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Effects of COVID-19 lockdown and unlock on health of Bhutan-India-Bangladesh trans-boundary rivers

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ABSTRACT

The COVID-19 pandemic significantly destructs the rhythm of global modern human civilization but worldwide lockdown radically recovers the health of the total environment. The Himalayan trans-boundary rivers provide huge provisional, regulatory and cultural ecosystem services to millions of people throughout the year but in the recent years the water quality is being deteriorated due to multiple reasons. In the last decade, India-Bangladesh political relationship has been slightly broken down due to water sharing and environmental flow of rivers. The COVID-19 lockdown offered a great scope to execute the comparative study among pre, lockdown and unlock phase. The research attempts to investigate the spatiotemporal water quality of trans-boundary rivers through WAWQI and irrigation water quality indices such as Sodium absorption ratio, Soluble sodium percentage, Potential salinity, Magnesium hazard and Kelly's index considering eighteen water quality parameters (pH, EC, TDS, TSS, Ca²⁺, Mg²⁺, Na²⁺, K⁺, F⁻, Cl⁻, NO³⁻, SO₄²⁻, PO₄³⁻, DO, T, TUR, COD and BOD). The result shows the strong positive correlation between EC and TDS during three phases. Significant reduction of BOD, COD and TUR has been noticed almost 70% stations during lockdown compared with prelockdown while augmentation of DO has been recorded around 40% stations. WQI of most of the stations shows around 80% improvement of water quality during lockdown period. Moreover, worst kind of WQI was found in the Mathabhanga-Churni river followed by Mahananda. During lockdown, the striking results show that SAR and MH were significantly amplified in most of the stations due to agricultural run-off.

1. Introduction

COVID-19 (novel corona virus-disease) confirmed case was first detected in the capital city Wuhan (the capital and the largest city in the Hubei Province in China) in late 2019 (Zhou et al., 2021). SARS-CoV-2 (The severe acute respiratory syndrome Coronavirus 2) has turned into a global pandemic from an epidemic (Huang et al., 2020; Sohrabi et al., 2020) in the year 2020 (Ma et al., 2020; WHO, 2021). The Coronavirus is a physically transferrable through the humans close contact (Wang and Du, 2020) and it is also floating in the air with the aerosol particles

(Lin et al., 2020). The spreading rates are also depending on the humidity and atmospheric temperature (Shao et al., 2021). Coronavirus disease is an illness of the respiratory system and with some symptoms such as coughing, shortness of breath, sneezing and viral fever. About 28 million people have tested positive in India out of 172 million positive cases which have been registered globally (WHO, 2021) whereas at the end of March 2020, the number was more than one million (Han et al., 2020). Most of the countries of the world have strictly imposed lockdown and social distancing norms to control the deadly COVID-19 virus following the guidelines of World Health Organization

Abbreviations: COVID-19, Coronavirus diseases 2019; WHO, World Health Organization; SARS-CoV-2, Severe acute respiratory syndrome coronavirus 2; WAWQI, Weighted Arithmetic Water Quality Index; WQI, Water Quality Index; SPM, Suspended Particulate Matter; pH, Potential of Hydrogen; EC, Electrical Conductivity; TDS, Total Dissolved Solids; TSS, Total Suspended Solids; Ca²⁺, Calcium; Mg²⁺, Magnesium; K⁺, Potassium; Na²⁺, Sodium; F⁻, Fluoride; Cl⁻, Chloride; NO³⁻, Nitrate; SO₄²⁻, Sulphate; PO₄³⁻, Phosphate; DO, Dissolve Oxygen; T, Temperature; TUR, Turbidity; COD, Chemical Oxygen Demand; BOD, Biochemical Oxygen Demand; MSI, Multispectral Imager; OLI, Operational Land Imager; USGS, United States Geological Survey; NIR, Near Infrared; SWIR, Short Wave Infrared; LULC, Land Use Land Cover; SAR, Sodium Absorption Ratio; PS, Potential Salinity; MH, Magnesium Hazard; KI, Kelly's Index.

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while in India the lockdown started on 25th March 2020 and it was continued up to 30th May 2020 (Bera et al., 2020). After that the lockdown has been withdrawn through different phases like unlock-1, 2, 3 and 4 whereas few states of India partial or complete lockdown were continued up to the end of 2020. Although human life or human health (Qiu et al., 2018) is badly obliterated due to such virus and incidentally COVID-19 has given an opportunity to repair the health of the total environment all over the World (Muhammad et al., 2020). Many research regarding COVID-19 and environmental health showed that the health of the total environment has been improved through continuous effects of lockdown (Bera et al., 2021a). Before the pandemic, the level of environmental pollution (Masese et al., 2009) was too much higher but after the emergence of the pandemic situation, the pollution level of the overall environment (Arora et al., 2020) has been incredibly reduced (Qiu et al., 2018). Significant reduction of particulate matter (PM_{10} and $PM_{2.5}$) (Bera et al., 2021b,c) into the atmosphere and slight improvement of concentration of Ozone (O_3) gas (Bera et al., 2021b) was also recorded in different cities of the world at the end of lockdown phase (Mahato et al., 2020). Globally, a significant research showed that -17% carbon emissions has been decreased at the early 2020 (Quéré et al., 2020).

However, not only the air quality was improved due to the COVID-19 first phase lockdown, but also the surface water quality was considerably enhanced and water pollution of ecological environment has been reduced through the natural purification process (Chakraborty et al., 2021c). During the several phases of lockdown (Dutta et al., 2020), pollutant loads such as industrial effluents, urban sewages, agricultural sewages, wastewater etc. (Mello et al., 2018; Khan et al., 2021) have been surprisingly reduced into the river Ganga. A study on river Damodar showed that the water pollution level was considerably diminished in the industrial belt of eastern India during lockdown by avoiding of industrial heavy metal pollutants and industrial liquid sewages (Chakraborty et al., 2021a). Similarly, the above mentioned research reveal that 90.90% of samples water were good during the lockdown period. Another scientific investigation on river Yamuna focused that the declining rate of BOD, COD and suspended particulate (SPM) matter has been registered during the different phases of lockdown (Patel et al., 2020). Similarly, a study in India (Vembanad Kayal, Kerala) also highlighted that how much the supply of suspended particulate matter (SPM) Decreased 15.9% during lockdown) was restricted in the lake water during COVID-19 lockdown and the purification level of lake water has been detected applying remote sensing techniques (Yunus et al., 2020). Another work also investigated that the water quality (Dissolved Oxygen and organic pollutants) was detected through the different spectral bands of OLI image analysis and it showed that how remote sensing technique helped to monitor the spatiotemporal data regarding the water quality assessment (Li et al., 2020).

In general, the impression of land use/land covers also influences the hydro-ecological (Mello et al., 2018) condition of a river. Improvement of biological conductivity of the surface water helps the ecological flow of water. In this context, Water Quality Index (WQI), Water Pollution Index (WPI) and Trophic State Index (TSI) have been used to identify the quality or health status of river water (Chakraborty et al., 2021b). Meanwhile, various land-use or anthropogenic activities (Luo et al., 2020; Sukla and Saxena, 2020) along with unexpected population growth largely influence the water quality in different dimensions (Mcgrane, 2016). Most of the surface and subsurface water quality has been assessed by the standard limits or permissible drinking water limits guided by the World Health Organization (WHO, 2011). The main objective of the study is to assess the water quality of trans-boundary rivers (Indo-Bangladesh) particularly pre, during lockdown and unlock applying water quality index. River Torsha and Jaldhaka originate from Bhutan Himalayas and ultimately flow through India and Bangladesh whereas Teesta, Mahananda (mostly runs on Indian territory) and Mathabhang-Churni originate within Indian territory but ultimately they are flowing on vast landscape of Bangladesh. These sig-

nificant international rivers support multiple provisional, regulatory and cultural ecosystem services to millions of people particularly Bhutan, India and Bangladesh. But in the recent years, the health of these important rivers has been deteriorated due to various causes and COVID-19 lockdown gave great opportunities to do the comparative study and brings point and non-point sources of pollution along with policy framing supportive relevant documents to administrators of Bhutan, India and Bangladesh. There is big research gap in this context because yet not published any trans-boundary river health study during, pre lockdown and unlock phase. This scientific study will definitely outline a sustainable management policy for maintenance of river ecosystem health but there was some limitations due to data shortage and laboratory facilities during strict lockdown phase.

2. Methods and materials

2.1. Study sites

Trans-boundary river represents a hydro-geographic unit which is divided by static national or international political boundaries (Rahman et al., 2019). The importance of trans-boundary rivers is always high due to their international significance in social, cultural, economic, political, ecological and physical aspects. India and Bangladesh are sharing 54 trans-boundary rivers which are part of the Ganga-Brahmaputra-Meghna (GBM) river system (Nishat et al., 2014). To resolve the sensitive issues regarding water sharing of Indo-Bangladesh trans-boundary rivers, Indo-Bangladesh Joint Rivers Commission (1972) was set up and several agreement and treaties have been emerged e.g., Ganga Water Treaty in 1996 and Teesta Agreement in 2011.

