to heterogeneous pollution status throughout the river stretch. All confluence points have been considered due to the high possibility of the commencement of pollutants intermixing with fresh water. Subsequently, water samples of various depths have been collected but not significant results have come out. Therefore, to get authentic and momentous pollution status, the mentioned method has been used. Similarly, a composite sampling technique (5 random samples at confluence point) has been taken to reduce the data error and simultaneously to improve the uniformity among the samples. The sample locations are marked by a portable GPS receiver, and these locations are shown in Fig. 1. Here, five samples were collected from each sample site at 0.5 m depth within 5 m radius of discharge effluents area and mixed properly in such a way to obtain the representative mix of samples (1 lit) (Sharma et al. 2020a; Vasistha and Ganguly 2020a; Vasistha and Ganguly 2020b). The samples were collected in pre-cleaned and de-ionized bottles and preserved in a proper way. Different types of physical, chemical, and biological parameters were considered for the assessment of river water quality. The parameters like pH and EC were analyzed in the field using portable devices (Hanna HI9811–5). TDS was measured by the procedure given by Hem (1991). The concentration of HCO$_3^-$, SO$_4^{2-}$, Fe, TN, BOD, and DO was determined by the standard procedures (APHA 2012). TH was estimated by the EDTA titrimetry method (Adimalla and Wu 2019). The spectrophotometer was also used to measure Fe, SO$_4^{2-}$ concentration in the laboratory. Bicarbonate (HCO$_3^-$), Ca$^{2+}$, Mg$^{2+}$, and Cl$^-$ were measured by the volumetric method. BOD was tested by incubation of sample water at 20 °C temperature for 5 days (APHA 5210 B). DO was estimated by Winkler’s method on the spot immediately (Chatterjee et al. 2010). Chlorophyll a was estimated by acetone method by using a spectrophotometer. Total phosphorus was determined by the standard method (4500-P) of APHA (2012). Total nitrogen (TN) was measured by the ion chromatography method. Transparency of river water was measured by Secchi disk of 8 in. diameter with attached cord in the center of the disk and expressed in meters at the maximum depth where the disk was seen into the water.

**Water quality index**

The Bureau of Indian Standard Water Quality Index (BSI WQI) is the Indian national WQI standard parameters which are defined by the Government of India under IS: 10500. However, to identify the overall status of all the parameters, the widely accepted water quality index (WQI) technique is used. In this study, all the relevant parameters were used to calculate WQI. There are four important steps, which are applied to determine the WQI (Mukherjee et al. 2012; Singh et al. 2018; Vasistha and Ganguly 2020b):

Step 1: a weight ($w_i$) was assigned for each parameter by their relative influence on the overall quality of water. The $w_i$ ranges from 1 to 5. After rating, relative
weight ($W_i$) was computed by using the following formula (Table 1)

$$W_i = w_i / \sum_{i=1}^{n} w_i$$

(1)

Where $W_i$ is relative weight to be determined; $w_i$ is the weight of parameters concerned, and $n$ is the total number of parameters.

Step 2: next, quality rating ($q_i$) was calculated by the concentration of parameter for each sample ($c_i$) multiplied by their respective standard limit ($s_i$). All the standard limits were taken from BIS guideline (2012) (Table 1)

$$q_i = (c_i \times s_i) \times 100$$

(2)
Where $q_i$ is quality rating, $c_i$ means concentration of each parameter in every sample, and $s_i$ denotes standard or desirable limit of the parameter as specified in BSI 10500 (2012).

Step 3: sub-index (SI) was calculated by multiplying $q_i$ with $w_i$

$$SI_i = W_i \times q_i$$  \hspace{1cm} (3)

Where

$SI_i$ signifies sub-index function for $i$th parameter. $W_i$ stands relative weight determined for the parameter. $q_i$ means rating scale based on quality.

