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Water quality assessment in the ecologically stressed lower and estuarine stretches of river Ganga using multivariate statistical tool

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Abstract Water quality of the Ganga River system is changing day by day due to multifold increase in population, especially near the banks of river Ganga, and associated exponential amplification of anthropogenic activities also played a remarkable role in it. The ecologically important lower and estuarine stretch of river Ganga comprising 7 different sampling stations, i.e., Jangipur, Berhampore, Balagarh, Tribeni, Godakhali, Diamond Harbour and Fraserganj, were selected for the study as the stretch is enriched with the vast number of floral and faunal diversity. The study was conducted for a period of 5 years, i.e., from 2016 to 2020. In the study, various analytical tools and techniques were used for the assessment of riverine water quality, i.e., for calculation of water quality index (WQI); The National Sanitation Foundation Water Quality Index (NSF-WQI) and the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) were used for the assessment. Along with WQI various statistical univariate as well as multivariate analytical tools like principal component analysis, correlation, ANOVA, and cluster analysis were also used to achieve the desired outputs. In the study, it has been observed that NSF-WQI varied from 61 to 2552, in which the higher value of NSF-WQI denoted the unsuitability of the water quality concerning the drinking water standards and vice versa. The CCME-WQI represented a similar trend as that of NSF-WQI, as it varied from 18 to 92 in which the lower value denoted degradation in the drinking water quality and vice versa. The study revealed that the Diamond Harbour-Fraserganj stretch is having an undesired level of water quality which were analyzed based on the drinking water guideline values of the Bureau of Indian Standards and that of NSF-WQI and CCME-WQI.

Keywords Ganga River system · NSF-WQI · CCME-WQI · Multivariate analysis · Transboundary River

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Introduction

Ganga river system is India's largest and world's fifth-largest river which flows an approximate path length of 2525 km, draining through five important states of the country, viz., Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, and West Bengal. It is a livelihood provider for more than 400 million people, i.e., for approximately 40% of the country's population, through tourism, drinking water, sanitation, irrigation, fisheries, travel, hydroelectricity, and recreation (Singh et al., 2019; Trivedi, 2010). Due to its great religious as well as socio-economic and socio-cultural importance, the river Ganga is regarded as a soul purifier (Ramakrishnan, 2003) and is the major source of water supply for the water-stressed India, where the per annum water supply is 1588 m^3 for each person (Matta et al., 2020). Despite being so valuable river for the country's development, it has been overexploited over time due to incremental population expansion. The advancement in society and increased rate of urbanization have also led to amplified pollution load in the river Ganga by the means of industrialization coupled with the use of excessive fertilizers for increasing agricultural production in farmlands leading to an enhanced rate of nutrient loading in the river, which has somehow resulted in significant alternation in the riverine ecology and in some places it has also lead to algal bloom (Dixit et al., 2017; Pandey et al., 2014). The increased pollution in the river system is also the result of a multifold rise in the discharge of organic as well as inorganic pollutants in the riverine system (Dwivedi et al., 2018). The pollution load in the river is increasing at an augmentable pace but in respect of that, the treatment plants are limited. The water quality index and multivariate statistical analysis are being used globally and regarded as the best tool for the assessment of the aquatic ecosystems nowadays (Kumar et al., 2021; Varol, 2020; Yadav et al., 2010), which has also been used for the assessment of the water quality in the different stretches of the Ganga river system (Rakesh Bhutiani et al., 2015; Dimri et al., 2021; Gurjar & Tare, 2019; Kumar et al., 2015). The multivariate statistical analysis provides the facility of interpretation for huge datasets in a concise and easiest form and helps in the identification of possible causes for deterioration of the water quality of the riverine systems (Du et al., 2019; Gurjar & Tare, 2019; Li et al., 2018; Shrestha & Kazama, 2007; Ustaoğlu et al., 2020). Similarly, among many water quality analysis techniques, the water quality indices are the unified mathematical effectual technique that has been used since 1965 by Horton (Horton, 1965); it is also used for the assessment and categorization of the water bodies (Uttrakhand at a Glance, 2019). The water quality indices are the universally accepted statistical technique used for the classification and characterization of the aquatic ecosystem in relation to freshwater ecology and their pollution status; it has been used by various policymakers and researchers (Li et al., 2009; Tripathi & Singal, 2019). The WQI is calculated considering the specified guidelines for the various water quality parameters prescribed for human consumption and aqua environmental conditions (Herojeet et al., 2015). There are a diverse number of WQI used globally for the calculation of WQI indices (Zhang et al., 2021) but none of them are accepted globally, so to increase the reliability multiple numbers of WQIs are being used for the assessment of the water quality Index (Bhakar & Singh, 2019; Zotou et al., 2020). The NSF water quality index and CCME water quality index are the most widely used indexing tool used in many parts of the world (Gupta et al., 2017). The CCME WQI is the composite method for calculation of WQI developed by the Canadian Council of Ministers of the Environment (Yotova et al., 2021) which can be used for the assessment of the water quality in different environmental conditions. Similarly, the NSF water quality index has also been used frequently by several researchers for the categorization of the water body. The regular monitoring and management of the riverine ecosystem are needed for adopting better management and implementation strategies required for the rejuvenation of the river system. The purpose of the present study is to evaluate the water quality status in the lower stretch of the ecologically important river Ganga and find out the major influencing parameters responsible for the unacceptance/deterioration of the water quality in the region. The study also evaluates the variation in the drinking water quality status of the river system. For the purpose many of the univariate as well multivariate statistical tools such as ANOVA, water quality index, principal component analysis, correlation, and cluster analysis were performed.

Materials and methods

The material and methodology section of the study mainly comprises four sub-steps, i.e., site selection, sample collection, sample analysis, and data analysis (Fig. 1).

Study area

The present study was carried out at 7 sampling sites, viz. Jangipur, Berhampore, Balagarh, Tribeni, Godakhali, Diamond Harbour, and Fraserganj, for which the GPS coordinates have been given in Fig. 2, located on the lower and estuarine stretch of the river Ganga covering more than 500 km channel

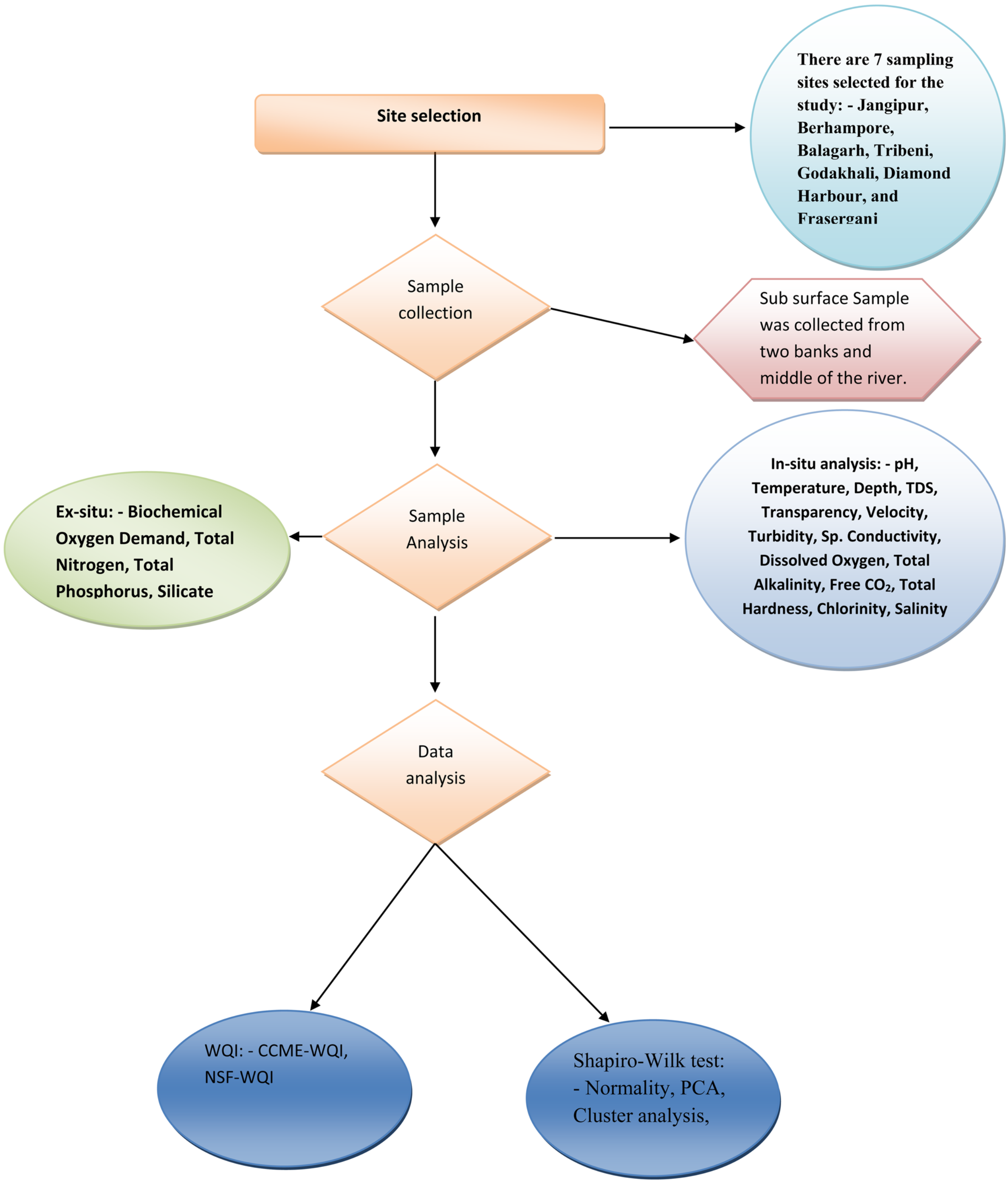


Fig. 1 Flow chart of the used materials and methodology

length. The study stretched both the tidal as well as non-tidal zones of the river, covering the riverine freshwater, estuarine freshwater, and estuarine saline water zones of the river. The study was conducted in the four major seasons, i.e., winter, summer, pre-monsoon, and monsoon.