Out of 54 rivers, the study was accomplished in five different India-Bangladesh trans-boundary rivers (Torsha, Jaldhaka, Teesta, Mahananda, and Mathabhang-Churni) because of their high international importance, more prone to pollution and availability of data (Table 1). Major rivers like Ganga and Brahmaputra are not considered due to large basin area and lack of data availability. The river Teesta (410 km), Mahananda (389 km), Jaldhaka (250 km) and Torsha (145 km) are originated from the Eastern Himalayan range and they are flowing through Rajmahal-Garo Gap (Niyogi, 1981) whereas Mathabhang-Churni (184 km) is formed within the Bengal Basin region (Rudra, 2018). All the above mentioned rivers are directly linked with the Ganga-Brahmaputra river system (Basu and Chakraborty, 1972). Here, Torsha, Jaldhaka, and Teesta are significant tributaries of the mighty river Brahmaputra (Jamuna in Bangladesh) while Mahananda

Table 1
Monitoring Stations, Station Codes and Coordinates of Selected trans-boundary rivers.

River	Monitoring Stations	Station Code	Coordinates
Mahananda	Siliguri	St-1	26.7094 N 88.4255 E
	Ramghat	St-2	26.7020 N
Teesta	Sevoke	St-3	88.4084 E 26.8909 N 88.4727 E
	Jalpesh	St-4	26.5250 N 88.8677 E
Jaldhaka	Dhupguri	St-5	26.5821 N 89.0052 E
Torsha	Hasimara	St-6	26.7335 N 89.3510 E
	Ghughumari	St-7	26.3337 N 89.3286 E
Mathabhang-Churni	Majhdia	St-8	23.4195 N 88.7253 E
	Gobindapur	St-9	23.3673 N 88.6120 E
	Ranaghat	St-10	23.1050 N 88.5606 E

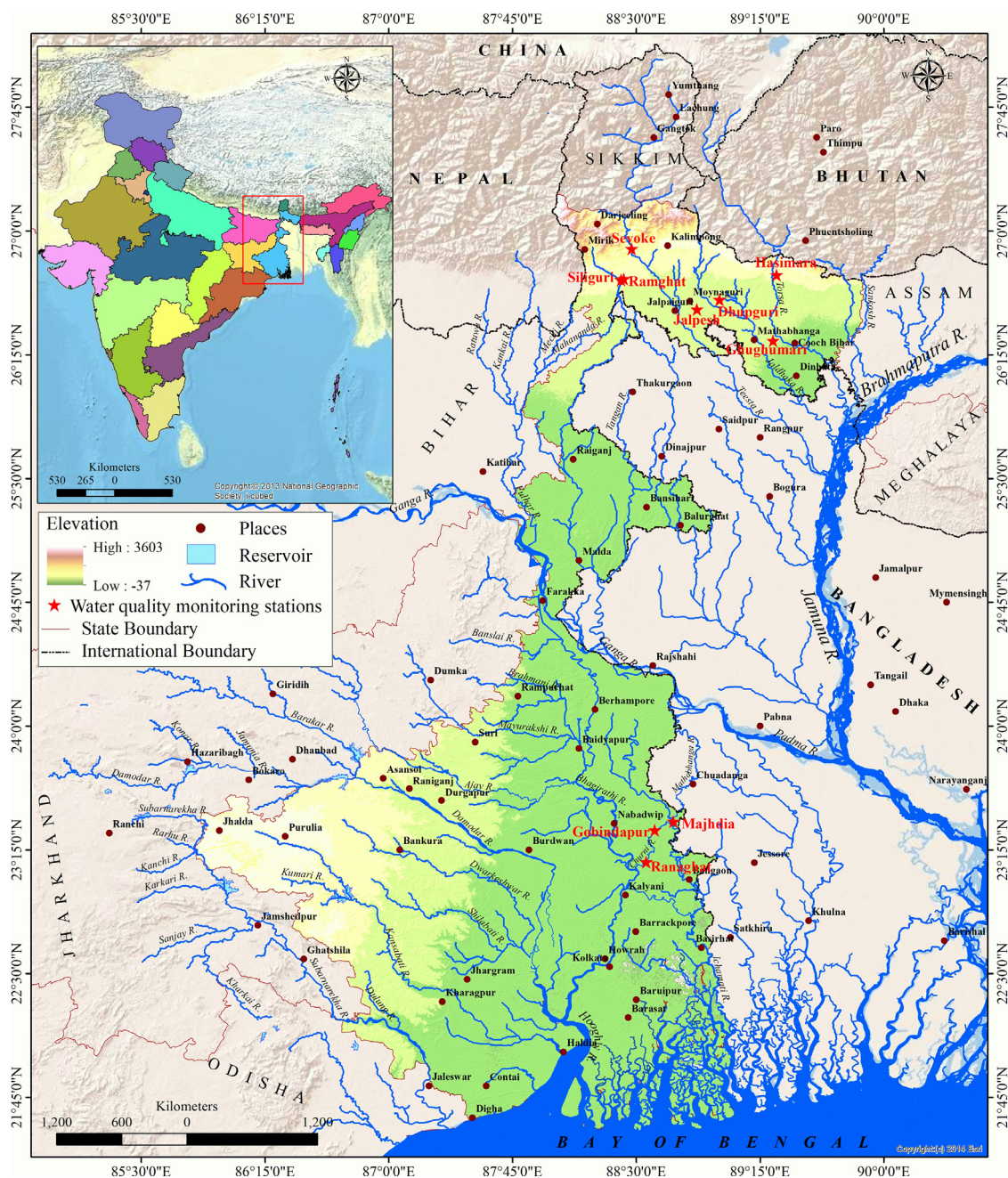


Fig. 1. Location map of the study sites.

is a tributary of river Ganga. The remaining river Mathabhanga-Churni is an important distributary of river Bhagirathi-Hooghly. The Ganga-Brahmaputra River system is also well known for the world's largest sediment carrying load as high as 10^9 t/y (Goodbred and Kuehl, 2000). The geographical extension of these trans-boundary rivers (Fig. 1) is between $22^{\circ}55'N$ to $28^{\circ}10'N$ and $88^{\circ}0'E$ to $90^{\circ}0'E$. Around 76.8% of the estimated annual rainfall occur due to southwest monsoon and it is highly variable. The average rainfall pattern of the study area ranges from a minimum of 1295 mm to a maximum of 3945 mm (Das and Banerjee, 2020). The altitude of the study area varies between 6000 m and 2 m above mean sea level. According to Koppen (1936), the total study area covers three major climatic typologies like (a) Dfc (Cold, Humid winters type with shorter summer) (b) Cwg (Monsoon type with dry winters) and (c) Aw (Tropical Savannah). Most of the areas are characterized by a high-density of population except highly elevated

mountainous regions. This region has more than 120 Million population and it hosts around 2% of world's total population (Mukherjee et al., 2009).

2.2. Data collection, sampling, and monitoring parameters

After the outbreak of covid-19, all nations had taken different preventive measures to control the spreading rate. Lockdown was imposed by various countries worldwide and strictly banned the national and international transportation networks. At the end of March 2020, the Govt of India ordered to control the movement of people and imposed strict lockdown. For the current study, month-wise water quality datasets for 10 stations of five trans-boundary rivers were acquired from West Bengal Pollution Control Board (<https://www.wbpcb.gov.in/>) during three different phases: pre-lockdown, lockdown and post-lockdown or unlock.

December 2019 and January 2020 of pre lockdown, April and May 2020 of lockdown, and December 2020 and January 2021 of unlock phase have been considered for the study.

Selected eighteen physicochemical and biological parameters like pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Potassium (K^+), Sodium (Na^{2+}), Fluoride (F^-), Chloride (Cl^-), Nitrate (NO_3^-), Sulphate (SO_4^{2-}), Phosphate (PO_4^{3-}), Dissolve Oxygen (DO), Temperature (T), Turbidity (TUR), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD) were inspected according to the standard methods (APHA, 2012) to monitor the river water quality.

Sentinel 2A (a polar-orbiting satellite) LIC Multispectral Imager (MSI) images (100 km*100 km tile) have been used to prepare the land use and land cover maps in the present study. Sentinel-2A images of 22nd December 2020 images were downloaded from the United States Geological Survey (USGS) website (<https://earthexplorer.usgs.gov/>). Six bands out of thirteen total bands of MSI have been selected. The bands are B02 (Blue), B03 (Green), B04 (Red), B08 (NIR), B11 (SWIR), B12 (SWIR). The bands B02, B03, B04, and B08 have a spatial resolution of 10 m, and the remaining B11 and B12 have 20 m spatial resolution.

2.3. Water quality index (WQI)

Water Quality Index (WQI) is a very good method that summarizes different water quality parameters dataset into a single-valued dimensionless integer (Sener et al., 2017). Primarily WQI was proposed by Horton (1965) based on ten most widely used water quality parameters, and later various researchers (Brown et al., 1970; McClelland N.I., 1974) have tried to modify it. Recently, many new indices have emerged namely (a) British Columbia Water Quality Index (BCWQI) (Debels et al., 2005), (b) Oregon Water Quality Index (OWQI) (Kannel et al., 2007), (c) Florida Stream Water Quality Index (FWQI) (SAFE, 1995), (d) Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) (Khan et al., 2005), (e) National Sanitation Foundation Water Quality Index (NSFWQI) (Mirzaei et al., 2005) and (6) Weighted Arithmetic Water Quality Index (WAWQI) (Brown et al., 1970; Bouslah et al., 2017).