Step 4: WQI was calculated by summation of all sub-index in a sample:

$$BISWQI = \sum_{i=1}^{n} SI_i$$  \hspace{1cm} (4)

Fig. 2 Some pictorial glimpses of water pollution in Damodar riverbed near industrial sites. (a) Drainage of industrial polluted water to the river by nallas, (b) abundance of phytoplankton in the river water, (c) solid effluents of industries mixing with river water, (d) industrial site in the bank of river Damodar, (e) phytoplankton development in the river water, and (f) visibly clear river water during lockdown period
Table 1 Threshold values and relative weight (Wi) used for different water quality parameters (after Singh et al. 2018; Vasistha and Ganguly 2020a)

| Parameters | Threshold value (BIS 2012) | Weight (wi) | Relative weight (Wi) |
|------------|---------------------------|-------------|----------------------|
| pH         | 6.5                       | 5           | 0.088                |
| TDS (mg/l) | 500                       | 5           | 0.088                |
| EC (μg/cm) | 300                       | 5           | 0.088                |
| TH (mg/l)  | 300                       | 4           | 0.070                |
| TA (mg/l)  | 200                       | 4           | 0.070                |
| Ca²⁺ (mg/l)| 75                        | 4           | 0.070                |
| Fe (mg/l)  | 0.3                       | 4           | 0.070                |
| Mg²⁺ (mg/l)| 200                       | 3           | 0.053                |
| BOD (mg/l)| 5                         | 5           | 0.088                |
| DO (mg/l) | 6                         | 5           | 0.088                |
| Cl⁻ (mg/l)| 250                       | 5           | 0.088                |
| SO₄²⁻ (mg/l)| 200                     | 5           | 0.088                |

The categorization of WQI rating values (Singh et al. 2018; Vasistha and Ganguly 2020a) was followed by the BISWQI method and classified into five groups as “excellent” (<50), “good” (50–100), “poor” (100–200), “very poor” (200–300), “unfit for drinking” (>300). The values of WQI were interpolated with the inverse distance weightage (IDW) method by using the ArcGIS 10.4 for its spatial variation in two different situations (pre-lockdown and during lockdown).

Trophic state index (TSI)

Trophic level index was measured by the logarithmic transformation (Ln) of Secchi disk depth (SD), chlorophyll a (Chl a), total nitrogen (TN), and total phosphorus (TP) values of sample water by the following equation (Carlson 1977; Shekha et al. 2017):

\[
TS(\text{SD}) = 60.0 - 14.41 \times \text{Ln}(\text{SD})
\]

\[
TS(\text{TP}) = 14.42 \times \text{Ln}(\text{TP}) + 4.15
\]

\[
TS(\text{Chl.a}) = 30.6 + 9.81 \times \text{Ln}(\text{Chl.a})
\]

\[
TS(\text{TN}) = 54.45 + 14.43 \times \text{Ln}(\text{TN})
\]

\[
TSI = \left[\frac{TS(\text{SD}) + TS(\text{TP}) + TS(\text{Chl.a}) + TS(\text{TN})}{4}\right]
\]

Where SD indicates Secchi disk depth (m), TP indicates total phosphorous (μg/l), Chl a indicates chlorophyll a (μg/l), and TN indicates total nitrogen (mg/l).

TSI values were classified according to Carlson’s method and grouped into seven categories as “Oligotrophic” (<30), “Oligotrophic” (30–40), mesotrophic (40–50), low eutrophic (50–60), moderate eutrophic (60–70), high eutrophic (70–80), and very high eutrophic (>80). The values of TSI of both seasons have been interpolated using the IDW method on the Arc GIS platform for the creation of a spatial distribution map.

Statistical analysis

The descriptive statistics and Pearson’s correlation coefficient analysis are often used in environmental monitoring dataset applications for reducing dimensionality and biasness that will be helpful for the evaluation of the data. In this study, the effect of lockdown on the quality of river water was statistically tested using t-test. The null hypothesis was that there was no significant difference of water quality between the two time periods. Null hypothesis (H₀) will be rejected if the calculated value (T) appears more than the critical value (table value) at a pre-defined significant level (0.05 for this study). If the calculated value is less than the table value then the null hypothesis will be accepted (Rao et al. 2018). The calculation procedure of the “t” test has been done through the following formula.

\[
d = \frac{\sum d}{n}
\]

\[
S = \sqrt{\frac{\sum d^2 - (\bar{d})^2 \times n}{n-1}}
\]

\[
T_{test} = \frac{d \times \sqrt{n}}{s}
\]

Where d indicates the difference between two variables, n indicates the total number of variables, d specifies the value of mean difference, and S shows the standard deviation of the differences. All statistical analysis has been carried out through SPSS-16 software.