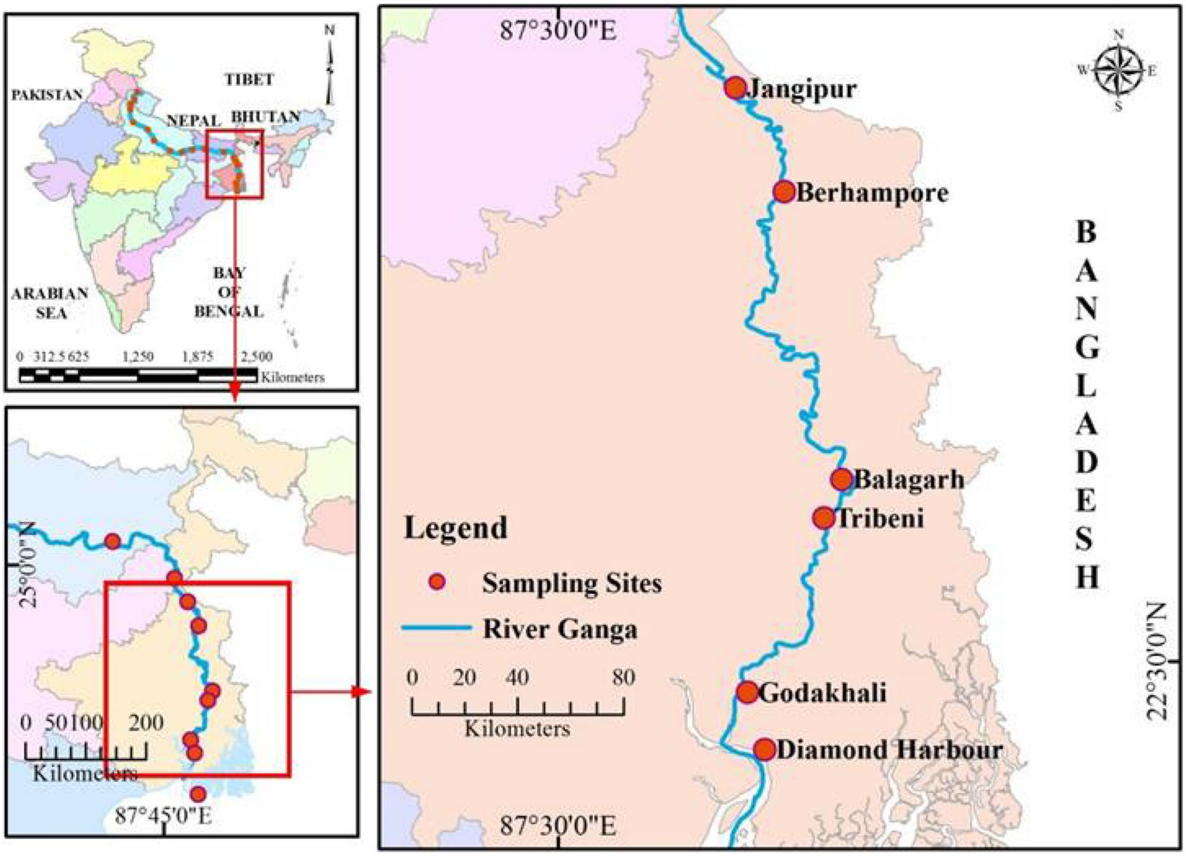


Fig. 2 Study area map

Collection of water sample

The sampling was carried out during 4 different seasons, i.e., winter, summer, pre-monsoon, and monsoon from 2016 to 2020, following the prescribed protocols in APHA 2005 (APHA, 2005). The sampling was done between 9 A.M. and 10 A.M. For the purpose triplicate sampling was carried out and the samples were collected from both the banks and middle of the river. For the purpose of nutrient analysis, the 1000-ml TARSON® high-density polyethylene (HDPE) bottles were used. Prior to each sampling the bottles were autoclaved, rinsed with dilute nitric acid, and double-distilled water. Further during the sampling, the bottles were rinsed with river water. The subsurface water samples were collected and were brought air-tight with the help of Parafilm at 4 °C in the icebox to the laboratory for further analysis.

Analytical method

Most of the field parameters such as dissolved oxygen (DO), alkalinity, total hardness, and free CO_2 were analyzed in situ following APHA 2005, for which the analytical methods are given in Table 1. Further, the parameters such as water temperature, TDS, pH, turbidity, salinity, and specific conductivity were measured using the multi-parameter analysis equipment AQUAREAD 7000®. Velocity was measured using a digital flow meter (Global Instrument FP-111®). The depth was measured using digitalized depth sounder HONDEX PS-7®. The transparency was measured using Secchi disk. Further for the biochemical oxygen demand, the samples were brought to the laboratory and kept in BOD incubator at 27 °C for 3 days and analysis was carried out. The nutrient parameters total phosphorus, silicate, and total nitrogen were analyzed following APHA 2005.

Table 1 Analytical procedure and apparatus used during the analysis of the water samples

Parameters studied	Analytical method/apparatus used
Water temperature (°C)	AQUAREAD 7000®
Depth (m)	HONDEX PS-7®
Transparency (cm)	Secchi disk
Velocity (m/s)	Global instrument model no. FP-111, USA Digital flowmeter
Turbidity (NTU)	AQUAREAD 7000®
Specific conductivity (mS/cm)	AQUAREAD 7000®
pH	AQUAREAD 7000®
DO (ppm)	Titrametric method (APHA, 2005)
BOD (ppm)	Titrametric method (APHA, 2005)
Total alkalinity (ppm)	Titrametric method (APHA, 2005)
Free CO_2 (ppm)	Titrametric method (APHA, 2005)
Total hardness (ppm)	EDTA titrametric method (APHA, 2005)
Chlorinide (ppm)	Argenometric method (APHA, 2005)
Salinity (ppt)	AQUAREAD 7000®
Total-N (ppm)	Kjeldahl method (APHA, 2005)
Total-P (ppm)	Digestion method (APHA, 2005)
Silicate (ppm)	Molybdosilicate method (APHA, 2005)
TDS (ppt)	AQUAREAD 7000®

Quality control

All the instruments used during the analytical procedures were pre-calibrated using the standard solution and procedure recommended by the company. After each analysis, all the electrodes of AQUAREAD 7000® were pre-washed using double-distilled water. During the analysis, each electrode was conditioned and stabilized. During the laboratory analysis for each spectroscopic reading standard and the blank sample had been run along with analysis, and triplicate readings were taken to reduce the chances of error. The glassware used during the processes was of NABL certified class "A" manufactured by Borosil®. The used chemicals during the study process were of MERCK®.

Statistical analysis

For the statistical analysis Microsoft Excel 2007, PAST 4.02, and IBM SPSS 22 softwares were used. For the calculation of WQI, Microsoft Excel 2007 software was used. To study the variation among the different water quality parameters, the box-whisker plot was prepared using IBM SPSS 22 software, as the box-whisker plot classifies the differences in the standard deviation among the different studied water quality variables (Kumari et al., 2013; Singh et al., 2018).

Principal component analysis (PCA)

PCA is the advanced form of multivariate statistical tool used for the classification and grouping of different ecological niches with the use of different water quality parameters (Tripathi & Singal, 2019). So, to elucidate the abnormality and enhance the feasibility of the datasets for the study of the physico-chemical properties of the Ganga River water the principal component analysis (PCA) was performed using IBM SPSS 22 software. Prior to this, the Kaiser-Meyer-Oklin and Barlet sphericity tests were performed to understand the reliability of the results. To check the normality, the Shapiro-Wilk and Kolmogorov-Smirnov tests were carried out. For reduction of data to the relatively less significant variables, varimax rotation was used so that association between the data source and required factors can be made (Noori et al., 2010). With the help of Kaiser normalization, the PCs having eigenvalue greater than 1 were recognized and selected which were observed in the scree plot.

Cluster analysis (CA)

Cluster analysis is the multivariate statistical tool used for the classification of different study sites based on the similarities between them (Alam et al., 2021). So to find out the closely related sampling sites based on their physicochemical characteristics the Bray-Curtis cluster analysis was performed using the mean value of datasets. Bray-Curtis cluster analysis is the authenticated cluster analysis tool used for the classification based on different similarities (Jain, 2020; Kour et al., 2021). For this purpose, PAST 4.03 statistical software was used. Different dendrogram were formed in the form of graphical summary and Euclidean distance (Dabgerwal & Tripathi, 2016).

Calculation of water quality index

The water quality of any aquatic environment signifies its chemical, physical, and biological characteristics (Kumar et al., 2021). The water quality index (WQI) is a significantly important tool used for evaluating the complete status of the water body by denoting a single number value which is the aggregation of multiple physicochemical parameters. In the present study two of such water quality index assessment techniques, viz., Canadian Council of Ministers of the Environment (CCME-WQI) and National Sanitation Foundation water quality index (NSF-WQI), were used.

Canadian Council of Ministers of the Environment water quality index (CCME-WQI)

The CCME-WQI was used to evaluate the temporal variation in the water quality which is composed of three factors, F_1 (Scope), F_2 (Frequency), and F_3 (Amplitude).

where.

F_1 **(Scope):** It is the calculation of percentage variables that do not fulfill the desired specified limit set by the BIS (2012) (Table 2).

F_2 **(Frequency):** It is the percentage value of the individual parameter which does not fulfill the prescribed safe limits (failed tests).

F_3 **(Amplitude):** It is the difference value by which the specific parameter does not fulfill the desired limit.

And for the calculation of these three factors, the following formulas were used:

Table 2 BIS standard of water parameters used for calculation of WQI

Parameter	Standard permissible limit (BIS, 2012)
pH	**6.5–8.5**
TDS (ppm)	**< 2000**
DO (ppm)	**> 6**
Specific conductance (µS/cm)	**< 300**
Nitrate (ppm)	**< 45**
BOD (ppm)	**< 5**
Alkalinity (ppm)	**< 200**
Hardness (ppm)	**< 300**

$$F1 = \left(\frac{\text{Number of failed variables}}{\text{Total number of variables}}\right) \times 100 \quad (1)$$

$$F2 = \left(\frac{\text{Number of failed test}}{\text{Total number of tests}}\right) \times 100 \quad (2)$$

F_3 (Amplitude) is calculated following three sub-steps:

The individual parameter which does not fulfill the specified desired limit is known as execursion.

$$\text{Execursion} = \left(\frac{\text{Failed test value}}{\text{Objective}}\right) - 1 \quad (3)$$

For the case where the test value should not fall below the objective,

$$\text{Execursion} = \left(\frac{\text{Objective}}{\text{Failed test value}}\right) - 1 \quad (4)$$

Then, the collective amounts by which individual tests are out of compliance are calculated by

$$\text{NSE} = \frac{\sum_{i=1}^{n} \text{execursion}}{\text{Total number of tests in the results}} \quad (5)$$

Using Eq. (5) now,

$$F3 = \left(\frac{\text{NSE}}{0.01(\text{NSE}) + 0.01}\right) \quad (6)$$

$$\text{CCME} - \text{WQI} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \quad (7)$$

Table 3 Reference range for CCME-WQI

WQI	Condition	Grade
95–100	Excellent	A
80–94	Good	B
65–79	Fair	C
45–64	Marginal	D
0–44	Poor	E

Finally, the values are compared with the reference grading scale provided for the CCME-WQI calculation as given in Table 3.