This research was based on the most widely used WAWQI method, developed by Brown et al. (1970) which was immensely backed by NSFWQI (United States National Sanitation Foundation) (Lumb et al., 2011). Previously, several significant works have been done on several polluted Indian rivers based on this methods such as Kolong River (Bora and Goswami, 2016), Doyang River (Lkr et al., 2020), Narmada River (Gupta et al., 2017), Sabarmati River (Khatriet al., 2020), Ganga River (Prasad et al., 2020), Rangit River (Gupta et al., 2016), Nag River (Dutta et al., 2018), Vellar River (Deepa and Venkateswaram, 2018) etc. WHO (2011) guidelines of permissible limits are selected for the physicochemical parameters of standard water quality (Table 2). The WQI values of 10 stations were calculated based on the selected parameters by using the equation given by Brown et al. (1970).

$$WQI = \frac{\sum Q_n w_n}{\sum W_n} \quad (1)$$

Where, Q_n means quality rating of n'th water quality parameter, W_n represents unit weight of n'th water quality parameter.

Calculation of Quality Rating (Q_n) of each parameter from the following equation,

$$Q_n = \frac{V_n - V_0}{S_n - V_0} \times 100 \quad (2)$$

Where, V_n stands for actual concentration of n'th parameter, S_n denotes standard value of n'th parameter, V_0 represents Ideal value in pure water (i.e., PH=7, DO=14.6 mg/L).

Unit weight (W_n) has been calculated by using the formula given by Tiwari and Mishra (1985).

$$W_n = K/S_n \quad (3)$$

Table 2
Calculation of Relative Weight of the Water Quality Parameters.

Parameters	Who standards (2011) (S_n)	Unit	Relative Weight (W_n)
pH	6.5–8.5	–	0.0708
EC	300.00	$\mu\text{s}/\text{cm}$	0.0018
TDS	500.00	mg/L	0.0011
TSS	500.00	mg/L	0.0011
Ca^{2+}	75.00	mg/L	0.0071
Mg^{2+}	50.00	mg/L	0.0106
Na^{2+}	12.00	mg/L	0.0443
K^+	200.00	mg/L	0.0027
F^-	1.50	mg/L	0.3540
Cl^-	250.00	mg/L	0.0021
NO_3^-	45.00	mg/L	0.0118
SO_4^{2-}	355.00	mg/L	0.0015
PO_4^{3-}	5.00	mg/L	0.1062
DO	5.00	mg/L	0.1062
T	4 0.00	$^{\circ}\text{C}$	0.0133
TUR	5.00	NTU	0.1062
COD	10.00	mg/L	0.0531
BOD	5.00	mg/L	0.1062

Where, K is proportionally constant, and it can be determined by using this equation,

$$K = \frac{1}{\sum (1/S_n)} \quad (4)$$

Mathematical calculations of relative weight and standard values of selected parameters are represented in Table 2. Categorization of water qualities is based on WAWQI (Brown et al., 1970) that is also provided in the Table 3.

2.4. Application of descriptive statistics and correlation matrix

In this study, the total 18 water quality parameters have been analyzed using the descriptive statistics for the health of trans-boundary rivers (Table 5). In order to identify the fluctuation of water quality during the different phases of lockdown, pre lockdown and unlock, Karl Pearson's (Pearson product movement correlation coefficient, r) correlation matrix has been computed (Table S1, S2, S3 Supplementary file). The correlation coefficient values are ranging from +1 to -1 (Aydin et al., 2021) where near to the +1 value indicates the strong positive and near to the -1 figure denotes strong negative relation between the variables. Hence, the physical, chemical and biological parameters have been considered to study the health conditions of the Indo-Bangladesh trans-boundary rivers. Co-variation matrix has been done by the equation.

$$r = \frac{\sum_{i=1}^n (x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} \quad (5)$$

Where, r represents correlation coefficient, x denotes independent variables and y means dependent variables, s_x and s_y are the standard deviation of the sample.

2.5. LULC and irrigation water quality indices

In India, various contemporary studies have been conducted on the impact of landuse and land cover change and its impact on surface water quality (Fierro et al., 2017; Li et al., 2019). Spatial analysis of several influential pockets along both sides of the five trans-boundary rivers have been intensively studied in the LULC mapping due to the large basin area of the trans-boundary rivers. ERDAS IMAGINE 2015 software was used to classify the different attributes of LULC and ArcGIS 10.3.1 Desktop (ESRI) was used to prepare the layout of the LULC map. This supervised classification was based on the Maximum Likelihood Classifier method.

Subsequently, water quality also determines the suitability of the water for irrigation purposes (Almeida et al., 2008). Many research outputs showed that the specific index has been applied to comprehend the

Table 3
Categorization of Water Quality Based on Weighted Arithmetic WQI Method (Brown et al., 1970).

Water Quality Index (WQI)	Water Quality Status	Possible Uses
0–25	Excellent Water Quality	Drinking, Irrigation, And Industrial
26–50	Good Water Quality	Drinking, Irrigation, And Industrial
51–75	Poor Water Quality	Irrigation And Industrial
76–100	Very Poor Water Quality	Irrigation
>100	Unfit For Consumption	Proper Treatment Required

water quality for different usages. Here, the various important water evaluation indices like Sodium Absorption Ratio, Soluble sodium percentage, Potential salinity, Magnesium Ratio, Kelly's Index have been used to determine the irrigation suitability of water (Sundaray et al., 2009; Srinibasmoorthy and Sharma, 2014; Shil et al., 2019). These are systematically discussed.

2.5.1. Sodium absorption ratio (SAR)

The Sodium Absorption Ratio (SAR) is an important index to measure the concentration and possibility of sodium hazard with respect to Ca^{2+} and Mg^{2+} (Shammi et al., 2016). It also helps to determine the irrigation suitability of water (Sappa et al., 2014) whereas sodium is direct influential factor for the salinity concentration which may toxic to different crop fields. Higher value of SAR indicates a negative impact on environment specifically on soil. EC and SAR are closely interrelated with each other (Wilcox, 1955). The SAR of 10 stations was calculated by using the formula which was given by US Salinity Laboratory (Richards, 1954a).

$$SAR = \frac{Na^{2+}}{\frac{\sqrt{Ca^{2+} + Mg^{2+}}}{2}} \quad (6)$$

2.5.2. Soluble sodium percentage (SSP)

In irrigation water, the quantity of sodium is commonly defined as soluble sodium percentage (SSP) or % Na^{2+} . The percentage of Na^{2+} in water is extensively used to determine its suitability for irrigation (Ragunath, 1987; Shah et al., 2019;). Permeability can be hampered due to its interaction with soil results clogging of particles in the riparian tract (Vasanthavignar et al., 2010). It was proposed by Wilcox (1955) and the formula was developed by Todh (1980).

$$SSP = \frac{Na^{2+} + K^+}{Ca^{2+} + Mg^{2+} + K^+ + Na^{2+}} \times 100 \quad (7)$$

2.5.3. Potential salinity (PS)

Potential Salinity (PS) is an important index which has been used to assess the water quality for irrigation purposes. Potential Salinity (PS) was used to examine the irrigation water quality independently on soluble salts such as sulfate and chloride concentration and it was developed by Doneen (1961). Soluble salts get accumulated in the soil due to the excessive irrigation and it increases the overall salinity of the soil (Udom et al., 2019).

$$PS = \text{Cl}^- + \frac{1}{2} \text{SO}_4^{2-} \quad (8)$$

2.5.4. Magnesium hazard (MH)

The concentration of magnesium in the soil is calculated by the Magnesium ratio (Shil et al., 2019). Magnesium is a geochemical property of soil and water. Higher magnesium concentration derives the chances to make alkaline the soil and water which affects to the agricultural crops.

Magnesium Hazard has calculated by Paliwal (1972), and the Magnesium ratio has been computed for the Mahanadi River water for irrigation purposes (Sundaray et al., 2009). A case study on the Mahanandi River showed that the status of irrigation water has been assessed by applying this index (Shil et al., 2019). However, the formula of Magnesium Hazard (MH) is represented as:

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad (9)$$

2.5.5. Kelly's index (KI)

Kelly's index (KI) indicates the sodium concentration in soil and surface water against the magnesium concentration (Kelly, 1940). According to the standard value of Kelly's index, when the KI value is less than 1, it is acceptable while the value of KI more than 1 is not suitable for irrigation purposes. The equation of Kelly's Index is given as:

$$KI = \frac{Na^{2+}}{Ca^{2+} + Mg^{2+}} \quad (10)$$

3. Results

3.1. Changing water quality during the different phases of the study

Physicochemical properties of water are very much dependent on three crucial phases like prelockdown, lockdown, and unlock. Phase-wise variations of principal parameters are represented in Fig. 2a to 2f. The mean temperature of the selected rivers during prelockdown, lockdown and unlock were 19.5 °C, 26.8 °C and 21.1 °C respectively. Most of the pH values of the stations range within the standard values (6.5–8.5) as per WHO (2011) guideline during pre (~7.4), lockdown (~7.5), unlock (~7.3). Interestingly, a significant reduction in BOD and COD has been noticed in 70% of stations except St-8, St-9 and St-10 during the lockdown (BOD: 0.75–15 mg/L; COD: 14.46–55 mg/L) than prelockdown (BOD: 0.85–13 mg/L; COD: 12.43–76 mg/L) and unlock (BOD: 1.50–10.50 mg/L; COD: 8.42–77 mg/L) phases. In contrast, only 40% of stations (St-2, St-3, St-4 and St-6) have faced augmentation in DO (0.65–7.80 mg/L) while 70% of stations have showed the reduction of TUR (1.47–11.34 NTU) during the lockdown phase.