Results and discussion

Hydro-chemical characteristics

Descriptive statistics and correlation coefficient are popularly used to detect the trend of variables and the interrelation among variables (Das and Nag 2017). Descriptive statistics of river water quality parameters during the pre-lockdown period (Table 2) show that the trend of chemical concentration of river water was in the order of HCO₃⁻ > Cl⁻ > SO₄²⁻ > Ca²⁺ > Mg²⁺ > TN > Fe²⁺ in this season. In the pre-lockdown period, skewness of pH, TDS, EC, TA, Ca²⁺, Cl⁻, SO₄²⁻, Chl a, PO₄³⁻, and TN indicates negative distribution while TH, Fe, Mg²⁺, HCO₃⁻, and BOD signify positive distribution of their values. On the other hand, during lockdown, chemical concentration showed an order of Cl⁻ > HCO₃⁻ > SO₄²⁻ > Ca²⁺ > TN > Fe²⁺. Similarly, skewness of pH, TDS, EC, TA, Ca²⁺, Cl⁻, SO₄²⁻, DO, Chl a, PO₄³⁻, and TN designates negative distribution,
whereas TH, Fe, Mg\(^{2+}\), Hco\(^{-3}\), and BOD show positive distribution of their values (Table 3).

**Physical parameters**

The water pH is very essential and primary indicator of water quality. It indicates the hydrogen concentration in the water. According to BIS, the desirable limit of pH in drinking water is 6.5. In pre-lockdown, pH level ranges from 7.04 to 8.21 with an average value of 7.45 ± 0.38 (mean ± SD). During the unlock period, the pH level of all the samples ranges from 6.12 to 7.72 with an average of 6.92 ± 0.48. The lower level of pH in the unlock period is mainly due to less or no mixing of industrial effluents containing high alkaline solutions. TDS or total dissolved solid level in river water is increased by mixing of various soluble minerals, industrial waste effluents etc. The desirable limit of TDS in drinking water is 500 mg/l given by BIS. Electronic conductivity or EC indicates the physical pollutant load of water. The higher value of EC reflects the lower quality of drinking water. According to BIS, the standard limit of EC in drinking water is 300 μS/cm. Total hardness (TH) is also an important parameter for water quality

| Parameters | Mean  | SD    | Kurtosis | Skewness | Minimum | Maximum |
|------------|-------|-------|----------|----------|---------|---------|
| pH         | 6.92  | 0.48  | -0.71    | -0.16    | 6.12    | 7.72    |
| TDS (mg/l) | 524.86| 26.30 | -0.67    | -0.43    | 480.00  | 563.20  |
| EC (μg/cm) | 820.09| 41.09 | -0.67    | -0.43    | 750.00  | 880.00  |
| TH (mg/l)  | 282.00| 30.38 | -0.07    | 0.34     | 240.00  | 340.00  |
| TA (mg/l)  | 313.64| 39.57 | 0.50     | -0.97    | 230.00  | 360.00  |
| Fe (mg/l)  | 3.59  | 0.46  | -1.91    | 0.32     | 3.10    | 4.20    |
| Ca\(^{2+}\) (mg/l) | 64.82 | 9.84  | -1.00    | -0.32    | 50.00   | 79.00   |
| Mg\(^{2+}\) (mg/l) | 27.00 | 3.00  | -0.68    | 0.08     | 22.00   | 32.00   |
| Hco\(^{-3}\) (mg/l) | 179.09| 18.14 | -0.58    | 0.04     | 150.00  | 210.00  |
| Cl\(^{-}\) (mg/l) | 198.18| 17.22 | -1.31    | -0.23    | 170.00  | 220.00  |
| So\(^{-4}\) (mg/l) | 127.27| 34.38 | -0.54    | -0.67    | 70.00   | 170.00  |
| BOD (mg/l) | 7.27  | 2.41  | 2.31     | 1.54     | 5.00    | 13.00   |
| DO (mg/l)  | 7.31  | 0.60  | 0.53     | -0.74    | 6.15    | 8.15    |
| Chl a (mg/l) | 29.18 | 9.01  | -0.84    | -0.81    | 14.00   | 39.00   |
| PO\(_4\) (mg/l) | 18.36 | 6.10  | -1.29    | -0.61    | 9.00    | 25.00   |
| TN (mg/l)  | 34.65 | 6.67  | -0.08    | -0.64    | 22.40   | 43.80   |