National Sanitation Foundation water quality index (NSF-WQI)

For the calculation of NSF-WQI, the model used was as that of Deshmukh and Aher (2016). For the study, the parameters selected were the same as used by Mitra et al. (2018a) in the same study region of Hooghly estuary, which were pH, temperature, total dissolved solids (TDS), turbidity, dissolved oxygen (DO), nitrate, phosphate, and biochemical oxygen demand (BOD). For this purpose, each parameter is given individual weight, i.e., assigned weight (A_w) on a scale of 1 to 5, where 1 is for the least influencing parameter and 5 is the highest assigned weight as given in Table 4. After deciding the assigned weight (W_a), the relative weight (W_r) was calculated using the following sub-steps (Fig. 3) and later was compared with the reference values given by Yadav et al. (2010) (Table 5).

Table 4 Assigned and relative weight of different parameters used for calculation of NSF-WQI

Parameter	A_W	Relative weight
pH	4	0.125
TDS	4	0.125
DO	4	0.125
Conductivity	4	0.125
Nitrate	4	0.125
BOD	5	0.15625
Alkalinity	3	0.09375
Hardness	4	0.125
$\sum A_W$	32	

Results and discussion

The ecology of the riverine system as well as the livelihood of the dependent population significantly pivot on the water quality of the riverine system. The analyzed stretch of the river Ganga is well recognized for its ecological richness and is a livelihood provider for millions of population (Lakra et al., 2010; Naskar, 1990). The stretch of the river is having a great number of aquatic flora and fauna (Roshith et al., 2013).

Water temperature (°C)

Water temperature has an effective role in aquatic ecology and it significantly influences the health status of the aquatic community. The gonadal maturity of many organisms such as various fish species is greatly dependent upon the water temperature (Agatsuma, 2020). It also modulates the physical property of the aquatic system such as water viscosity and DO saturation (Du et al., 2019). The average water temperature in the lower stretch of the Ganga river system varied significantly ($p < 0.05$) among the sampling stations and the recorded average values were between 26.9 ± 0.88 °C and 29.4 ± 1.16 °C (Fig. 4 and Table 6). The highest average temperature of 29.4 ± 1.16 °C was observed at Godakhali and the lowest of 26.9 ± 0.88 °C was recorded at Balagarh. During the entire sampling period, the lowest detected temperature of 20.8 °C was observed at Berhampore. The highest temperature of 33.6 °C was observed at Tribeni which may be due to the discharge influx received from the Bandel thermal power station situated on the bank of the river at Tribeni, as reported by Bera (2016) and Mitra et al. (2018a). As illustrated in Fig. 4 from the analysis of the box-whisker plot it is also known that the highest variation of water temperature has also been recorded in Tribeni. The recorded temperature was higher than the earlier study of Manna et al. (2013) in all the studied sites. The rising temperature in the region may have been caused due to the impact of anthropogenic activities, global warming and climate change, which has also been reported in many rivers worldwide (Kaushal et al., 2010; Vass et al., 2009).

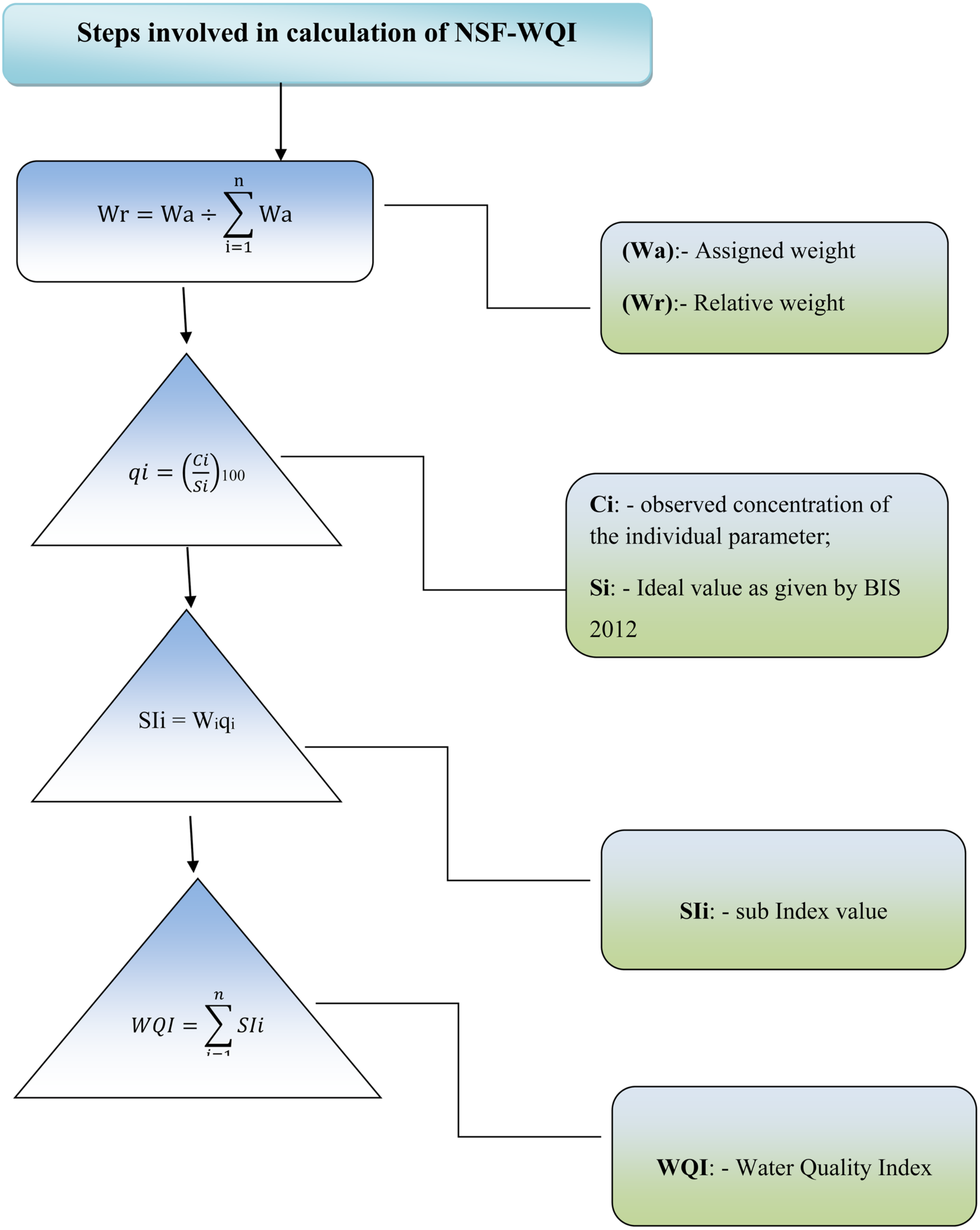


Fig. 3 Steps involved in calculation of NSF-WQI

Table 5 Range of NSF WQI and respective water quality status given by Yadav et al. (2010)

Range of WQI	Water quality status
0–25	EXCELLENT
26–50	GOOD
51–75	POOR
76–100	VERY POOR
>100	UNSUITABLE

Depth (m)

The impact of water depth on riverine ecology and drinking water source of the river is greatly interdependent and has been reported from the studied sites by Das and Mukherjee (2019). With time, the river depth is getting lowered, and the impact of global warming is playing a pivotal role in such changes (Zhang et al., 2011). The study sites comprise of different ecological regimes, viz., the freshwater riverine zone, the upper stretch of the estuary, and the brackish water, i.e., the lower stretch of the estuary. The average depth of the studied stretch of the Ganga River system was 9.72 ± 0.82 m. The highest and lowest average depth was observed 13.95 ± 3.11 m and 5.52 ± 1.37 m, respectively, at Diamond Harbour and Fraserganj (Table 6), and both the sites lie in the lower estuarine tidal stretch of the river. However, statistically, no significant ($p > 0.05$) differences were observed among the sampling stations except Fraserganj. During the entire sampling period, the highest (19.18 m) depth was recorded at Diamond Harbour. A water head difference of 3–5 m is common at the stretch due to the tidal effects (Manna et al., 2013). The higher depth at Diamond Harbour is also been reported in the earlier studies in the region by Manna et al. (2013). From the box-whisker plot also (Fig. 4) highest variation of depth has been reported in Diamond Harbour with a greater lower quartile in the region. The same has also been reported in other rivers of the world such as in the Yellow River of China (Xie et al., 2021).

Transparency (cm)

River transparency shows the clarity and the condition of the water quality and has an inverse relation with turbidity (Effler, 1988; Matchitt, 2019). The observed average transparency in the studied lower stretch of river Ganga was 31.2 ± 3.23 cm. The average transparency (about 50 cm) was found statistically similar ($p > 0.05$) in the non-tidal Jangipur–Berhampore stretch of the river. The tidal zone has a positive influence on turbidity as has also been reported in Tamar estuary, Australia by Fischer et al. (2017). The rest of the stations showed significant variability ($p < 0.05$). The highest average transparency was observed as 50.7 ± 9.39 cm at Jangipur. The lowest average transparency (17.04 ± 3.79 cm) was observed at Diamond Harbour (Table 6), which may be due to the tidal impact in the river. From the whisker-box plot analysis (Fig. 4) it is also clear that maximum variation of transparency was observed at Berhampore, with a maximum lower quartile value. A similar type of situation has been reported in other water bodies such as in Okpoka Creek of the Niger delta (Augustina, 2014).

Velocity (m/s)

Riverine water velocity has a significant influence on reducing the pollution of the river system as it can assimilate the responsible pollutants (Matta, 2014). But with the incorporation of the multifold anthropogenic effect on the river and construction of dams and barrages on the river has resulted in the reduction in the riverine flow (Mani et al., 2019; Wang et al., 2012; Wen et al., 2017). The riverine velocity significantly ($p < 0.05$) differed among the sampling stations. The average velocity recorded at the studied stretch was 1.55 ± 0.43 m/s. The highest average velocity was observed 3.01 ± 2.29 m/s at Fraserganj (Table 6). The impact of barrages on the flow of the Ganga river system in the upper stretch of the river system has been explained between Bijnor and Narora by Sonkar and Gaurav (2020). Similarly, in the present study also, the lowest average velocity of 0.53 ± 0.13 m/s was recorded at Jangipur, the sampling station just after the Farraka barrage where the flow and water discharge is regulated by the Farakka Barrage Authority (Manna et al., 2013; Mitra et al., 2018a). The whisker-box plot (Fig. 4) also showed that maximum up quartile variation was observed at Fraserganj. However, in the entire sampling period, the lowest flow of 0.15 m/s was observed at Diamond Harbour and the highest of 9.83 m/s at Fraserganj which may have occured due to the tidal effect of the river.