Box and whisker diagram (Fig. 2g) represents the trends and ranges of WQI of all the selected stations. The mean values of WQI during pre, lockdown and unlock were 79.43, 54.99 and 69.63 respectively. Upper and lower whisker values of prelockdown, lockdown and unlock phases ranged from 135.40 to 43.92, 80.84 to 37.65 and 132.81 to 52.04. While Fig. 2h is clearly showing individual station-wise fluctuation of WQI. The highest (135.40) and lowest (37.65) WQI have reported from St-8 (prelockdown) and st-5 (lockdown).

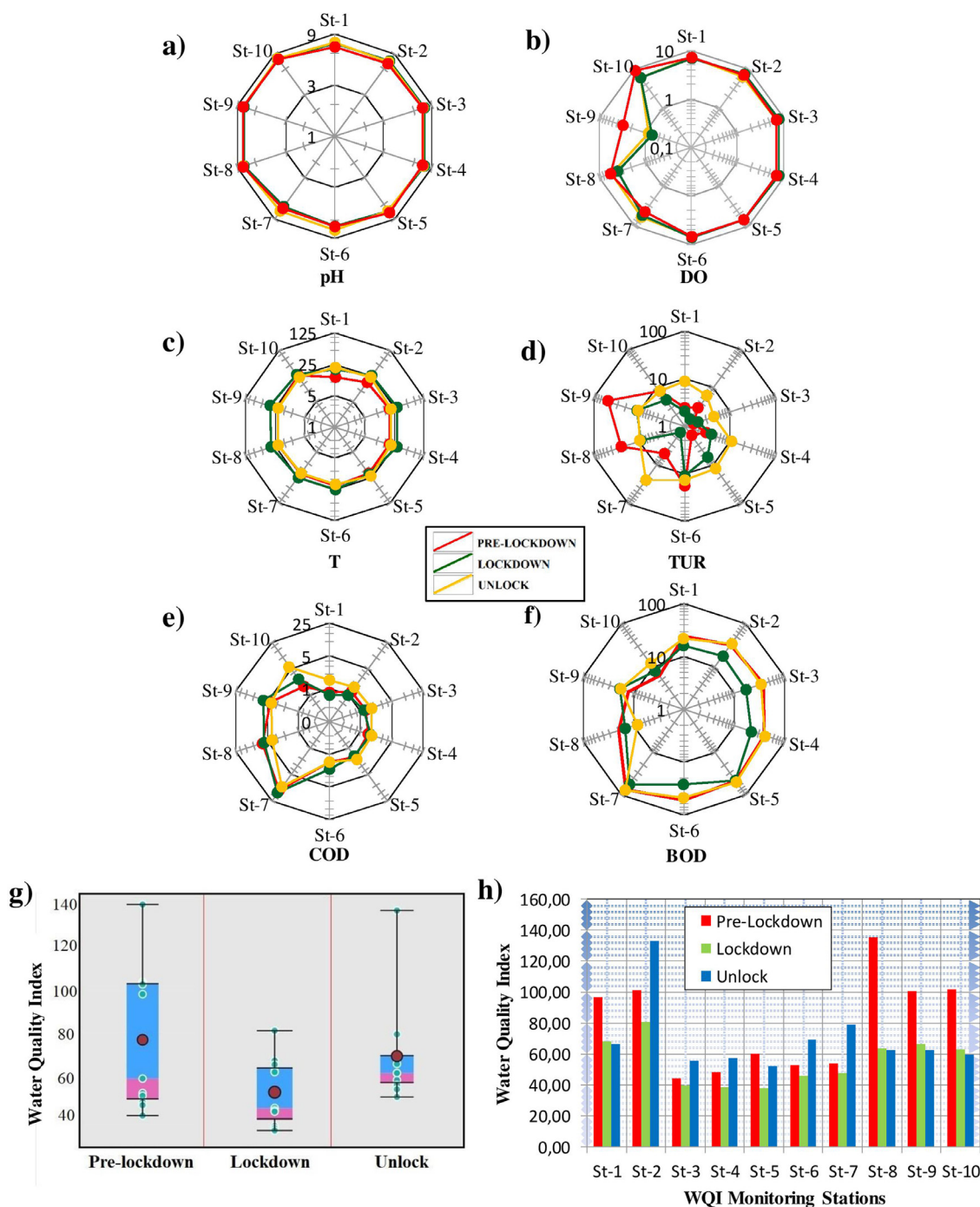


Fig. 2. Fluctuation of individual parameters such as a) pH b) DO c) T d) TUR e) COD and f) BOD, g) box and whisker plot shows phase wise deviation and of WQI and h) Individual station wise WQI during prelockdown, lockdown and unlock phase.

3.2. Fluctuation of surface water properties with descriptive statistics

Surface water quality is shown as descriptive statistics to analyze the nature of data in different pandemic phases. Descriptive statistics summarize (Tables 5a, 5b and 5c) the mean, range and standard deviation for all stations. The pH value of surface water samples ranged from 6.5 to 7.9, 7.1 to 8.2 and 6.67 to 7.93 during pre, lockdown and unlocks phase respectively. In prelockdown period the cation concentrations such as Mg^{2+} , K^+ , Na^{2+} and Ca^{2+} ranged from 0.87 to 25.31 mg/L, 1.15 to 6.00 mg/L, 0.45 to 15.16 mg/L and 8.02 to

105.12 mg/L, with an average of 10.07 ± 3.88 mg/L, 3.59 ± 0.52 mg/L, 7.923 ± 1.021 mg/L and 35.56 ± 3.39 mg/L respectively. In contrast, during the lockdown period, the presence of Mg^{2+} , K^+ , Na^{2+} and Ca^{2+} ranged from 1.73 to 25.34 mg/L, 0.70 to 7.30 mg/L, 1.05 to 95.30 mg/L and 8.82 to 96.17 mg/L with an average of 10.44 ± 4.53 mg/L, 3.39 ± 0.75 mg/L, 16.35 ± 13.12 mg/L, and 31.44 ± 4.70 mg/L. The concentration of these cations has been dramatically decreased in the lockdown phase. The mean concentration of DO has been increased in the lockdown (min:0.65 mg/L, max:7.85 mg/L) compared to prelockdown (min:0.85 mg/L, max:7.25 mg/L).

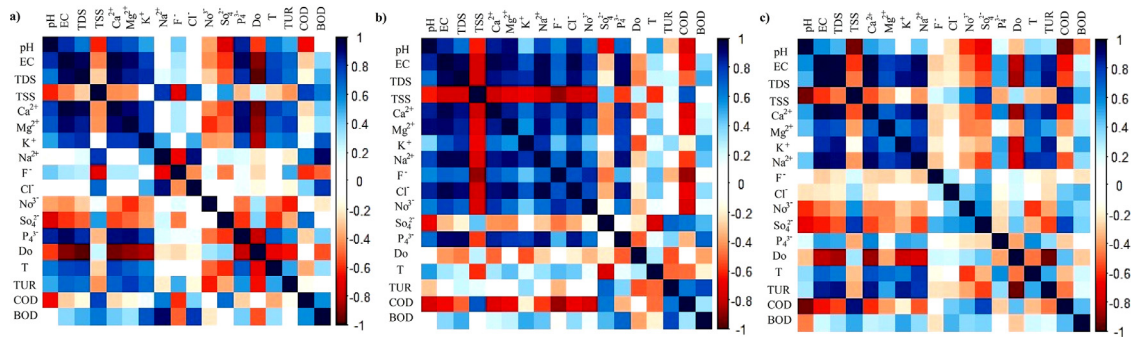


Fig. 3. Pearson correlation analysis among water quality parameters in different phases a) Pre lockdown b) Lockdown c) Unlock.

