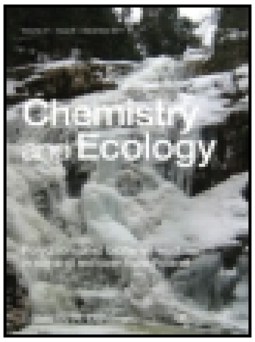

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RESEARCH ARTICLE

Sewage fluxes and seasonal dynamics of physicochemical characteristics of the Bhagirathi-Hooghly River from the lower stretch of River Ganges, India

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ABSTRACT

To understand the temporal variations of the physicochemical characteristics of the Bhagirathi-Hooghly River (BHR), three locations representing three districts of West Bengal were selected. The material fluxes from 34 drains during pre-monsoon season was quantified. The analysis of variance (ANOVA) revealed that no significant spatial variations were observed for the physicochemical parameters, whereas seasonal variations were significant. The mean discharge was found to be highest (247.2×10^3 m^3 d^{-1}) in the midstream drains. Highest mean concentrations of dissolved oxygen (DO) (7.35 mg L^{-1}) and nitrate (0.81 mg L^{-1}) were observed during the post-monsoon season followed by the monsoon and pre-monsoon. According to the BIS, WHO and the European standard of water quality (pH, 6.5–8.5; Nitrate, 0–2.5 mg L^{-1};DO, ≥5 mg L^{-1}), the results of the respective parameters revealed the BHR system is maintained at high to good water quality, meaning that the BHR system is slightly altered from its pristine environment. The mean concentrations of biological and chemical oxygen demands were found to be high during the monsoon season, revealing that a large quantity of refractory organic matter is transported to the eastern Bay of Bengal from the Ganges.

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Anthropogenic runoff; biological oxygen demand; chemical oxygen demand; factor analysis; drains; discharge

1. Introduction

Rivers and their associated estuaries are the prominent interfaces between the land and the continental shelf [1], and deliver about 90% of the continental weathering products along with anthropogenic inputs in the form of dissolved and particulate material loads into the world oceans [2]. Mostly, these environments are influenced by domestic and industrial inputs as the banks of rivers and estuaries have become highly populated throughout the decades [3]. The sustainability of the large riverine systems influenced by human activities depends on the water quality of the system. The water quality of riverine systems in developing cities is under threat due to the influence of anthropogenic

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activities. In particular, the rapid industrialisation, socio-economic growth and growing human population over the past four decades had led to severe domestic runoff [4–7]. Multiple stressors on water quality with different spatial and temporal scales have influenced the ecological balance of such riverine systems [8–10]. Intensive human settlements and their activities along the riverbanks typically deteriorate the river water quality [11–13] and influence the organic loads that ultimately affects the biogeochemical cycling in aquatic ecosystems [14,15]. Especially, severe river pollution may occur in large river basins due to the lack of proper sewage treatment facilities [16]. Evaluation of the anthropogenic loadings and their influence on river water quality at a watershed level is crucial to understand and maintain sustainable water quality in riverine systems.

The River Ganges is one of the largest riverine system in the world. Originating from the Gangotri Glacier system and traversing approximately 2525 km, the Ganges discharges into the Bay of Bengal. It is believed to be a sacred river of India and has been reported by several researchers to possesses antimicrobial and medicinal properties [17,18]. The river Ganges is under severe anthropogenic threat due to the cumulative pollution of point and non-point sources, which ultimately affect water quality. Many studies are focused on the interactions between the physicochemical characteristics and heterotrophic bacteria [19–22]. Furthermore, research has also focused on the distribution of heavy metal pollution influenced by the different industries, such as metal working and electroplating industries, and thermal power plants [23–28]. The biological and toxicological aspects of sediment and water of the Ganges has been discussed elsewhere [29–37]. Domestic and industrial runoff into the Ganges are responsible for ~75% of its pollution generated by the cities or towns along the Ganges [38]. The studies on the quantification of the drainage runoff and their associated material fluxes into the river Ganges are rare. In this regard, the current study aims to provide a baseline information on the drainage fluxes and temporal variability of the physicochemical characteristics of the lower stretch of River Ganges.