| Parameters | Mean  | SD    | Kurtosis | Skewness | Minimum | Maximum |
|------------|-------|-------|----------|----------|---------|---------|
| pH         | 6.92  | 0.48  | -0.71    | -0.16    | 6.12    | 7.72    |
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| EC (μg/cm) | 820.09| 41.09 | -0.67    | -0.43    | 750.00  | 880.00  |
| TH (mg/l)  | 282.00| 30.38 | -0.07    | 0.34     | 240.00  | 340.00  |
| TA (mg/l)  | 313.64| 39.57 | 0.50     | -0.97    | 230.00  | 360.00  |
| Fe (mg/l)  | 3.59  | 0.46  | -1.91    | 0.32     | 3.10    | 4.20    |
| Ca\(^{2+}\) (mg/l) | 64.82 | 9.84  | -1.00    | -0.32    | 50.00   | 79.00   |
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| TN (mg/l)  | 34.65 | 6.67  | -0.08    | -0.64    | 22.40   | 43.80   |
assessment. It is the concentration of two cations-calcium and magnesium in water. The higher level of TH decreases the solubility of soap in water. The standard limit of TH in drinking water is 200 mg/l. In the study area, the concentration of TDS, EC, and TH in pre-lockdown period ranges from 665.6 to 806.4 mg/l, 1040 to 1260 μS/cm and 350 to 580 mg/l with an average value of 740.65 ± 50.23 mg/l, 1157.27 ± 78.49 μS/cm, and 470.90 ± 80.18 mg/l, respectively, while in lockdown phase it ranges from 480 to 563.2 mg/l, 750 to 880 μS/cm, and 240–340 mg/l with an average value of 524.85 ± 26.29 mg/l, 820.09 ± 41.09 μS/cm, and 282 ± 30.38 mg/l, respectively. The concentration of total alkalinity (TA) varies from 350 to 540 mg/l with an average of 467.27 ± 56.23 in the pre-lockdown period. During lockdown, the TA fluctuates from 230 to 360 mg/l with an average of 313.63 ± 39.56. The BIS has fixed the permissible limit of TA, which is 200 mg/l. It is clearly noticed that the closing of industrial and mining activities in Damodar river bank has highly reduced the concentration of physical quality parameters in river water during the lockdown period.

Chemical parameters

Chemical parameters such as Fe, Ca^{2+}, Mg^{2+}, HCO_3^−, Cl^−, SO_4^{2−}, and TN are very important elements, which are mainly contributed by various industrial activities. According to BIS (2012), the standard limit of Fe, Ca^{2+}, Mg^{2+}, HCO_3^−, Cl^−, SO_4^{2−}, and TN is 0.3 mg/l, 75 mg/l, 30 mg/l, 200 mg/l, 250 mg/l, 200 mg/l, and 45 mg/l, respectively. In pre-lockdown period, the values of Fe, Ca^{2+}, Mg^{2+}, HCO_3^−, Cl^−, SO_4^{2−}, and TN were ranged from 3.1 to 5.74 mg/l, 94 to 194 mg/l, 50 to 85 mg/l, 370 to 580 mg/l, 290 to 480 mg/l, 300 to 410 mg/l, and 43.2 to 82 mg/l, respectively. During lockdown, the concentration of these four parameters ranges from 3.1 to 4.2 mg/l, 50 to 79 mg/l, 22 to 32 mg/l, 150 to 210 mg/l, 170 to 220 mg/l, 70 to 170 mg/l, and 22.4 to 43.8 mg/l, respectively. Subsequently, phosphorous (PO_4) varied from 40 to 90 μg/l and 9 to 25 μg/l in pre-lockdown and during lockdown, respectively. It is clear that low input of chemical elements through industrial effluents reduces the concentration of heavy metals in river water during the lockdown period.