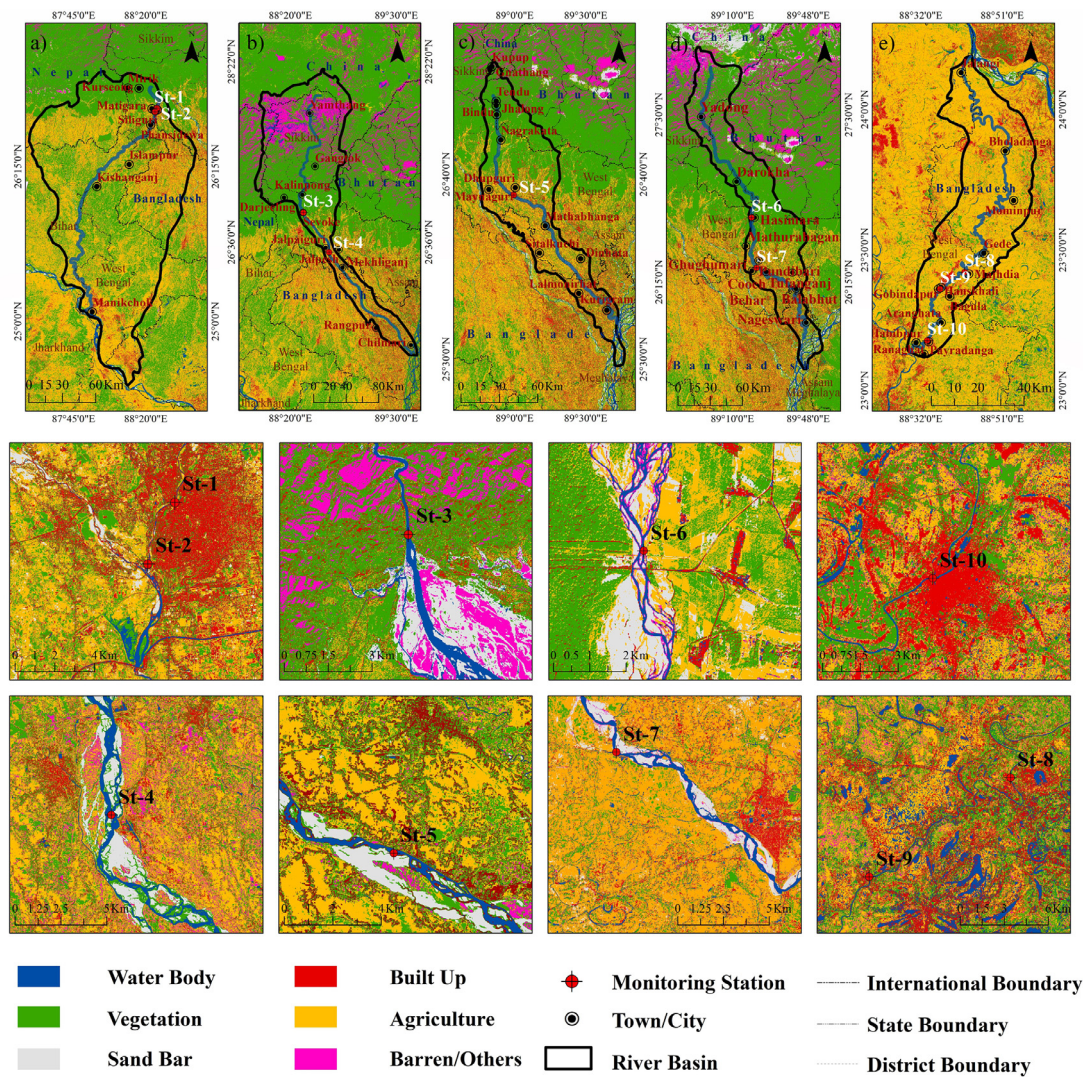


Fig. 4. Spatial patterns of LULC of the five selected trans-boundary rivers like a) Mahananda, b) Teesta, c) Jaldhaka, d) Torsha, e) Mathabhanga-Churni and their major influential pockets.

3.3. Correlation among water quality parameters

The correlation coefficient analysis is a statistical technique that explains the linear relationships between two variables of the water quality parameters. In this present study correlation matrix (0.05% significance level) is shown for prelockdown, lockdown and unlock periods (Table S1, S2, S3 Supplementary file). Highly positive interrelations were no-

ticed during the prelockdown period in between EC & TDS ($r = 0.982$; $p < 0.05$), EC & Ca^{2+} ($r = 0.969$; $p < 0.05$), EC & Na^{2+} ($r = 0.829$; $p < 0.05$), Ca^{2+} & K^+ ($r = 0.930$; $p < 0.05$) and TDS & Na^{2+} ($r = 0.829$; $p < 0.05$). Hence, EC is the dominant surface water quality parameter in all the periods. The good and strong associations of TDS and Ca^{2+} ($r = 0.955$; $p < 0.05$), EC and Ca^{2+} ($r = 0.989$; $p < 0.05$), EC and Mg^{2+} ($r = 0.925$; $p = 0.05$) and Mg^{2+} and TUR ($r = 0.795$; $p < 0.05$) are found in the lock

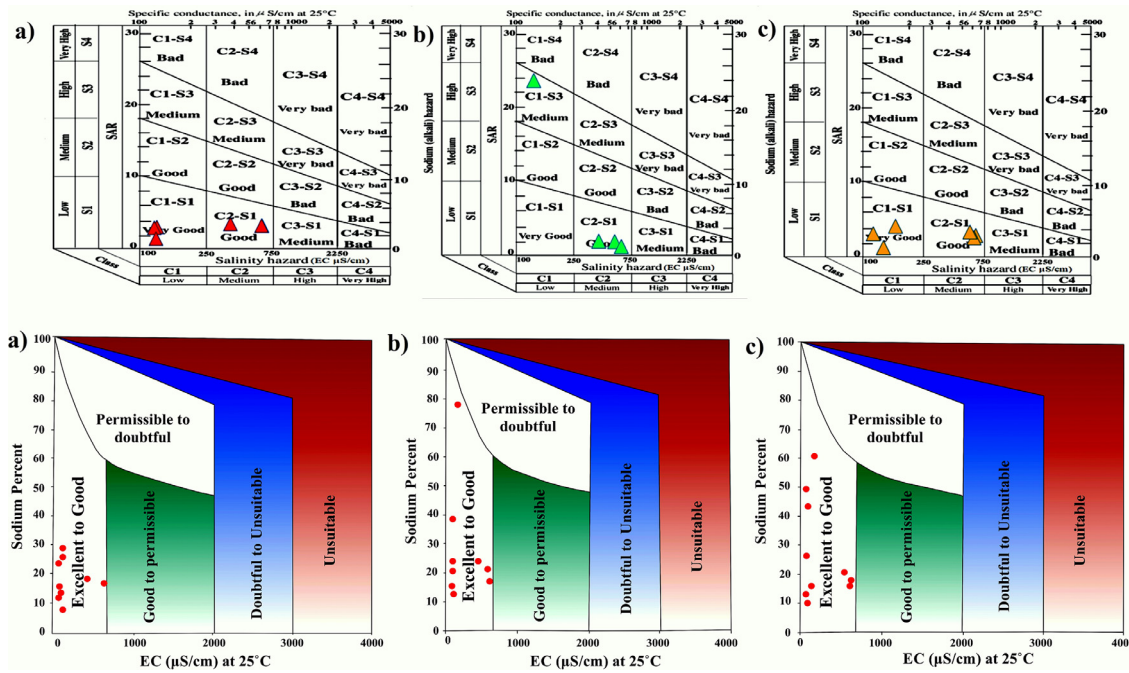


Fig. 5. Salinity hazard classification of the stations for irrigation waters a) US Salinity Laboratory's (USSL) diagram b) Wilcox's diagram (Wilcox, 1948).

Table 4
Water quality of 10 stations during the phases of covid-19 induced lockdown.

River	St. Name	Station	Pre-Lockdown	Lockdown	Unlock
Mahananda	Siliguri	St-1	96.53	67.85	66.34
	Ramghat	St-2	101.37	80.84	132.81
Teesta	Sevoke	St-3	43.92	39.50	55.32
	Jalpesh	St-4	48.43	38.59	57.21
Jaldhaka	Dhulguri	St-5	59.94	37.65	52.04
	Hasimara	St-6	52.51	45.80	69.40
Torsa	Ghughumari	St-7	53.67	47.36	79.17
	Majhdia	St-8	135.40	63.29	62.37
Mathabhanga-Churni	Gobindapur	St-9	100.78	66.16	62.39
	Ranaghat	St-10	101.84	62.89	59.33

down phase (Fig. 3). In unlock period EC holds significant positive correlation with TDS ($r = 0.949; p < 0.05$) whereas, pH, EC and TDS were negatively interrelated with TSS and a mild significant correlation is found between SO_4^{2-} and PO_4^{3-} ($r = -0.096; p < 0.05$).

3.4. Impact of land use and land cover on the surface water quality

Land use and land cover has been considered as key influencer of surface water quality since the 1970s (Li et al., 2019). Therefore, there would be no noticeable negative influence on water quality without anthropogenic interference. The water quality of the selected trans-boundary rivers is under stress due to unscientific agricultural activities (e.g., excessive use of fertilizers, pesticides and irrigation), municipal wastewater, industrial effluents, domestic sewage (Khan et al., 2020) contamination through infiltration, leaching and run-off (Mello et al., 2018). These chemical substances get accumulated into the river bed over time. Agricultural land is represented as the dominant class covering more than 50%, followed by natural vegetation (>18%) along the river side for all the trans-boundary rivers (Fig. 4). Jaldhaka Basin

has the highest agricultural land (about 67%) while lowest at Teesta Basin (around 41%). Likewise, Mathabhanga-Churni Basin has the highest built-up area (around 10%), followed by Mahananda (around 6%), Teesta (around 4%), Jaldhaka (around 3.8%) and Torsha (about 3%). Meanwhile, a small pocket in the upper Teesta basin represents a highly vegetated area (around 50%) while a lower pocket shows the dominance of agricultural land (about 65%). In contrast, pockets of Mahananda and Mathabhanga-Churni basins are examples of highly populated as well as urbanized areas (around 35% and 30% respectively).