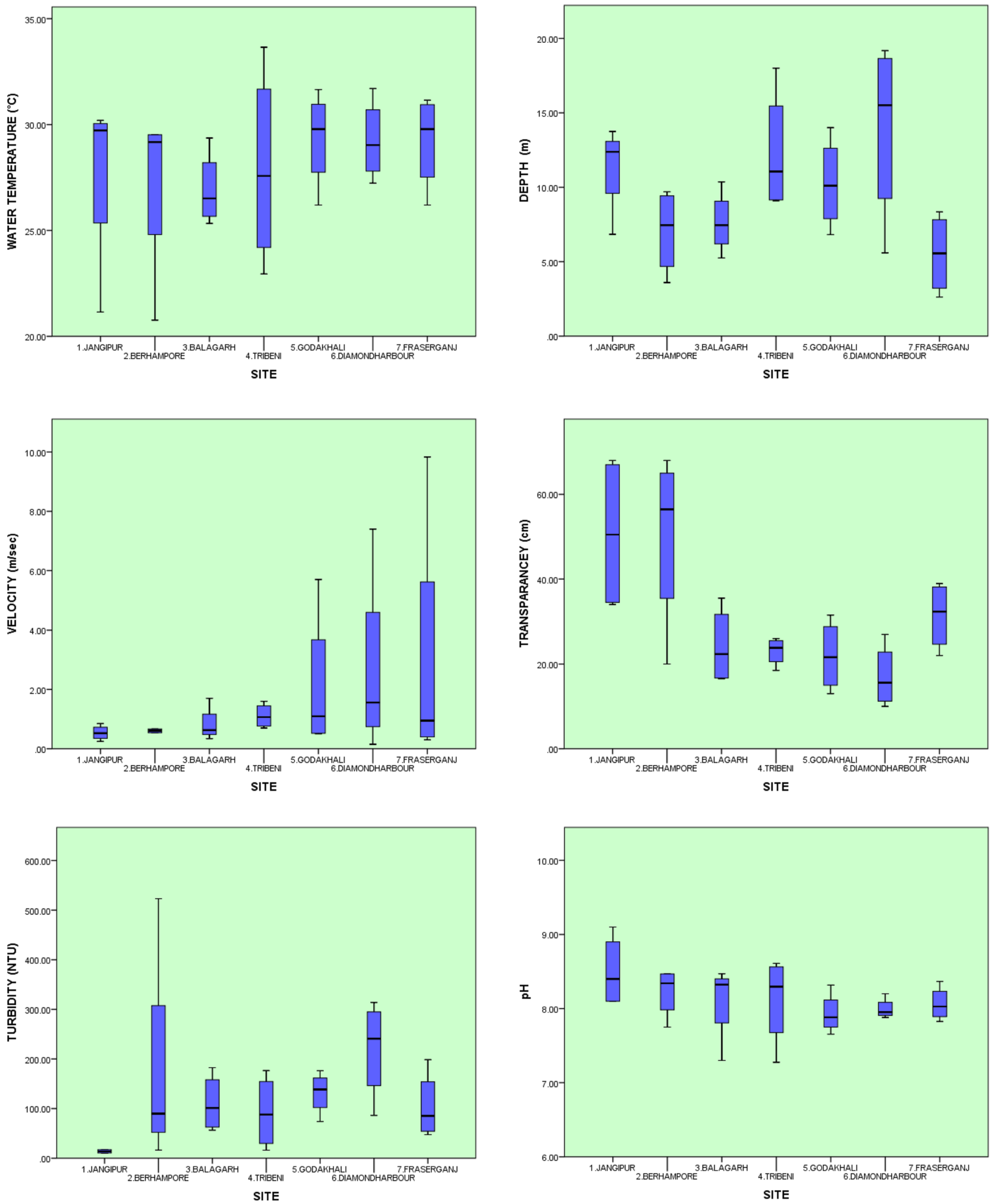


Fig. 4 Box plot of different analyzed parameters

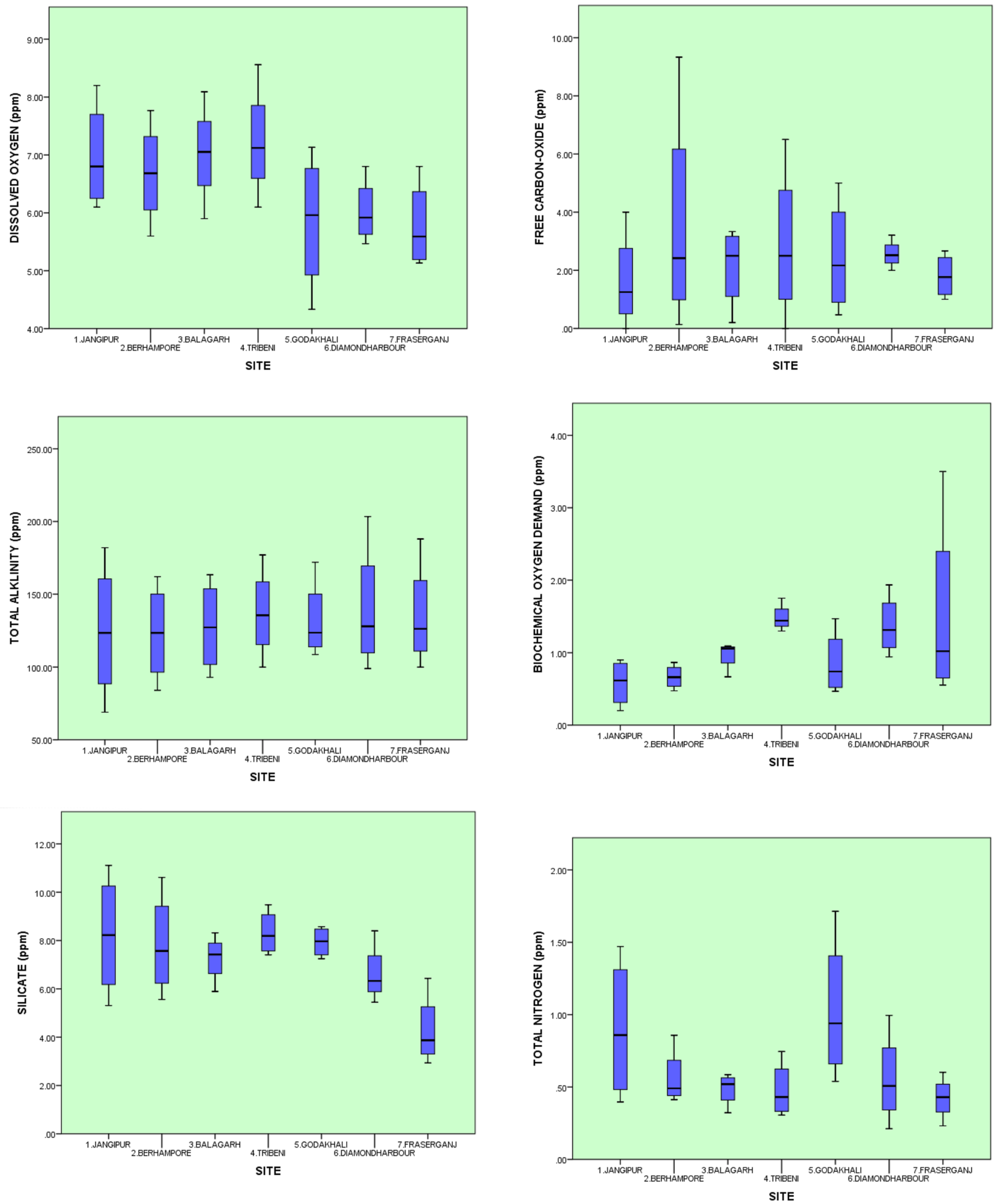
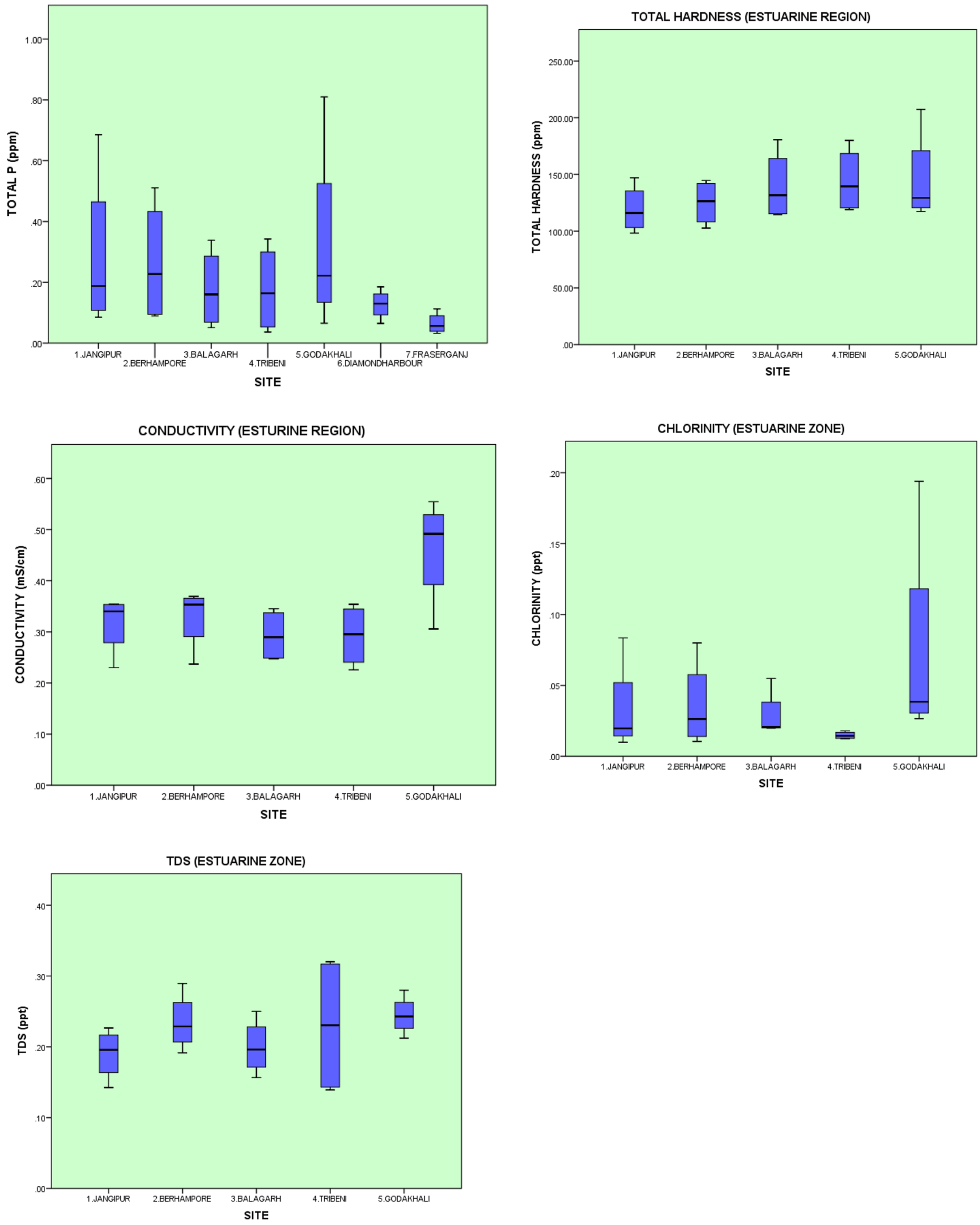