Biological parameters

Biological oxygen demand (BOD) is a very essential water quality parameter. The various chemical reactions, respiration of microbial elements, aquatic animals, and decomposition of organic pollutant burn oxygen, and thus BOD increases in the aquatic ecosystem. The higher level of BOD indicates poor water quality. BIS has specified that the desirable limit of BOD in drinking water is 5 mg/l. In the study area, BOD in pre-lockdown ranged from 7 to 18 mg/l with a mean value of 12.54 ± 3.47 mg/l. In the lockdown period, low or no mixing of organic chemicals has helped to decrease the level of BOD in this river water and it ranges from 5 to 13 mg/l with an average value of 7.27 ± 2.41 mg/l (mean ± SD). DO or dissolved oxygen is totally the opposite of BOD. It indicates the availability of oxygen in water. The higher rate of DO signifies better quality of water. It is very necessary for the water ecosystem. BIS has fixed the threshold value of DO to be 6 mg/l. In the pre-lockdown period, the range of DO was 4.2–5.67 mg/l with a mean value of 4.87 ± 0.49 mg/l, and during lockdown, it has been increased to a range of 6.15 to 8.15 mg/l with an average value of 7.31 ± 0.59 mg/l. No mixing of industrial waste water helps to generate more DO in river water during the lockdown phase by aquatic plants. Chlorophyll a concentration is ranged from 54 to 99 μg/l in pre-lockdown period and 14 to 39 μg/l during the lockdown period with an average of 76.09 ± 16.85 and 29.18 ± 9.00, respectively.

Pearson’s correlation

Correlation coefficient of pre-lockdown (Table 4) shows that there is a highly positive correlation of Ca^{2+}, HCO_3^−, and Cl^− with pH, EC with HCO_3^−, TH and TA with Mg^{2+}, BOD with Fe, Ca^{2+} with HCO_3^−, Cl^−, and SO_4^{2−}. Similarly, the highly positive correlation is also established of Mg^{2+} with Cl^− and BOD, HCO_3^− and SO_4^{2−} with Chl a and PO_4. The negative correlation is showed among TH, Fe with pH, while Do has a negative correlation with all parameters except pH and chlorophyll a. During the lockdown period, a high positive correlation is found among pH, Fe, Cl^− and Chl a, TDS, EC with Cl^−, TA with Mg^{2+}, Ca^{2+} with NO_3^−, Cl^−, SO_4^{2−} with Chl a, PO_4, and TN (Table 5). It is evidenced from this matrix that during both the time periods, no significant relationships have been established between the chemical parameters. It is due to the independent characteristics of these parameters.

Impact on individual quality parameters

The impact of lockdown on the concentration of individual water quality parameters was tested using the t-test technique. T-test of 16 different variables during pre-lockdown and unlock period shows that the t-value of all parameters is greater than their table values or critical values at 0.05 level of significance (Table 6). Therefore, it can be inferred with confidence that lockdown has brought significant impacts to reduce the Damodar river water quality, particularly at middle catchment. It is now clear that the industrial activities are the main reason for the deterioration of the river water quality.

Impact on overall water quality

The assessment of water quality has been conducted by using WQI, and this index is ranged from 219.71 to 326.17 in the
pre-lockdown period with a mean value of 286.70 (Table 7). During the lockdown period, WQI ranges from 171.53 to 222.12 with a mean value of 195.52. The comparison of WQI between pre-lockdown and lockdown period was tested using t-test with 5% level of significance. According to the BIS guideline, the WQI values of sample sites 1, 2, 3, 6, 7, and 11 indicate “very poor” quality (WQI = 200–300) of river water. The sample sites 4, 5, 8, 9, and 10 indicate “unfit for drinking” (WQI > 300) in the pre-lockdown period (Fig. 3a). Subsequently, coal mining activities and harmful chemical waste of sponge iron factory contributed various pollutants to the river Damodar. The sample sites S4, S5, S8, S9, and S10 (the confluence zones) were the most deteriorated within the study area. The polluted waste solid, liquid effluents with high quantity of chemicals from iron and steel industries, chemical industries, and thermal power plant were regularly released into the river, and as a result, the river water is severely polluted. It leads to increase the TDS, EC, TH, and