3.5. Suitability of water quality for irrigation purposes

The trans-boundary rivers have significant involvement in irrigation purposes for both the country India and Bangladesh. The excessive concentration above the desirable limit of salinity is harmful to flora and fauna. In this present study, the Sodium Absorption Ratio of these selected trans-boundary rivers is ranged between 0.14 and 24.77. SAR values are plotted against corresponding EC in the US Salinity Laboratory (USSL, 1954) diagram (Fig. 5). Meanwhile, around 70% of values

Table 5a
Descriptive statistics of various water quality parameters of selected trans-boundary rivers during Pre lockdown phase.

PARAMETERS	Mahananda		Teesta		Jaldhaka	Torsha	Mathabhanga-Churni			
	Siliguri (st-1)	Ramghat (st-2)	Sevoke (st-3)	Jalpesh (st-4)	Dhupguri (st-5)	Hasimara (st-6)	Ghughumari (st-7)	Majhdia (st-8)	Gobindapur (st-9)	Ranaghat (st-10)
pH	6.85±0.04	6.45±0.07	7.39±0.27	7.41±0.29	7.58±0.04	7.63±0.33	7.2 ± 0.14	7.78±0.06	7.74±0.06	7.89±0.04
EC	121.05±2.47	116.22±17.28	62.14±5.27	59.65±1.32	60.55±3.24	82.52±6.12	119.9 ± 0.99	647.4 ± 52.75	655.25±49.14	651±72.97
TDS	90±2.83	125±21.21	59±4.24	68±5.66	78±8.49	29.42±26.28	76±11.31	433±55.15	410±19.8	420±5.66
TSS	56±5.66	81±1.41	33±7.07	41±4.24	45±21.21	20±2.83	41±9.9	25±9.9	13±1.41	22±2.83
Ca ²⁺	20.05±3.4	26.46±5.66	8.82±1.13	8.02±2.27	14.43±0	12.83±2.27	22.45±0.01	103.06±6.99	105.12±12.57	79.34±13.21
Mg ²⁺	8.64±3.25	6.62±1.22	1.44±0.41	0.87±0.4	4.32±2.86	4.61±0	9.79±2.45	11.95±7.16	11.27±2.97	25.31±17.95
K ⁺	4.1 ± 0.14	4 ± 0.14	1.15±0.21	1.9 ± 0.14	1.9 ± 0.14	1.55±0.07	1.75±0.78	5.75±0.21	6 ± 0.14	5.7 ± 0.57
Na ²⁺	7.2 ± 0.14	7.1 ± 0.14	0.7 ± 0.28	0.8 ± 0.14	0.45±0.07	1.03±0.32	0.6 ± 0	15.8 ± 0.71	16±0.71	15.16±6.43
F ⁻	0.26±0.01	0.19±0.06	0.24±0.01	0.23±0.02	0.63±0.71	0.13±0.01	0.14±0	0.18±0.03	0.2 ± 0.01	0.19±0.03
Cl ⁻	9.79±2.76	15.17±11.76	10.28±2.07	6.36±2.08	13.7 ± 1.39	13.7 ± 4.15	6.74±1.23	8.68±0	8.68±0	11.09±0.68
NO ³⁻	0.87±0.35	2.19±1.05	2.48±2.35	0.55±0.42	0.81±0.08	0.71±0.33	0.74±0.07	0.54±0.08	0.49±0.06	0.54±0.06
SO ₄ ²⁻	15.83±0.71	46.8 ± 0.99	21.46±1.71	14.53±0.04	40.69±2.15	14.18±4.74	28.56±1.49	7.41±1.2	8.56±0.71	8.4 ± 0.27
PO ₄ ³⁻	0.02±0.01	0.05±0	0 ± 0	0.01±0	0.03±0.01	0.02±0	0.01±0	0.03±0.02	0.53±0.67	0.03±0.02
DO	6.85±0.07	5.84±0.01	7.25±0.21	6.5 ± 0.42	7 ± 0.28	7 ± 0.28	7.05±0.07	0.85±0.07	3.6 ± 3.96	5.3 ± 0.28
T	21±1.41	20.1 ± 0.14	13±4.24	16.5 ± 0.71	19±0	18.5 ± 0.71	19±0	21.5 ± 3.54	25.5 ± 2.12	21.5 ± 3.54
TUR	17.95±4.74	5.27±3.98	2.4 ± 0.53	2.97±1.63	1.51±0.13	2.9 ± 2.34	1.72±0.83	49.7 ± 42.99	29.6 ± 22.06	25±7.21
COD	52±1.41	76±4.24	24.5 ± 0.71	32±7.07	37.5 ± 2.12	39±2.83	47.5 ± 2.12	12.43±7.47	15.15±0.21	19.72±17.78
BOD	1.5 ± 0.14	13±4.24	0.85±0.07	1.25±0.64	1.3 ± 0.71	1.5 ± 0.42	1.75±0.49	4.18±1.8	3.8 ± 1.27	6.43±4.28

Table 5b
Descriptive statistics of various water quality parameters of selected trans-boundary rivers during Lockdown phase.

PARAMETERS	Mahananda		Teeta		Jaldhaka	Torsha	Mathabhanga-Churni			
	Siliguri (st-1)	Ramghat (st-2)	Sevoke (st-3)	Jalpesh (st-4)	Dhupguri (st-5)	Hasimara (st-6)	Ghughumari (st-7)	Majhdia (st-8)	Gobindapur (st-9)	Ranaghat (st-10)
pH	7.44±0.06	7.2 ± 0.57	7.53±0.16	7.26±0.21	7.3 ± 0.14	7.41±0.3	7.14±0.06	7.85±0.04	7.83±0.06	8.02±0.14
EC	87.71±31.52	140.31±29.84	48.1 ± 14.28	62.94±0.68	40.91±3.83	61.01±30.55	35.71±0.71	673.95±20.86	656.85±28.92	599.95±80.4
TDS	96±25.46	159.5 ± 86.97	50±25.46	138±70.71	90±39.6	49±35.36	74±4	423±24.04	394±16.97	329±41.01
TSS	56±11.31	134±87.68	26±19.8	49±43.84	49.5 ± 36.06	30.5 ± 14.85	40±2	22±0	21±7.07	19±7.07
Ca ²⁺	15.63±1.7	22.45±0.01	9.62±0.01	8.82±3.4	9.62±5.66	13.63±3.4	15.63±0.03	86.17±8.73	96.17±5.42	83.31±9.46
Mg ²⁺	11.52±0.81	7.14±0.48	3.46±0.81	1.73±0.81	4.32±4.48	6.91±1.63	9.52±0.02	25.34±10.56	27.21±19.95	15.69±7.03
K ⁺	4.95±1.63	6 ± 1.7	1.3 ± 0.71	2 ± 0.28	0.7 ± 0.14	0.85±0.35	2.95±0.05	6.55±1.34	7.3 ± 0.28	5.5 ± 0.14
Na ²⁺	3.4 ± 4.24	95.3 ± 121.2	1.05±1.06	4.45±1.06	3.45±2.33	1.95±0.07	3.4 ± 0.4	16.2 ± 0	15.75±0.35	19.75±0.07
F ⁻	0.25±0.01	0.01±0	0.27±0	0.22±0.02	0.13±0.01	0.1 ± 0.01	0.15±0.01	0.23±0.06	0.23±0.05	0.22±0.04
Cl ⁻	11.86±1.22	26.42±6.91	12.72±1.38	8.8 ± 6.92	5.13±3.82	9.3 ± 3.46	11.86±0.45	10.96±1.35	9.97±1.46	12.45±2.05
NO ³⁻	0.15±0.07	1.02±0.02	2.1 ± 0.28	2.97±0.63	0.78±0.11	0.26±0.05	0.15±0.01	0.48±0.13	0.44±0.21	0.46±0.13
SO ₄ ²⁻	12.88±2.82	18.92±7.42	16.02±6.27	8.38±3.56	19.37±23.04	12.12±2.93	8.88±0.88	10.19±3.22	9.41±4.38	9.71±3.68
PO ₄ ³⁻	0.01±0	0.03±0.02	0 ± 0	0 ± 0	0.01±0.01	0.01±0.01	0.01±0.01	0.07±0.04	0.06±0.04	0.05±0.04
DO	7.15±0.92	5.45±0.64	7 ± 0.28	7.35±0.64	7.6 ± 0.57	7.85±0.78	7.15±0.05	0.7 ± 0.42	0.65±0.21	4 ± 0.85
T	25.5 ± 2.12	25.5 ± 2.12	19.5 ± 3.54	25.5 ± 2.12	27.5 ± 0.71	28.5 ± 0.71	16.5 ± 0.5	32.5 ± 0.71	32.75±1.06	31±1.41
TUR	11.05±1.48	1.5 ± 0.42	2 ± 0.14	1.48±0.39	1.93±0.04	3.78±0.59	8.05±0.05	11.34±3.2	9.69±2.42	9.42±3.51
COD	26±2.83	55±4.24	16±2.83	18±0	17±4.24	22±0	9.2 ± 0.01	18.55±8.4	23.94±3.67	14.47±2.62
BOD	2.05±0.35	15±4.24	0.75±0.07	1 ± 0.28	1.2 ± 0.57	1.7 ± 0.14	2.05±0.02	6.13±0.18	7.71±2.76	5.68±3.92

Table 5c
Descriptive statistics of various water quality parameters of selected trans-boundary rivers during Unlock phase.