Fig. 4 (continued)



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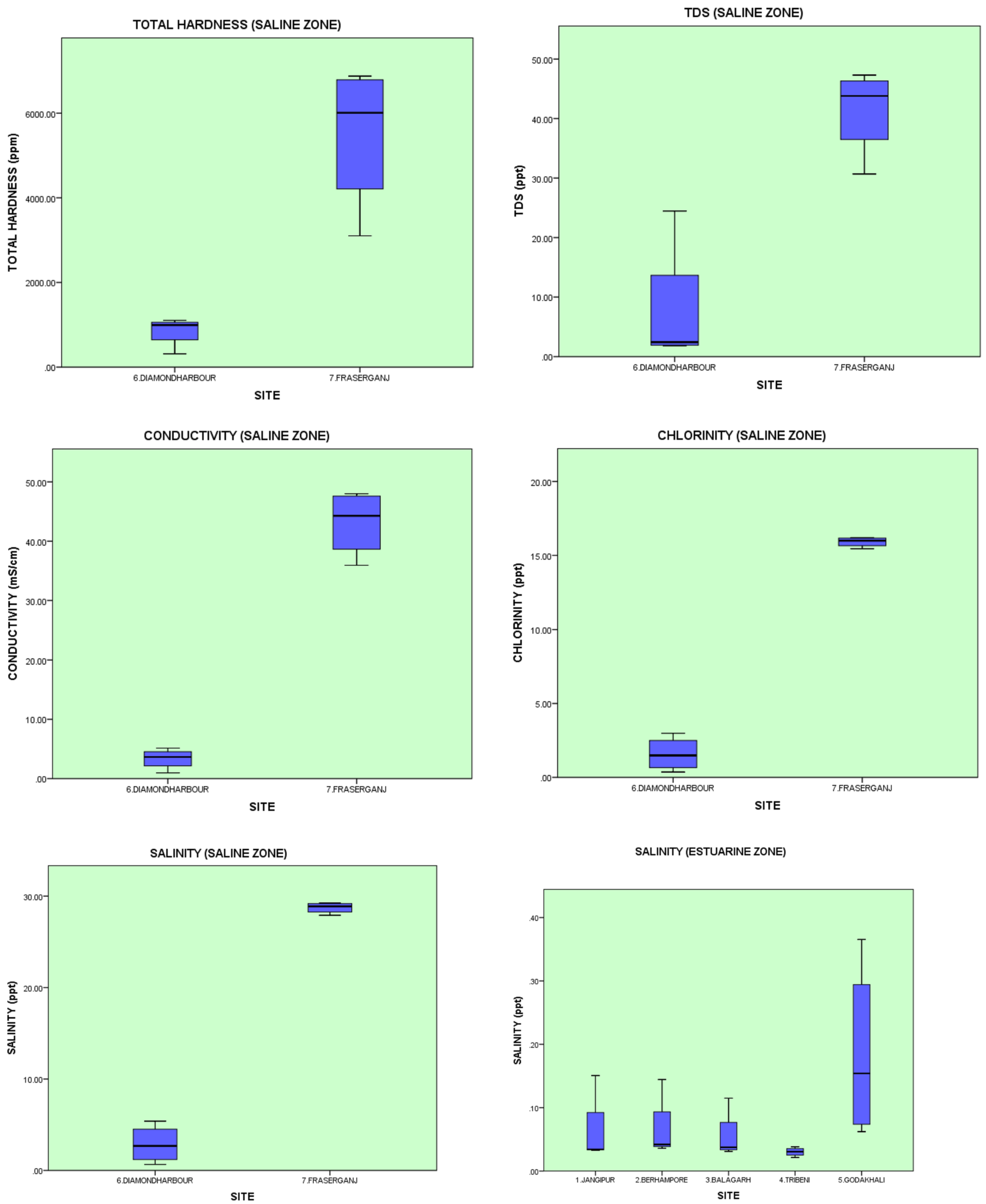


Fig. 4 (continued)

Table 6 Average water quality parameters recorded from the lower stretch of river Ganga

	Jangipur	Berhampore	Balagarh	Tribeni	Godakhali	D. Harbour	Fraserganj
Water temperature (°C)	27.7 ± 2.19	27.2 ± 2.14	26.9 ± 0.88	27.9 ± 2.36	29.4 ± 1.16	29.3 ± 0.96	29.2 ± 1.13
Depth (m)	11.3 ± 1.53	7.0 ± 1.44	7.6 ± 1.05	12.3 ± 2.10	10.3 ± 1.54	13.9 ± 3.11	5.5 ± 1.37
Transparency (cm)	50.7 ± 9.39	50.2 ± 10.68	24.2 ± 4.59	23.0 ± 1.68	21.9 ± 4.22	17.0 ± 3.79	31.4 ± 4.05
Velocity (m/s)	0.54 ± 0.13	0.60 ± 0.04	0.82 ± 0.30	1.11 ± 0.21	2.10 ± 1.23	2.67 ± 1.61	3.01 ± 2.29
Turbidity (NTU)	13.80 ± 1.91	179.3 ± 115.73	110.4 ± 29.42	92.1 ± 37.60	131.9 ± 21.54	220.6 ± 50.02	104.1 ± 34.15
Specific conductivity (mS/cm)	0.32 ± 0.03	0.33 ± 0.03	0.29 ± 0.03	0.29 ± 0.03	0.46 ± 0.05	3.34 ± 0.88	43.13 ± 2.82
pH	8.5 ± 0.24	8.2 ± 0.17	8.1 ± 0.27	8.1 ± 0.30	7.9 ± 0.14	8.0 ± 0.07	8.1 ± 0.12
DO (ppm)	7.0 ± 0.47	6.7 ± 0.45	7.0 ± 0.45	7.2 ± 0.51	5.8 ± 0.60	6.0 ± 0.28	5.8 ± 0.38
BOD (ppm)	0.6 ± 0.16	0.7 ± 0.08	1.0 ± 0.10	1.5 ± 0.10	0.8 ± 0.22	1.4 ± 0.21	1.5 ± 0.68
Total alkalinity (ppm)	124.5 ± 23.93	123.2 ± 16.99	127.7 ± 15.89	137.0 ± 15.85	132.0 ± 13.91	139.6 ± 22.52	135.2 ± 18.76
Free CO_2 (ppm)	1.6 ± 0.85	3.6 ± 2.01	2.1 ± 0.70	2.9 ± 1.36	2.4 ± 1.00	2.6 ± 0.25	1.8 ± 0.38
Total hardness (ppm)	119.3 ± 10.63	125.0 ± 10.10	139.6 ± 15.63	144.5 ± 14.64	145.8 ± 20.81	851.8 ± 181.08	5498.7 ± 871.22
Chloride (ppm)	0.03 ± 0.02	0.04 ± 0.02	0.03 ± 0.01	0.02 ± 0.0	0.07 ± 0.04	1.58 ± 0.58	15.91 ± 0.17
Salinity (ppt)	0.06 ± 0.03	0.07 ± 0.03	0.06 ± 0.02	0.03 ± 0.00	0.18 ± 0.07	2.86 ± 1.05	28.72 ± 0.30
Total-N (ppm)	0.90 ± 0.25	0.56 ± 0.10	0.49 ± 0.06	0.48 ± 0.10	1.03 ± 0.25	0.56 ± 0.16	0.42 ± 0.08
Total-P (ppm)	0.29 ± 0.14	0.26 ± 0.10	0.18 ± 0.07	0.18 ± 0.07	0.33 ± 0.16	0.13 ± 0.02	0.06 ± 0.02
Silicate (ppm)	8.2 ± 1.28	7.8 ± 1.08	7.3 ± 0.50	8.3 ± 0.47	7.9 ± 0.32	6.6 ± 0.63	4.3 ± 0.76
TDS (ppt)	0.19 ± 0.02	0.23 ± 0.02	0.20 ± 0.02	0.23 ± 0.05	0.24 ± 0.01	7.79 ± 5.56	41.40 ± 3.71

Turbidity (NTU)

Turbidity of the riverine system is directly or indirectly being influenced by many biotic as well abiotic factors such as transparency, flow, and tidal effect of the river (Al Ja'Aidi et al., 2004; Stevenson & Bravo, 2019). The turbidity can influence not only the drinking water quality but also various aquatic organisms and the aquatic ecosystem as a whole. It can affect important aquatic organisms such as benthic organisms, planktons, and fishes (Cyrus & Blaber, 1987). In the present study, the sampling stations exhibited an insignificant ($p > 0.05$) difference in turbidity. The average turbidity in the entire sampling station was recorded 122 ± 21.29 NTU. The highest average turbidity was observed as 221 ± 50.02 NTU at Diamond Harbour (Table 6). The lowest of 13.80 ± 1.91 NTU was observed at Jangipur. One of the reasons for higher turbidity at Diamond Harbour may be due to the confluence with the river Rupnarayana (Manna et al., 2013). The whisker-box plot showed that maximum variation in the up and low quartiles was observed at Tribeni (Fig. 4), which may have been caused due to an influx of thermal discharge from BTPS. In the entire stretch of the river, the turbidity was recorded much above the drinking water acceptable limit of 5 NTU, as given by BIS (2012) and the EPA USA (2018b).