| Table 4 | Pearson’s correlation matrix of water quality parameters during pre-lockdown phase |
|---------|---------------------------------|
| PH  | TDS  | EC  | TH  | TA  | Fe  | Ca  | Mg  | HCO3 | Cl  | SO4 | BOD | DO  | Chl a | PO4 | TN |
| PH  | 1    |    |     |     |     |    |     |     |      |     |      |     |     |     |    |
| TDS | 0.29 | 1.00 | 1.00 |     |     |    |     |     |      |     |      |     |     |     |    |
| EC  | 0.29 | 1.00 | 1.00 |     |     |    |     |     |      |     |      |     |     |     |    |
| TH  | −0.02 | 0.57 | 0.57 | 1.00 |     |    |     |     |      |     |      |     |     |     |    |
| TA  | 0.15 | 0.39 | 0.39 | 0.49 | 1.00 |     |     |     |      |     |      |     |     |     |    |
| Fe  | −0.10 | 0.38 | 0.38 | 0.54 | 0.57 | 1.00 |     |     |      |     |      |     |     |     |    |
| Ca  | 0.69 | 0.15 | 0.15 | 0.14 | 0.15 | 0.03 | 1.00 |     |      |     |      |     |     |     |    |
| Mg  | 0.36 | 0.56 | 0.56 | 0.68 | 0.80 | 0.42 | 0.46 | 1.00 |     |      |     |     |     |     |    |
| HCO3 | 0.66 | 0.76 | 0.76 | 0.44 | 0.31 | 0.27 | 0.65 | 0.63 | 1.00 |     |      |     |     |     |    |
| Cl  | 0.63 | 0.50 | 0.50 | 0.53 | 0.53 | 0.29 | 0.68 | 0.77 | 0.86 | 1.00 |     |     |     |     |    |
| SO4 | 0.56 | 0.31 | 0.31 | 0.48 | 0.46 | 0.39 | 0.61 | 0.58 | 0.70 | 0.89 | 1.00 |     |     |     |    |
| BOD | 0.24 | 0.43 | 0.43 | 0.49 | 0.59 | 0.66 | 0.53 | 0.62 | 0.64 | 0.77 | 0.83 | 1.00 |     |     |    |
| DO  | 0.05 | −0.14 | −0.14 | −0.21 | −0.55 | −0.10 | 0.08 | −0.23 | −0.11 | −0.23 | −0.21 | −0.15 | 1.00 |     |    |
| Chl a | 0.42 | 0.29 | 0.29 | 0.19 | 0.06 | 0.11 | 0.60 | 0.32 | 0.73 | 0.79 | 0.77 | 0.73 | 0.05 | 1.00 |    |
| PO4 | 0.41 | 0.52 | 0.52 | 0.55 | 0.42 | 0.44 | 0.58 | 0.61 | 0.78 | 0.90 | 0.86 | 0.90 | −0.05 | 0.87 | 1.00 |
| TN  | 0.26 | −0.15 | −0.15 | −0.23 | −0.28 | −0.18 | 0.24 | −0.15 | 0.34 | 0.36 | 0.30 | 0.12 | −0.13 | 0.61 | 0.28 | 1.00 |