2. Sampling and analytical methodology

2.1. Study area

The River Ganges enters West-Bengal at the Farakka Barrage in Murshidabad district and flows approximately 260 km before emptying it's into the Bay of Bengal at Ganga Sagar. The Ganges, after entering West Bengal, is recognised as Bhagirathi-Hooghly River (BHR). The BHR system serves as the significant drinking water source for the entire West Bengal, as well as serving agriculture, aquaculture and industrial usages (KMDA, 2017). The river is under severe anthropogenic threat due to the number of human settlements along the banks of the BHR system and industrial runoff. Apart from the threats from domestic and industrial runoff, the BHR system also receives high agricultural runoff in the upper region. The sampling was done once per month at all the locations.

2.2. Sampling and analysis

Three sampling locations were selected from three districts (i.e. Hooghly (WB 21), North 24 Parganas (WB 23), and Howrah (WB 27)), for assessing the water quality of BHR system for a period of nine months i.e. from August 2017 to May 2018, except January. In addition, 34 drains were sampled along with the upstream of the respective three districts during pre-monsoon season of 2018 to estimate the material discharge fluxes into the BHR system (Figure 1). The study area map was prepared using the ArcGIS 10.3 software. A composite sampling was conducted during low tide (to avoid the BHR influence on the discharges during high tide) with an interval of 1 h over a period of 4 h, at the confluence point or above the confluence point (~ distance of 0.5 km from the confluence point) of the respective drain with the BHR system. Net sewage discharge (Q_d) of the drain was estimated by following the conventional area velocity method. The velocity of the drain flow was measured by the floating ball method with respect to time, also measuring the depth and width of the drain to calculate the cross-sectional area. The total quantity of BOD, COD, nitrate, phosphate and TSS transported from the drain to the river Ganges per day considered as the net discharge flux of the individual parameter. The flux of the individual parameter was calculated using following equation:

$$Z = Q_d \times C_Z$$

where Z is the flux of the individual parameter, Q_d is the net discharge of the drain and C_Z is the concentration of the individual parameter (i.e. concentration of BOD, COD, Nitrate, Phosphate and TSS). The net fluxes of BOD and COD were expressed in mega gram oxygen per day ($Mg\ O_2\ d^{-1}$), whereas nitrate, phosphate and TSS were expressed as mega gram per day ($Mg\ d^{-1}$). The study area and study locations were shown in Figure 1.

About 5 L of sub-surface water was collected by using a shallow water sampler to estimate the physicochemical parameters like temperature, pH, conductivity, total suspended solids (TSS) dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD) and nitrate. *Insitu* temperature was recorded using a Brannan thermometer. Samples were collected in high-density polyethylene (HDPE) containers for the estimation of general parameters (1Ltr) and BOD (2.5 L). All the samples were preserved at −4°C until analysis. Sub-samples were collected for the estimation of COD separately in 100 mL pre-cleaned Nalgene bottles and preserved with 0.2 mL conc. H_2SO_4 to bring the pH ≤ 2. DO was fixed *insitu* with Winkler's reagents. Conductivity was measured *insitu* using a handheld conductivity meter; pH was measured by using a pH meter (accuracy ± 0.007). Dissolved oxygen (DO) was measured using the Winkler's titration with its analytical precision expressed as a standard deviation (±0.07% for DO). Nitrate and phosphate concentrations were measured using the standard spectrophotometric procedure and the precision of their analyses was found to be ±0.002. The samples preserved with H_2SO_4 were used for the COD analysis following acid digestion in the presence of $K_2Cr_2O_7$; this process was followed by back titration with ferrous ammonium sulfate. All the sample analysis was completed within 2 days after sampling, except for BOD. All the analysis was performed according to American Public Health Association (APHA) [39] protocols. The samples collected from riverine waters for BOD were collected in 300 mL BOD bottles. Whereas, the samples collected from the sewer networks/drainages were diluted with aerated water, added a known volume of micronutrients, and collected in 300 mL BOD bottles. The time zero samples were immediately fixed with Winkler's reagents for the estimation of control. Another set of samples were maintained at 27°C temperature in the BOD incubator for 72 h before fixation. The change in DO concentrations between initial and after incubation was measured as BOD [40].