Specific conductivity (mS/cm)

The specific conductivity of the riverine water is considered the best indicator of pollution in the riverine system (Bon et al., 2020; de Sousa et al., 2014; Loock-Hattingh et al., 2015). In the study of freshwater stretch, the observed average specific conductivity was in the narrow range of 0.29 to 0.33 mS/cm, while as per expectations, its average value gradually increased downward in the estuary from 0.46 ± 0.05 mS/cm at Godakhali to 3.34 ± 0.88 mS/cm at Diamond Harbour and 43.13 ± 2.82 mS/cm at Fraserganj (Table 6). The lowest average specific conductivity of 0.29 ± 0.03 mS/cm was observed at Tribeni. In the entire study period, maximum specific conductivity (48 mS/cm) was observed at Fraserganj and the minimum was observed at Jangipur (0.23 mS/cm). The findings were higher than the earlier studies made by Manna et al. (2013). And, in the majority of the sampling sites, the average specific conductivity was more than the drinking water permissible limit (< 0.30 mS/cm), as prescribed by the BIS (2012).

pH

pH is the measurement of acidity and basicity of the water, and in the present study, it has been observed that all the stations had alkaline pH. The observation was similar to the earlier study of Manna et al. (2013) and Mitra et al. (2018b). The variations in the average pH of the sampling sites were significant ($p < 0.05$). The overall average pH was 8.13 ± 0.40. Among the stations, the highest average pH of 8.5 ± 0.24 was observed at Jangipur while the lowest of 7.9 ± 0.14 was observed at Godakhali (Table 6). The impact of the discharge of huge organic matter enriched domestic and industrial sewages from the agglomerated Kolkata City, and their decomposition in the riverine environment has coupled lowering of pH at Godakhali. During the entire sampling period, the maximum pH value of 9.1 was observed at Jangipur, while the minimum of 7.3 was recorded at Tribeni. The box-whisker plot also showed that maximum variation of pH was observed at Balagarh and Tribeni (Fig. 4). The observed average pH values were within the drinking water permissible range of 6.5–8.5, as prescribed by the BIS (2012) and EPA (2018). The pH range was found suitable for the aquatic community as well. The results were similar to the upper part of the Ganga river system (Dutta et al., 2020; Dwivedi et al., 2018; Matta et al., 2020).

Dissolved oxygen (ppm)

The presence of an adequate amount of dissolved oxygen in the aquatic system is a good indicator of diversity richness and good riverine health (Banerjee et al., 2019). The average dissolved oxygen in the studied stretch was 6.5 ± 0.19 ppm. The sampling sites exhibited a significant difference in their average content ($p < 0.05$). The highest average dissolved oxygen of 7.2 ± 0.51 ppm was observed at Tribeni, while the lowest of 5.8 ± 0.60 ppm was at Fraserganj. The maximum value (8.6 ppm) was observed during the entire sampling period at Tribeni, while the minimum (4.3 ppm) was at Godakhali (Table 6). Obviously, with the increase in salinity, the dissolved oxygen content decreases, and thus, as per expectations, the lower level of average dissolved oxygen was recorded at Fraserganj, the last sampling site in the estuary. Like pH, the entry of organic matter enriched sewages from the agglomerated Kolkata City was responsible for lowering the dissolved oxygen in the riverine stretch below Kolkata, as was recorded at the Godakhali sampling site. As a whole, the average dissolved oxygen in the entire studied stretch was good as per the standards of CPCB (2011) except the Godakhali stretch (Fig. 4) where maximum variation in the DO was observed. A relatively lower dissolved oxygen value has been reported by Mitra et al. (2018a) from the studied stretch for the period 2014–2015. And the records were similar to that of Manna et al. (2013), i.e., > 5 ppm.

Biochemical oxygen demand (BOD) (ppm)

BOD is the tool for the measurement of anthropogenic activity and incidence of the increased organic load in the aquatic ecosystem (Khan et al., 2016). In the study, similar to dissolved oxygen, the average BOD varied significantly ($p < 0.05$) among the stations. The average BOD in the entire studied stretch was 1.1 ± 0.12 ppm; the highest average BOD was observed to be 1.5 ± 1.3 ppm at Fraserganj. The lowest average BOD was 0.6 ± 0.2 ppm at Jangipur (Table 6). A higher variation was observed at Fraserganj (Fig. 4). The relatively higher values of the BOD at Fraserganj may be due to intensive fishing activity in the region as reported in the earlier studies of Bhaumik (2017), Bhaumik et al. (2012), and Sarkar et al. (2019).

Total alkalinity (ppm)

The total alkalinity of the river systems is mainly due to the presence of carbonates and bicarbonates of the alkali and alkaline earth metals. The average alkalinity in the entire stretch was 131 ± 6.30 ppm and it varied significantly ($p < 0.05$) among the sampling stations. The maximum total alkalinity (203 ppm) was observed during the entire sampling period at Diamond Harbour. However, the average total alkalinity was found within the drinking water permissible limit

(< 200 ppm) (Table 6), at all the stations as per BIS (2012), except a few occasions as recorded at individual sites. A more or less similar range of alkalinity has previously been reported from the same study stretch (Manna et al., 2013). The maximum variation was also observed in the Diamond Harbour (Fig. 4).

Free CO_2(FCO_2) (ppm)

Free carbon dioxide is an important parameter that supports the photosynthesis of various aquatic organisms and thus, has a definite role on the dependent organisms (Falkowski & Kiefer, 1985). The average FCO_2 in the entire stretch was 2.4 ± 0.38 ppm. Its variation was significant among the sampling stations. The highest average FCO_2 was 3.6 ± 2.01 ppm as recorded at Berhampore and the lowest of 1.6 ± 0.85 ppm was observed at Jangipur (Table 6). The whisker-box plot showed that maximum variation was observed at Berhampore and Tribeni (Fig. 4). The maximum value (9.3 ppm) of the parameter was also recorded at Berhampore. The FCO_2 is also being affected by various other constraints caused by the urbanization of the society as reported in the Yangtze River of China by Zhou et al. (2019).

Total hardness (ppm)

The total hardness of water is mainly due to the divalent metal cations calcium and magnesium. The freshwater stretch exhibited an average total hardness of 119.3 ± 10.63 to 146 ± 20.81 ppm. The lower estuarine stretch exhibited a steady increase in the average total hardness of 852 ppm at Diamond Harbour and 5499 ppm at Fraserganj (Table 6). The whisker-box plot of the data showed that Godakhali and Fraserganj had maximum variations (Fig. 4). The total hardness of the water differed from the findings of Manna et al. (2013) and was higher than the previous studies in the stretch. The estuarine stretches of the river exhibit a higher total hardness value than the acceptable drinking water permissible limits of BIS (2012), i.e., < 300 ppm.

Chloride (ppt)

The chloride content in water is due to its salt content which may be received from the pollutant sources or leaching from various rocks and minerals (APHA, 2005; WHO, 1993).In the Jangipur to Godakhali stretch the average chloride was in the range of 0.01 to 0.07 ppt and the variations among the sites were insignificant. The highest average chloride of 15.91 ± 0.17 ppt was at Fraserganj, i.e., the estuarine mouth (Table 6). The relatively higher similarity between the Diamond Harbour and Fraserganj is due to the tidal saline water ingress from the sea (Yanosky et al., 1995; Yuan et al., 2020).

Salinity (ppt)

The salinity of the studied stretch is greatly influenced by the tide and the saline water influx from the sea (Boesch et al., 1994). In the Jangipur to Tribeni stretch the average recorded salinity was up to 0.07 ppt. The highest average salinity of 28.72 ± 0.30 ppt was recorded at the Fresarganj area (Table 6). The whisker-box plot showed the maximum variation at Diamond Harbour (Fig. 4). As per expectations; the lower estuarine stretch exhibited a gradual increase in salinity. The findings were also similar to the earlier studies made in the stretch (Manna et al., 2013; Mitra et al., 2018a).

Total nitrogen (ppm)

The eco-environment of the riverine system is greatly influenced by nitrogen and its cycle (Xia et al., 2018). The average total nitrogen in the studied stretch was 0.63 ± 0.07 ppm. The highest average total nitrogen was found 1.03 ± 0.25 ppm at Godakhali and the lowest average content of 0.42 ± 0.08 ppm was observed at Fraserganj (Table 6). Among all the stations the maximum variance was observed at Godakhali (Fig. 4). The higher content of the total nitrogen at the Godakhali stretch was due to the effluents received in the river as mentioned, while its gradual decrease in the lower stretch was due to continued decomposition and dilution by the tidal seawater.

Total phosphorus (ppm)

The total phosphorus content in the river is a significant indicator of nutrient loading in the system (Bowes et al., 2003). It influences the planktonic growth in the riverine system as well (Labry et al., 2002), by which it can make a considerable impact on the ecology of the aquatic ecosystem. The average total phosphorus in the studied stretch was 0.20 ± 0.04 ppm. Like total N, the highest average total phosphorus (0.33 ± 0.16 ppm) was observed at Godakhali, while the lowest average content of 0.06 ± 0.02 ppm was observed at Fraserganj (Table 6). The variations in the average total phosphorus content among the sampling sites were found significant ($p < 0.05$). Among all the sites the maximum variation was observed at Godakhali (Fig. 4). The Godakhali stretch is having higher total phosphorus content similar to that of nitrogen and reflects the eutrophication in the region as reported in many other studies (Bowes et al., 2003; Dodds & Smith, 2016), and also from the studied stretch by other researchers (Manna et al., 2013; Mitra et al., 2018b).

Silicate (ppm)

Similar to other ions, silicates in the river are mainly due to weathering of rocks and minerals and various anthropogenic activities (Mortatti & Probst, 2003). The lower part of the studied stretch is influenced by the seawater influx as well (Mitra et al., 2018b). The average silicate content was similar among all the stations except Fraserganj, which significantly ($p < 0.05$) varied from other stations. This was expected since with an increase in salinity the silicate content decreases in the natural systems. Among all the sampling sites the maximum deviation was observed at Jangipur and Behrampore (Fig. 4). The average silicate in the studied stretch was 7.2 ± 0.36 ppm and the highest average content of 8.3 ± 0.47 ppm was observed at Tribeni (Table 6).