| Table 5 | Pearson’s correlation matrix of water quality parameters during lockdown phase |
|---------|---------------------------------|
| PH  | TDS  | EC  | TH  | TA  | Fe  | Ca  | Mg  | HCO3 | Cl  | SO4 | BOD | DO  | Chl a | PO4 | NO3-|
| PH  | 1    |    |     |     |     |    |     |     |      |     |      |     |     |     |     |
| TDS | 0.47 | 1.00 |     |     |     |    |     |     |      |     |      |     |     |     |     |
| EC  | 0.47 | 1.00 | 1.00 |     |     |    |     |     |      |     |      |     |     |     |     |
| TH  | 0.15 | −0.53 | −0.53 | 1.00 |     |    |     |     |      |     |      |     |     |     |     |
| TA  | 0.46 | −0.07 | −0.07 | 0.59 | 1.00 |     |     |     |      |     |      |     |     |     |     |
| Fe  | 0.61 | 0.10 | 0.10 | 0.05 | 0.17 | 1.00 |     |     |      |     |      |     |     |     |     |
| Ca  | 0.59 | 0.59 | 0.59 | 0.04 | 0.38 | −0.04 | 1.00 |     |      |     |      |     |     |     |     |
| Mg  | 0.31 | −0.02 | −0.02 | 0.23 | 0.68 | 0.38 | −0.06 | 1.00 |     |      |     |     |     |     |
| HCO3 | 0.33 | −0.10 | −0.10 | 0.28 | 0.55 | 0.41 | 0.06 | 0.75 | 1.00 |     |      |     |     |     |     |
| Cl  | 0.63 | 0.62 | 0.62 | −0.19 | 0.13 | 0.17 | 0.62 | 0.12 | 0.47 | 1.00 |     |     |     |     |     |
| SO4 | 0.69 | 0.38 | 0.38 | 0.15 | 0.57 | 0.06 | 0.63 | 0.50 | 0.56 | 0.75 | 1.00 |     |     |     |     |
| BOD | 0.49 | 0.27 | 0.27 | 0.10 | 0.50 | 0.06 | 0.24 | 0.36 | 0.46 | 0.62 | 0.60 | 1.00 |     |     |     |
| DO  | −0.34 | −0.11 | −0.11 | 0.07 | −0.37 | −0.25 | −0.22 | −0.31 | −0.62 | −0.59 | −0.39 | −0.75 | 1.00 |     |     |
| Chl a | 0.60 | 0.40 | 0.40 | 0.04 | 0.23 | 0.03 | 0.54 | 0.26 | 0.51 | 0.89 | 0.90 | 0.59 | −0.42 | 1.00 |     |
| PO4 | 0.48 | 0.34 | 0.34 | −0.01 | 0.19 | −0.01 | 0.39 | 0.33 | 0.55 | 0.84 | 0.86 | 0.60 | −0.41 | 0.98 | 1.00 |
| NO3- | 0.53 | 0.43 | 0.43 | 0.00 | 0.13 | −0.06 | 0.74 | 0.05 | 0.27 | 0.76 | 0.80 | 0.22 | −0.20 | 0.86 | 0.77 | 1.00 |
BOD levels in comparison with the normal time frame or pre-lockdown phase. In the lockdown phase, closing of mining activities and cement factory on the river bank improves the water quality of these given sites and the WQI values indicate “poor” category of the sample sites 1, 2, 3, 6, 7, and 11 (WQI = 100 – 200) while sample sites 4, 5, 8, 9, and 10 show “very poor” quality of water. The very poor water quality (sample sites 4, 5, 8, 9, and 10) is due to the location of Durgapur barrage as well as large amount of industrial effluents is being discharged to the main stream through the tributaries, which are connected with the lower stretch (in respect to studied river stretch) of the river Damodar. In case of the non-monsoonal period, pollutants with water are mostly confined behind the Durgapur barrage. In the lockdown phase, the WQI shows clean or transparent water by increasing DO and decreasing other parameters, and it brings comparatively better river health as well as suitable habitat for aquatic species (Fig. 3b). Thus, it is clearly observed that the closing of industrial activities and no mixing of effluents has significantly helped to improve water quality during the lockdown period.

**Impact of trophic state index (TSI)**

Based on the nutrient status of sample water, the TSI of river Damodar in the study area reflects (Table 8) “High” eutrophic zone (TSI = 70 to 80) all over the sample sites (Fig. 4a). During lockdown period, TSI value shows “Low” eutrophic zone (TSI = 50 to 60) for sample sites 1 and 2 while “Moderate” eutrophic zone (TSI = 60 to 70) has been identified at sample sites 3, 4, 5, 6, 7, 8, 9, 10, and 11 (Fig. 4b). Decreasing of chlorophyll content, phosphorous, and nitrogen in river water and increasing of Secchi desk transparency help to promote river health by reducing nutrient levels in the lockdown period. Good river health means standard water qualities where aquatic species can comfortably survive and the growth of benthic plants will be limited on the riverbed. The riverbed is gradually accumulated by nutrients from different non-point sources (industrial and modern agricultural systems), and these huge nutrients demand more oxygen during decomposition. But during lockdown, most of the sources are closed; as a result, the eutrophic zone of river stretch has been converted into oligotrophic and meso-eutrophic stage. This is a standard stage for aquatic plants and animals, and it brings superior water condition or high-quality river health for aquatic lives.