PARAMETERS	Mahananda		Teesta		Jaldhaka	Torsha	Mathabhanga-Churni			
	Siliguri (st-1)	Ramghat (st-2)	Sevoke (st-3)	Jalpesh (st-4)	Dhupguri (st-5)	Hasimara (st-6)	Ghughumari (st-7)	Majhdia (st-8)	Gobindapur (st-9)	Ranaghat (st-10)
pH	6.89±0.12	6.67±0.18	6.9 ± 0.14	7.02±0.01	7.32±0.11	7.31±0.22	7.46±0.06	7.93±0.32	7.84±0.13	7.78±0.08
EC	108.81±45.1	161.71±97.72	58.37±2.76	54.52±40	69.81±7.11	59.47±2.35	130.33±50.45	649.45±21.28	645.55±18.74	674.05±17.61
TDS	172±84.85	226.4 ± 57.13	110±59.4	157±120.21	67±35.36	115±94.76	120±147.08	340±25.46	331±72.12	391±69.3
TSS	45±9.9	68.5 ± 43.13	40±16.97	25±4.25	73±15.56	70±31.12	44±28.28	10±0	16±8.49	14±11.31
Ca ²⁺	8.41±5.11	3.21±0.01	11.2 ± 1.13	6.81±0.57	10.02±6.23	15.23±1.14	17.64±5.66	104.33±5.28	104.72±10.28	92.4 ± 15.08
Mg ²⁺	7.49±3.26	4.61±2.44	3.03±1.41	2.99±3.92	4.03±3.26	6.92±4.08	12.96±0.4	22.29±1.87	19.45±0.79	26.9 ± 5.76
K ⁺	3.81±0.01	3.85±0.07	0.85±0.35	3.5 ± 0.99	1.7 ± 0.14	0.65±0.08	2.05±1.63	4.6 ± 0.57	4.95±0.21	4.2 ± 0.28
Na ²⁺	7.7 ± 0.14	7.55±0.78	0.55±0.07	5.75±0.08	3.05±0.35	2.2 ± 1.56	2.9 ± 0.42	16.95±1.2	16.9 ± 0.57	19.15±2.47
F ⁻	0.18±0.01	0.11±0.02	0.23±0.01	0.22±0.01	0.12±0.01	0.16±0.06	0.13±0.03	0.24±0.04	0.25±0.04	0.26±0.01
Cl ⁻	3.42±2.08	2.93±0	1.97±1.36	2.94±2.78	2.44±2.08	0.98±0.01	2.93±1.39	9.5 ± 0.71	10.5 ± 0.71	10±1.41
NO ³⁻	0.13±0.15	0.03±0.02	0.59±0.79	0.02±0	0.02±0.01	0.03±0.03	0.03±0.03	0.61±0.09	0.72±0.08	0.5 ± 0.21
SO ₄ ²⁻	28.4 ± 21.97	42±4.85	28.61±27.43	3.97±2.59	15.21±1.82	7.4 ± 2.88	15.21±4.24	13.44±3.13	12.12±0.18	9.83±5.98
PO ₄ ³⁻	0.01±0	0.05±0.01	0.01±0.01	0.01±0.01	0.01±0	0.01±0.01	0.01±0.02	0.06±0.01	0.08±0.01	0.06±0.04
DO	6.85±0.07	4.4 ± 0.85	7.1 ± 0	7 ± 0.85	7 ± 0.57	7 ± 0.29	6.95±0.21	3.05±0.64	3.2 ± 0.99	5.6 ± 0.99
T	19.5 ± 0.71	19.5 ± 0.71	20.5 ± 0.71	23.5 ± 4.95	20.5 ± 0.71	20.5 ± 0.71	22.5 ± 2.12	21.5 ± 0.71	21.25±0.35	21.75±1.77
TUR	13.4 ± 0.85	25.3 ± 0.99	8.52±0.4	6.08±1.48	4.26±1.63	10.55±7.43	12.67±4.01	11.06±1.76	15.7 ± 5.37	9.85±1.77
COD	46.5 ± 2.12	77±12.73	22±2.83	35±4.24	35±4.24	41±7.07	49±4.24	18±8.49	21±4.24	8.42±0.82
BOD	1.5 ± 0.14	10.5 ± 0.71	1.55±0.49	1.6 ± 0.28	1.7 ± 0.42	1.8 ± 0.28	1.95±0.07	3.92±1.77	5 ± 0.71	3.75±0.64

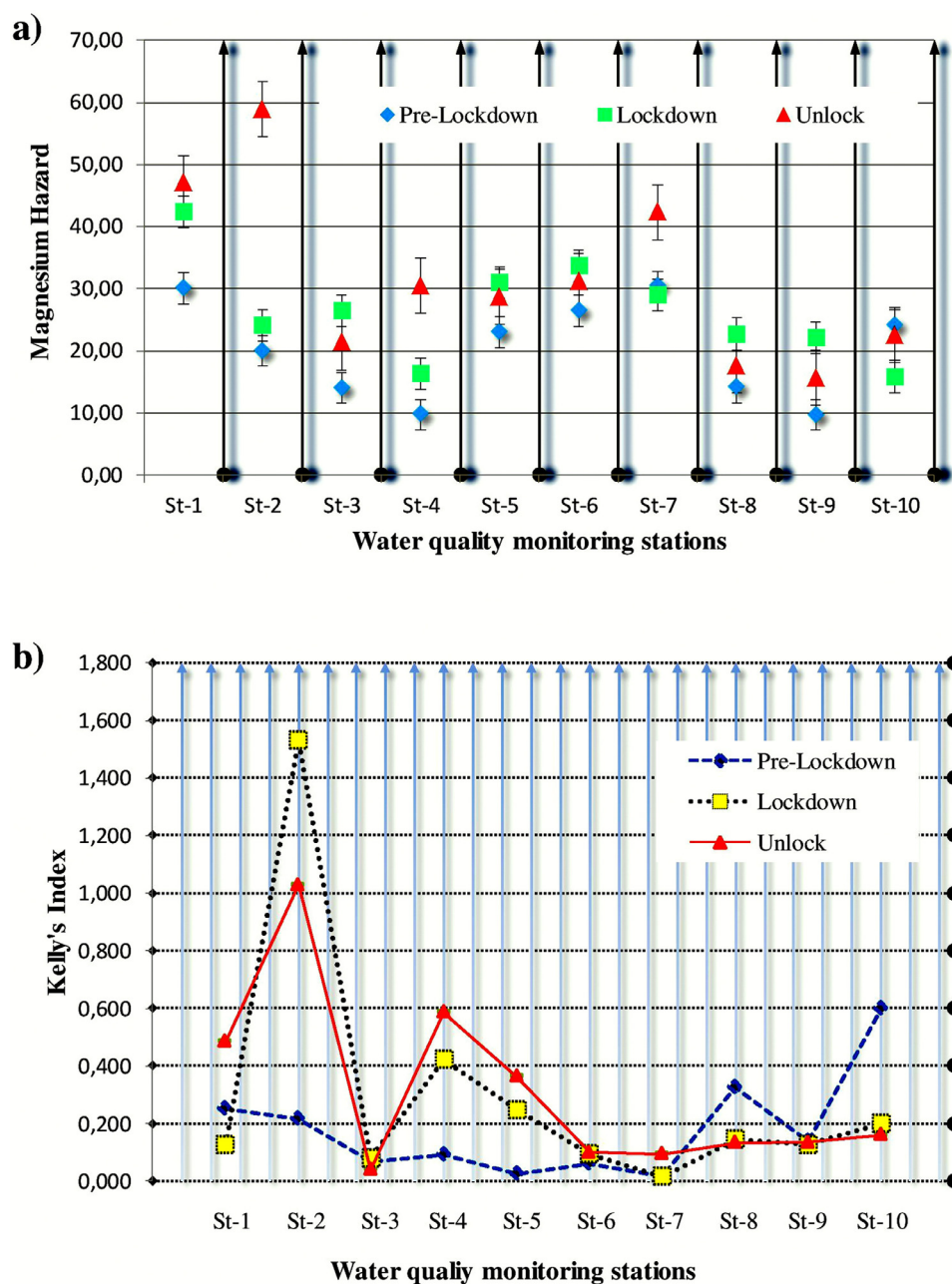


Fig. 6. Magnesium and sodium concentration of surface water during different phases a) Magnesium hazard index b) Kelly's index.

during prelockdown and unlock phases fall under C1-S1 category (very good) and the rest of the 30% fall under C2-S1 category (good). All the sample values during the lockdown phase fall on C2-S1 category (Good) except St-2 which is categorized as C1-S3 (medium).