Total dissolved solid (TDS) (ppt)

The dissolution of higher organic, as well as inorganic matriculates in the riverine system results in the rise in TDS value (Miraj et al., 2017). The lower stretch is also influenced by the saline water ingress which raises the TDS level of the estuarine system (Mitra et al., 2018b). The observed average TDS in the entire stretch was 7.18 ± 15.14 ppt. The highest average TDS was observed as 41.40 ± 3.71 ppt at Fraserganj while the lowest average was 0.19 ± 0.02 ppt at Jangipur (Table 6). Among the stations, the observed TDS at Fraserganj differed significantly from all the other sampling stations. The whisker-box plot showed that maximum deviation was observed at Fraserganj (Fig. 4). The higher TDS in the region of Diamond Harbour and Fraserganj is due to the saline nature of water through the influx of seawater. However, in the freshwater zones, TDS were within the drinking water permissible limit of < 2 ppt, as per BIS (2012).

Variability of different water quality parameters

The Hooghly Estuary is strongly influenced by the tidal effect; thus, many of its water parameters change rapidly. The present study, however, is a representation of long-term changes in the system. The depth profile exhibited maximum values in the Diamond Harbour area which has also been reported earlier (Manna et al., 2013; Mitra et al., 2018b). Although a huge amount of sediment is transported through the Hooghly estuary, the Calcutta Port Trust is maintaining the desired depth of the shipping channel by dredging and implementing the associated conservation measures. The productivity of an aquatic system is greatly dependent upon its temperature variations. In the studied stretch, the recorded temperature was in the favorable range of 20.8–33.6 °C. The higher values were recorded at the Tribeni sampling site due to probable discharge of effluents from the thermal power plant as also reported by Manna et al. (2013). In the non-tidal stretch, i.e., above Nabadweep, the average transparency was in the range of 50 cm. The tidal influence was recorded most impacting on transparency in the Balagarh–Diamond Harbour stretch with the gradual decrease in transparency from 24.2 to 17.0 cm and then again increase in transparency in the Fraserganj area with the observed average value of 31.4 cm due to the impact of seawater. The specific conductivity and its linked parameters such as salinity exhibited a gradual increase in the Godakhali-Fraserganj area (0.46–43.13 mS/cm; 0.18–28.72 ppt). The studied stretch exhibited moderate alkaline pH congenial for the growth and development of the aquatic community. The higher level of photosynthetic activity also maintained a higher pH range. After the construction of the Farakka barrage located about 543 km upstream from the sea mouth during the 1970s, the water flow in the stretch has increased considerably which has improved the DO content in the channel to the present average value of

5.8 to 7.2 ppm with respect to the pre-Farakka barrage period of 3.4–5.1 ppm (Bose, 1956). Total alkalinity decreased significantly in the post-Farakka barrage period with the present recorded average value of 123–140 ppm with respect to the pre-Farakka barrage period value of 100–350 ppm (Bose, 1956). The hardness level could not be traced for the pre-Farakka barrage period; however, in the post-Farakka barrage period its trend was recorded, compared with the studies reported by Manna et al. (2013) and Nath and De (1996). The nutrient elements nitrogen, phosphorus, and silicon were detected as nitrate, phosphate, and silicate in the previous studies while as total N, total P, and silicate in the present situation. The general trends of the parameters were more or less similar except the reporting of phosphate as the limiting nutrient in the estuary by Mitra et al. (2018b). The present study recorded sufficient content of all the three nutrient elements in the studied stretch in addition to a significantly higher content of both total N and total P at the Godakhali area due to the inflow of organic matter enriched effluents from the Kolkata City agglomerated area into the estuary. The silicate, however, exhibited a steady decline downward with the increase in salinity in the estuary. The values of all the studied water quality parameters were, however, in the favorable range for the growth and survival of the aquatic community.

Calculation of water quality index

A water quality index for the zonation of the water body has been utilized worldwide for quite a long time. It has also been used in the Ganga river system by Bhargava (1983) and Chauhan and Singh (2010). It is a very important tool for the management-related issues of the elixir of life, i.e., water. The two most widely used WQI calculation techniques were utilized in the present study.

National Sanitation Foundation water quality index (NSF-WQI)

NSF-WQI has widely been used in many studies to evaluate the water quality status of riverine ecosystems (Dimri et al., 2021; Liou et al., 2004; Pham, 2017; Vasanthavigar et al., 2010). Several researchers have utilized it to evaluate the Ganga river system (Bhutiani et al., 2016; Tripathi & Singal, 2019). The analysis output of NSF-WQI is given in Fig. 5 and Table 7. Its comparison with the rating chart given by Yadav et al. (2010) revealed the highest index value of 2552 at Fraserganj and the second-highest value of 186 at Diamond Harbour. The very high index values were due to the tidal effect in the region with an influx of saline water having associated higher hardness. Although in the rest of the stations the values of WQI ranged between 61-70 and were in the poor category.

Canadian Council of Minister of the Environment water quality index (CCME-WQI)

The CCME-WQI has also been used by many researchers to categorize the water quality of the riverine systems (Ghosh et al., 2019; Mahagamage & Manage, 2014). The calculated CCME-WQI values

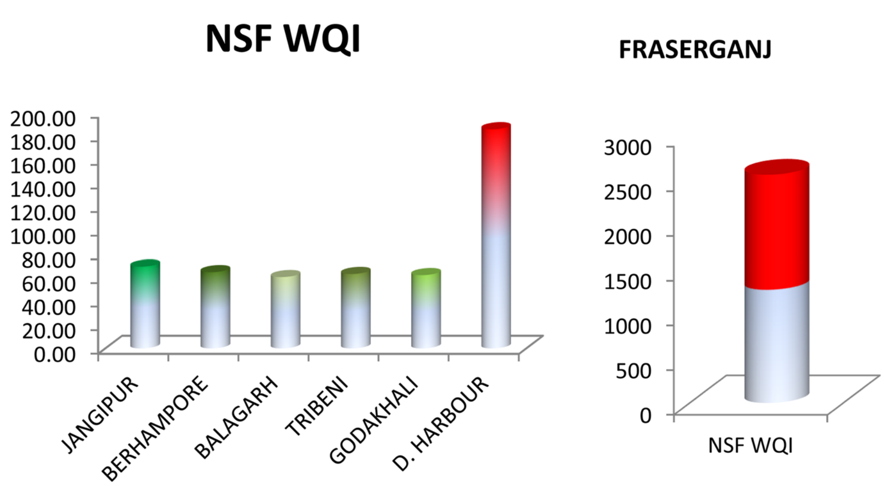


Fig. 5 Calculated NSF-WQI of different sampling stations

Table 7 Calculated NSF-WQI and CCME-WQI

Sampling stations	NSF-WQI	CCME-WQI
Jangipur	70	83
Berhampore	65	91
Balagarh	61	92
Tribeni	63	85
Godakhali	62	83
D. Harbour	186	35
Fraserganj	2552	18

are represented in Fig. 6 and Table 7. Similar to that of NSF-WQI, the CCME-WQI also showed a comparatively poor water quality as a drinking water source at stations Fraserganj and Diamond Harbour with index values of 18 and 35. The rest of the sampling stations had calculated index values between 83 and 92, indicating suitability as the drinking water source as per the categorization of the CCME-WQI.

Principal component analysis (PCA)

The use of multivariate statistical tools for assessment of water quality of the river systems has widely been employed by many researchers worldwide (Azhar et al., 2015; Matta et al., 2020; Yang et al., 2009), and among these is the principal component analysis which is one of the best-used statistical tools for the assessment of water quality status of the aquatic ecosystem. As there are multiple parameters to be studied, so it is difficult to study individual parameters; therefore, with the help of PCA the variables are reduced and dummy variables have been created using the PCA technique (Ali et al., 2021; Bhakar & Singh, 2019). Before performing PCA, the KMO and Barlet test of sphericity were performed to know the adequacy of the test. The results indicated that the KMO sampling adequacy was 0.515 while the significance level of the Barlet test of sphericity was 0.000 (Table 8). A total of 6 PCs were extracted (eigenvalue > 1) (Table 9 and Fig. 5) for which the 6 varimax rotated matrices are given in Table 10. Obtained total of 84.8% data variability was expressed by those 6 components (Fig. 7). The further varimax factor with varimax rotation and Kaiser normalization was used on principal components having eigenvalue > 1 and factor loadings were compared as per Liu et al. (2003), which describes that factor loading of more than 0.75 is considered strong loading, factor value between 0.75 and 0.50 was moderate, and factors between 0.50 and 0.30 are considered as weak loading. In the analysis, it was found that the 1st rotated component contributed 33.89% variability and the strong positive loadings were with conductivity (r = 0.97), total hardness (r = 0.95), chloride (r = 0.98), and total dissolved solids (r = 0.96) while moderate negative loading with silicate (r = − 0.72). This PC denotes the impact of weathering of rocks, mineralization, and dissolution of cations and anions, and the finding was similar to that of Mitra et al. (2018a). The second

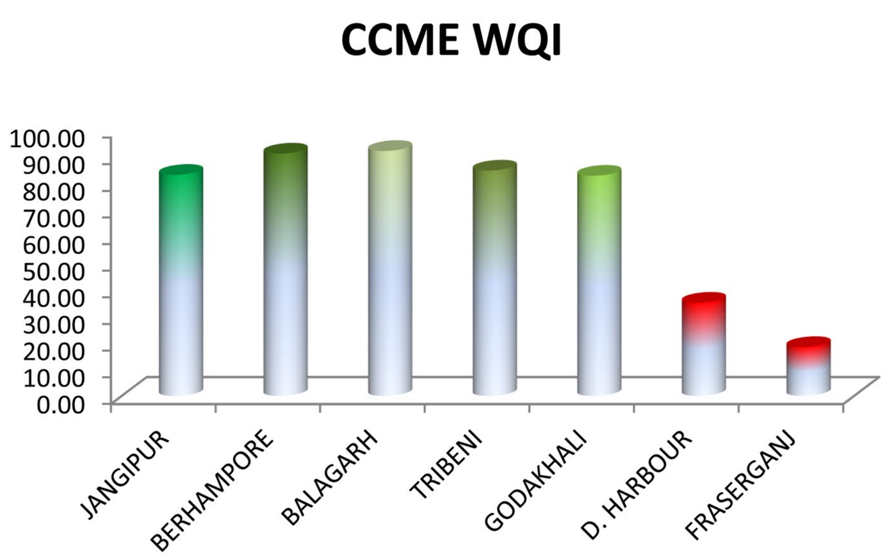


Fig. 6 CCME WQI observed at different sampling stations

Table 8 Calculated KMO and Barlett's test

Kaiser–Meyer–Olkin measure of sampling adequacy		.515
Bartlett's test of sphericity	Approximate chi-square	667.903
	df	153
	Significance	.000