**Conclusion**

From the scientific study, it is concluded that the effluents (solid/liquid) of riverside industries have a major harmful effect on the river Damodar. In the past normal years, the quality of this river water was very poor, and it directly damaged the water quality or health of the aquatic environment. The previous studies on the water quality of river Damodar proved that the river water throughout the catchment area was very much affected by nearby coal dust, iron and steel industries, power plants, chemical industries, etc. (Bhattacharyya et al. 2013; Sundararajan and Mohan 2011; Ghosh and Banerjee 2012; Singh et al. 2014; Chatterjee et al. 2010; George et al. 2010; Mukherjee et al. 2012). These previous research works focused that the abundance of TDS, TH, BOD, Fe, and NO₃⁻ in the river water is the principal cause of water quality deterioration. The present study also highlighted that all these
parameters are found beyond the permissible limit during pre-lockdown, while lockdown period water quality has significantly improved due to restricted economic activities. Thus, the countrywide lockdown due to the COVID-19 pandemic has brought noticeable changes to the overall quality of river water, and it has turned to be a positive condition for nature’s restoration. Industrial effluents from nearby chemical factories, thermal power stations, cement factories, and coal mining activities have been deteriorating the water quality of river Damodar in the last three or four decades. High concentration of pH, TDS, TH, TA, Fe, Ca\(^{2+}\), Mg\(^{2+}\), and BOD badly affects the functions of the river ecosystem and human health. The WQI of the pre-lockdown period indicates as “very poor” to “unfit for drinking” in the study area. Here, during lockdown, no mixing of industrial waste water has improved the water quality within a few months, and it has turned into very good condition. During lockdown, the eutrophic zones (applying TSI) have been significantly modified in different pockets throughout the stretch of river Damodar. The short-term lockdown is blessings for the health of the total environment. So,
Fig. 4 Spatial variation of river trophic state index. (a) Pre-lockdown phase and (b) during lockdown phase

Fig. 5 Restoration pathways of riparian vegetation and improving water quality
sustainable development is most important for the eco-restoration of different components of the environment along with further economic progress. Still, the river water is being polluted from various non-point sources such as agricultural run-off, urban wastewater, industrial waste, and garbage dumping. This ground reality or model is vital for sustainable land-use practices and water resource management (Fig. 5). Riparian vegetation zone influences river water chemistry through diverse processes including direct chemical intake and cycling by vegetation to indirect influences such as by supply of organic contents to shallow soils and channels, modification of water movement activities, and stabilization of soil properties (Malan et al. 2018; Chua et al. 2019). It is possible if the industries are situated near the river and clearly maintain the environmental guidelines while releasing their polluted solid or liquid waste into the river water (Fig. 5). So, wastewater and industrial waste should be discharged into the river or riparian wetland. The Government policies and actions are very much helpful for implementing measures such as the Water (Prevention and Control of Pollution) Act 1974, Environment Protection Act 1971. However, public awareness about the environment and human health will be the most vital apparatus for the achievement of environmental sustainability. More fundamental and applied research is required to make management policies and laws for sustainable river health restoration from irrational human use. The government should establish a separate department like “River Research Institute” to look after the overall health of the river through the changing natural and anthropogenic paradigm. This field-based scientific study will definitely assist the development planners, policy makers, and administrators for design sustainability during the modern industrial era.

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Author contributions P.K. Shit conceptualized and planned the study and reviewed and edited the manuscript. B. Chakraborty conducted the survey, water sampling, analyzed the data, and interpreted the results. S. Roy conducted the survey and prepared the maps. A. Bera conducted the survey and analyzed the data. P.P. Adhikary reviewed and edited the manuscript. B. Bera supervised the study and reviewed and edited the manuscript. D. Sengupta supervised the overall research and interpreted the results. G.S. Bhunia interpreted the results. All authors have read and approved the final manuscript.

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Compliance with ethical standards

Competing interests The authors declare that they have no competing interests.

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