The Soluble Sodium Percentage (SSP) or % Na²⁺ of the stations in the study area has been calculated to compare the suitability of irrigation water based on sodium concentration quality during all phases. Wilcox diagram is showing the SSP values which are plotted against EC values in Fig. 5 (Wilcox, 1955). The maximum tolerance limit of SSP (inland surface water) for irrigation is 60 as per ISI (1974) guidelines. Most of the stations (except St-2 during lockdown) ranged between 6.79 and 77.39. This range is under Excellent to Good Water category throughout the three phases.

Donnen (1961) determined the negative hazardous effect of Potential Salinity (PS) on water quality. The three major classes of PS are <3 (Class-I), 3–5 (Class-II) and >5 (Class-III). PS of all stations ranged between 4.67 and 38.56meq/l with an average of 21.61 meq/l. Hence,

around 80% of PS values of all three phases fall under Class-III (soil of high permeability); however, St-4 and St-6 denote Class-II (Soil of medium permeability during unlock phase).

More than 50% MH value denotes the high concentration of Mg²⁺ and less than 50% MH value indicates suitable condition of Mg²⁺ concentration which is normal for irrigation (Sundaray et al., 2009). During Lockdown period, MH value was fluctuated from 15.85(St-10) to 42.42 (St-1) whereas the MH value ranges between 15.66 (St-9) and 58.93(st-2) during Unlock (Fig. 6a). Thus, the mean MH value has been increased during the lockdown and unlock phase compared with the prelockdown phase.

KI values were ranged between 0.016 and 1.531 during different periods (Table 6) whereas in the lockdown (min: 0.016; max: 1.531), it was higher than the prelockdown. On the other hand, the KI value ranged between 0.039 (St-3) and 1.030 (St-2) during the unlock phase (Fig. 6b).

Table 6
Suitability of water quality indices for the irrigation purposes in different phases.

Stations	SODIUM ABSORPTION RATIO			SOLUBLE SODIUM PERCENTAGE			POTENTIAL SALINITY			MAGNESIUM HAZARD			KELLY'S INDEX		
	(SAR)			(SSP)			(PS)			(MH)			(KI)		
	Pre-Lockdown	Lockdown	Unlock	Pre-Lockdown	Lockdown	Unlock	Pre-Lockdown	Lockdown	Unlock	Pre-Lockdown	Lockdown	Unlock	Pre-Lockdown	Lockdown	Unlock
St-1	1.901	0.923	2.731	28.261	23.524	42.000	17.698	18.298	17.618	30.12	42.42	47.09	0.251	0.125	0.484
St-2	1.746	24.778	3.819	25.127	77.396	59.329	18.298	17.618	38.565	20.02	24.13	58.93	0.215	1.531	1.030
St-3	0.309	0.411	0.206	15.277	15.240	8.957	17.618	38.565	35.875	14.04	26.43	21.29	0.068	0.080	0.039
St-4	0.380	1.938	2.598	23.316	37.964	48.556	38.565	35.875	23.932	9.74	16.37	30.51	0.090	0.422	0.587
St-5	0.147	1.307	1.151	11.137	22.947	25.279	35.875	23.932	21.005	23.04	31.00	28.67	0.024	0.248	0.364
St-6	0.347	0.609	0.661	12.869	11.999	11.406	23.932	21.005	20.723	26.44	33.65	31.22	0.059	0.095	0.099
St-7	0.149	0.959	0.742	6.795	20.162	13.928	21.005	20.723	16.268	30.37	29.00	42.35	0.019	0.016	0.095
St-8	2.084	2.170	2.130	15.782	16.945	14.545	16.268	13.623	12.988	14.05	22.72	17.60	0.327	0.145	0.134
St-9	2.097	2.005	2.145	15.898	15.742	14.964	12.961	14.670	16.558	9.683	22.05	15.66	0.137	0.128	0.136
St-10	2.095	2.807	2.480	16.618	20.322	16.370	20.723	16.268	13.623	24.18	15.85	22.55	0.599	0.199	0.161

4. Discussion

This present study revealed that the lockdown recovered the river water quality as well as health of the total environment. The overall quality of pH for all trans-boundary rivers did not exceed the standard range (6.5–8.5) prescribed by WHO (2011). EC and TDS of Himalayan rivers are less in quantity due to negligible industrial sewage discharge into the Himalayan rivers. Here, river Mathabhanga-Churni crossed the permissible limits of EC, TSS and TDS due to the proximity of rapidly growing urban centers (such as Majhdia, Hanskhali and Ranaghat of India and Chuadanga in Bangladesh) and continuous supply of domestic sewages during all phases. Although, these parameters have slightly reduced during lockdown because of the high streamflow as a result of pre-monsoonal rainfall.

Besides this, sediments or sand bar depositions, inorganic as well as organic materials (like the dead plants and animals), urban stormwater and dams (Farakka dam, Teesta Dam III and IV) also disturb a river's natural turbidity which causes a decrease in DO (Tu, 2011), however DO has increased in various stations during lockdown. Natural vegetation is positively correlated with DO while negatively correlated with TDS, TSS, EC and COD because it acts as a natural filter for surface run-off. BOD and COD (negatively correlated with DO) have been improved at least 30% in most of the rivers during lockdown due to the complete shutdown but started to deteriorate again after the unlocking phase. On the other hand, the highest percentage of natural vegetation has been found along the riparian tract of Teesta; thus, St-3 and St-4 have overall good WQI among all trans-boundary rivers during three periods.

Excessive usage of fertilizers, pesticides and nutrients increase the PO_4^{3-} , NO_3^- and Ca^{2+} in rivers that causes eutrophication (Woli et al., 2004). Disbalance of Cl^- , Mg^{2+} , Na^+ , F^- and NO_3^- (positively correlated with temperature) are associated with the abundance of non-point source pollution (agricultural run-off and wastewater from industrial hubs) near rivers (e.g., Mahananda and Mathabhanga-Churni) which gets accumulated in river bed through leaching and run-off events during the monsoon period (Meneses et al., 2015).

Generally, SAR and SSP values are frequently high near agricultural land which results in breakdown of the physical structure of the soil (Barik and Pattanayak, 2019). As per Wilcox and USSL diagram, all the stations denote 'excellent to good' category for irrigation suitability of water with 'high to medium' permeable soil category in three phases. An important ecological factor salinity has a significant role in the survival of organisms (Shetaia et al., 2020). However, Potential Salinity is more dynamic in nature near coastal areas than inland water (Shil et al., 2019). KI value changes over time; thus, output of KI increases during the Lockdown period due to the higher rate of evaporation and less anthropogenic action in the lower Bengal region.

According to the index and status range of WQI, river Mahanada (St-2), Mathabhanga-Churni (St-8, St-9 and St-10) in the prelockdown period have the worst kind of water quality (Table 4) which is not suitable for both consumption and irrigation. Meanwhile, all the public sectors (organized and unorganized), industrial hubs were entirely shut down during the lockdown phase which causes around 80% improvement in water quality and started to fall again during unlock phase.

5. Conclusion

Covid-19 induced lockdown has a very significant footprint on the water quality of selected trans-boundary rivers because of decrease in industrial and urban pollutants. A comparative study of the prelockdown, lockdown and unlock phase has been established based on the interdependency and relationship among water quality parameters and LULC as well as irrigation suitability of water. The last stage of lockdown coincided with pre-monsoonal rainfall (April-May) and that had an effect on the dilution of pollutants of the rivers. Based on demonstrated results, it could be concluded that WQI has improved for all trans-boundary rivers due to the effects of lockdown. However, it could not hold the permissi-

ble limits after unlocking and again started to deteriorate the health of the above mentioned rivers.

Moreover, the worst kind of WQI (Brown et al., 1970) was found in the Mathabhanga-Churni River followed by Mahananda as a result of anthropogenic interference. Thus, implementation of some proper scientific measures is necessary for the identified polluted trans-boundary rivers to sustain the river health, such as i) riparian vegetation restoration and urban greening to control the volume of pollutant contamination; ii) scientific treatment of sewages and wastewaters before draining to rivers; iii) proper landuse planning within river corridors might have public concern for the maintenance of future sustainability of water quality; iv) usage of organic substitutes instead of chemical fertilizer and pesticides should be adopted to minimize the adverse effects. More scientific research is required to combat trans-boundary river health assessment and suitable policies should be framed to maintain the socioeconomic and political relationship among Indian, Bhutan and Bangladesh as neighboring countries. There is a big scope for further research on maintenance of ecological and environmental flow of river because these rivers contribute ample ecosystem services to the people of various countries like India, Bhutan and Bangladesh. Simultaneously, more suitable indices should be discovered on irrigation water quality assessment and dynamics of landuse/landcover along and proximity of river corridors for the neighboring people and river ecosystem health.

Author contributions

B. Bera conceptualized, formalized, investigated, supervised, edited and modified the whole manuscript. S. Sarkar acquired, analyzed, visualized data and wrote the draft manuscript. A. Roy contributed to acquire, investigation, analysis of the data and wrote the draft manuscript. S. Bhattacharjee reviewed, supervised and gave valuable input. P.K Shit reviewed, edited and assisted for the data visualization. All authors carefully read and approved the final manuscript.

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Data availability

All the used data sets are available at West Bengal Pollution Control Board (WBPCB), Govt. of India online portal (<https://www.wbpcb.gov.in/>).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

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