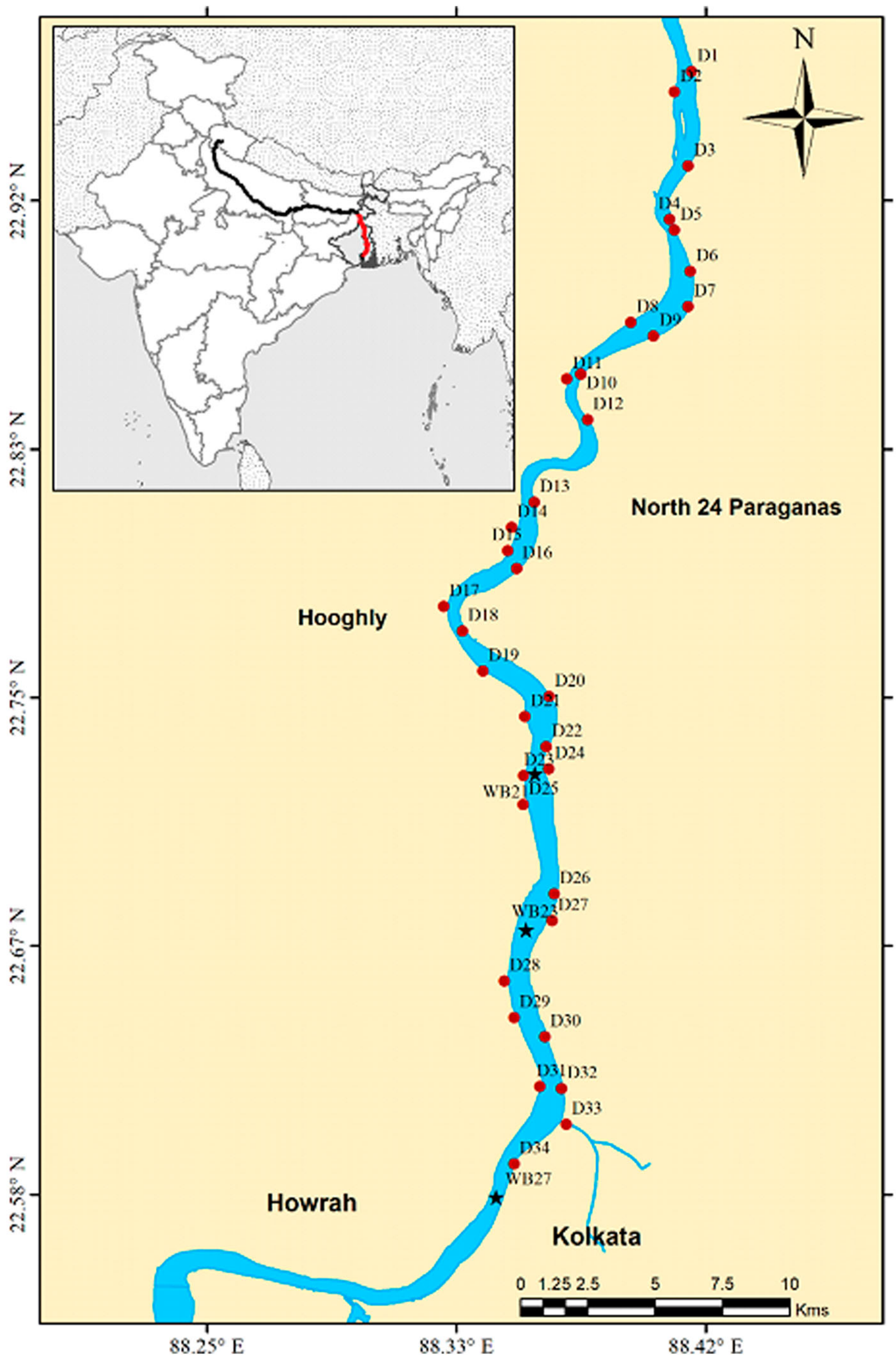

Figure 1. Map of the study area, with the black stars representing river sampling locations, and the red circles the drain sampling locations along the Bhagirathi-Hooghly River.

2.3. Statistical analysis

All the spatial distribution plots were prepared by using Golden Software Surfer 13.0. Analysis of Variance (ANOVA) was performed through *post hoc* Bonferroni's multiple comparison test on the water quality parameters to evaluate the spatio-temporal variations in the BHR system. In addition, Pearson correlation coefficients were derived to determine the inter-relationship between biological and non-biological parameters using PASW 18.0. Stepwise multiple regression analysis was performed on the entire dataset using the statistical package Minitab 16.1 to understand the relative importance of different parameters over the BOD concentrations, by considering BOD as dependent variable and DO, COD, Nitrate and TSS as independent variable.