Table 9 Eigenvalue and variance % of first 6 principal components

Component	Initial eigenvalues		
	Total	% of variance	Cumulative %
1	6.100	33.89	33.89
2	3.706	20.59	54.48
3	1.660	9.22	63.70
4	1.433	7.96	71.66
5	1.270	7.05	78.72
6	1.097	6.09	84.81

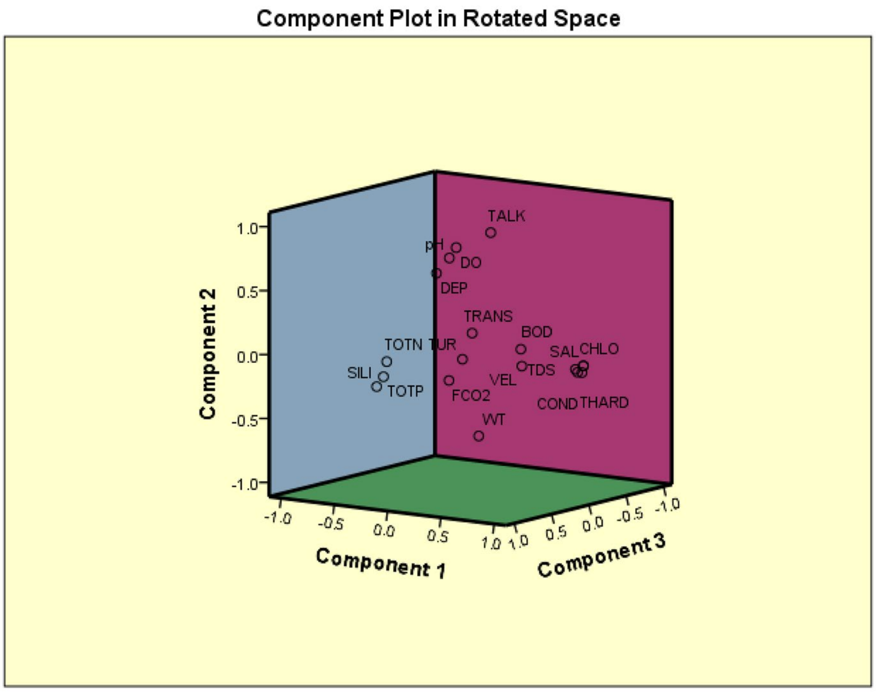
PC contributed 20.89% of the variance in which the strong positive loading was observed with total alkalinity ($r=0.90$), moderate positive loading with pH ($r=0.74$), DO ($r=0.71$), and depth ($r=0.56$), while negative loading with water temperature ($r=-0.66$). The PC might get influenced by weathering of rocks and severe anthropogenic activities. The third PC expressed 9.22% variation and was having a strong positive loading with total nitrogen ($r=0.91$) and total phosphorus ($r=0.83$). The PC signifies the nutrient loading in the river due to constrained riverine flow. The fourth PC contributed 7.96% of the variance and had strong positive loading with turbidity ($r=0.83$) and strong negative loading with transparency ($r=-0.78$). The PC adequately explains the inverse relationship between turbidity and transparency. PC5 contributed 7.05% of the variance and is having strong positive loading with free CO_2 ($r=0.82$), moderate positive loading with water temperature ($r=0.59$), and depth ($r=0.52$). The PC explains the importance of pollutant loading in the

Table 10 The squared sum of 6 varimax rotated principal components

	Component					
	1	2	3	4	5	6
WT	0.14	−0.66	0.09	0.15	0.59	0.14
DEP	−0.31	0.56	0.01	0.23	0.52	0.21
TRANS	−0.01	0.11	−0.04	−0.78	−0.19	0.09
VEL	0.32	−0.14	−0.23	0.16	0.11	0.78
TUR	−0.04	−0.08	0.05	0.83	−0.09	0.04
COND	0.97	−0.11	−0.11	−0.04	0	−0.07
pH	−0.02	0.74	0.26	−0.45	−0.1	0.11
DO	−0.35	0.71	−0.3	−0.39	−0.11	−0.12
BOD	0.3	−0.01	−0.25	0.28	0.11	−0.74
TALK	0.13	0.9	−0.09	0.04	−0.15	−0.12
FCO_2	−0.12	−0.25	0.11	0.01	0.82	−0.07
THARD	0.95	−0.1	−0.08	0	−0.06	0.17
CHLO	0.98	−0.05	−0.11	0	0	−0.03
SAL	0.98	−0.05	−0.11	0	0	−0.03
TOTN	−0.15	0.01	0.91	0.06	−0.05	0.09
TOTP	−0.24	−0.13	0.83	0.02	0.26	−0.13
SILI	−0.72	−0.34	0.23	0.04	0.24	0.02
TDS	0.96	−0.07	−0.04	0.09	−0.07	0.03

Extraction method: principal component analysis. Rotation method: varimax with Kaiser normalization

Fig. 7 Component plot for different environmental parameters in rotated space



system. The sixth component contributed 6.09% variance and was having strong positive loading with velocity ($r = 0.78$), while strong negative loading was observed with BOD ($r = -0.74$). The PC well explains the importance of riverine flow in reducing the influence of BOD in the system.

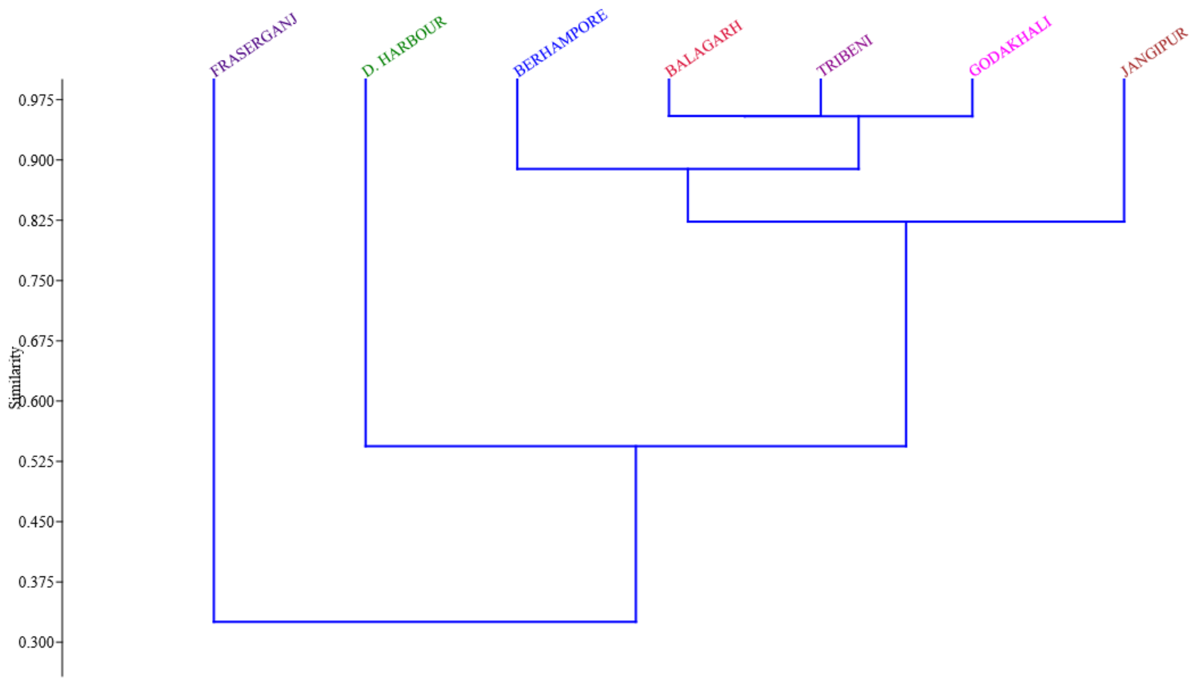


Fig. 8 Cluster analyses of different sampling stations

Cluster analysis

Cluster analysis is the best statistical analysis tool to classify the similar nature of objects into the same ordination (Shrestha & Kazama, 2007). The Bray–Curtis cluster analysis was performed to know the similarity among the different stations. The output is presented in Fig. 8 for the analysis of the cophenetic correlation that was calculated as 0.9843, indicating that the clustering result was good as shown by dendrogram (Fig. 8). The analysis showed the close relationship between Balagarh, Tribeni, and Godakhali; the sites are located in a series in the upper part of the estuary. The three stations were also having a close relationship with Berhampore and Jangipur, the riverine stretch. The Fraserganj and Diamond Harbour sites are having a close relationship due to saline water influx from the sea. Thus, as one proceeds from Jangipur towards the estuary, the variations in conductivity, salinity, TDS, total hardness, etc. separate one stretch from the other.

Conclusion

The present study gives the essential information and necessary insights into the water quality status of the ecologically important lower stretch of the river Ganga, which is encountered by multiple environmental stressors in the region. In the study, the comprehensive approach by using two of the water quality indices, i.e., NSF-WQI and CCME-WQI, well explained the status of the water quality in the region. From the analysis, it was observed that the water quality status of the two of the sampling stations, viz., Diamond Harbour and Fraserganj, were unsuitable as the drinking water sources. The rest of the sampling sites had moderate water quality. All the recorded water quality parameters were, however, recorded favorable for the survival of aquatic organisms. In the study along with WQI each of the used water quality variables have also been discussed in detail. The use of multivariate statistical tools also well explained the water quality status in the region by reducing the impact of multiple studied water quality variables. The cluster analysis differentiated the different sampling stations based on their water quality status and geographical distribution. Although with the initiatives of different government and non-governmental organizations, the studied river stretch is maintaining its earlier status as is found in the earlier studies, and is protected from further deterioration even though the pressure of the anthropogenic activities is enhancing due to population growth and associated issues. The efforts of the Ganga Action Plan and that of the National Mission for Clean Ganga are worth mentioning. The strong tidal action is also facilitating in maintaining the estuarine health.

Along with regular monitoring of the water quality status of the riverine ecosystem, the collaborative effort between the government and non-government agencies with the active involvement of local people can bring considerable changes in reducing pollution and related issues. Further, along with the studied parameters, there is also a need for regular monitoring of tidal impact which can directly or indirectly affect the health status of the human as well as the ecological niche of the aquatic organisms.

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Availability of data and material Experimental data will be provided by the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Ethics approval All the study work has been done following permission given by the Institute ethical committee, ICAR-CIFRI.

Consent to participate Not applicable.

Conflict of interest The authors declare no competing interests.

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