Factor Analysis (FA) is an environmetric technique that reduces the dimensionality of large data sets without losing any information and will allow us to understand the influence of the anthropogenic activities or *insitu* processes on the physicochemical variables of any ecosystem [41]. Before executing the FA, the raw analytical data should be normalised to avoid improper classification due to the difference in order of magnitude and range of the analytical parameters [42]. In addition, rotated Varimax variables should be used for a better identification of hidden factors [43]. FA simplifies the data structure from principal component analysis (PCA) by diminishing the inputs of less significant variables and rotating the axis defined by PCA by creating new variables called varifactors (VF), which involves the linear combination of unobservable and hypothetical variables [44–47]. The factor analysis (FA) is expressed as

$$Z_{ij} = a_{f1}f_{1i} + a_{f2}f_{2i} + a_{f3}f_{3i} + a_{f4}f_{4i} + \ldots + a_{fm}f_{mi} + e_{fi}$$

where Z, a and f are the component score, loadings and the factor score, respectively, and i, j and m are the component number, sample number, and the total number of variables, respectively. Moreover, e is the residual term accounting for errors or other source of information. In the present study FA was performed by considering the rotation of principal components by the Varimax method with Kaiser normalisation on the physicochemical parametric data *viz*., temperature, pH, conductivity, DO, TSS, Nitrate COD and BOD. The entire statistical computation for FA was executed in the statistical software package, PASW 18.0.

3. Results and discussions

3.1. Discharge and material fluxes from drains to the River Ganges

Discharge and material fluxes during pre-monsoon of 2018 were estimated from 34 drains along the lower stretch of River Ganges. The entire drains were classified into three categories based on region i.e. upstream, midstream and downstream of the BHR system. Among them 22 drains are from the upstream of WB 21, 5 drains are from midstream (i.e. between WB 21 to WB 23) and 7 drains are from downstream (i.e. between WB 23 to WB 27) of BHR. The average discharge flux was found to be highest in the midstream drains (247.2×10^3 m^3 d^{-1}) followed by upstream (171.66×10^3 m^3 d^{-1}) and downstream (116.73×10^3 m^3 d^{-1}) drains of BHR system. The discharge from the midstream drains might be due to the highest number of human settlement along the BHR system of North 24 Paraganas (https://www.census2011.co.in/district.php) which stands as the second-largest populated district in India. The level of industrialisation in the North 24 Paraganas may also be a contributing factor. In contrast, the upstream is mostly influenced by agricultural and domestic runoff, whilst the downstream is mainly influenced by domestic runoff. The mean discharge, water quality and the respective material loads from the drains during the pre-monsoon period of 2018 are represented in Table 1.

The material concentrations among the drains varied considerably from upstream to downstream. Despite the high material concentration in the downstream drains, the average material fluxes were found to be highest in the midstream drains except in the case of phosphate. Average phosphate discharge, found to be high in the upstream drains, might be due to high agriculture practices in the Nadia and Hooghly districts. Nitrate was found to be exceptionally high (30.24 mg L^{-1}) at Baranagar drain near Kuthi ghat (from the downstream drains), with the lowest discharge (2.37×10^3 m^3 d^{-1}) when compared to all the drains. In turn, the lowest concentration was found at Majer Khal (from the upstream drains). Whereas, the phosphate concentrations were found to be high in the upstream drains when compared with the downstream and midstream drains (Table 1). The average BOD concentration was observed to be low at the upstream drains and an increasing trend was found from mid to downstream drains; the respective increase in percentage of BOD concentration was found to be 16.6% and 22.3% when compared with upstream drains. The lowest BOD concentration

Table 1. Variation of physicochemical parameter concentrations from drains, discharge and material fluxes along the upstream, midstream and downstream of BHR System.

	Upstream drains	Midstream drains	Downstream drains	Total
pH	6.66–8.22 (7.3 ± 0.4)	7.25–7.86 (7.51 ± 0.27)	6.63–8.21 (7.25 ± 0.49)	6.63–8.22 (7.3 ± 0.41)
TSS (mg L^{-1})	10–250 (71.91 ± 63.75)	32–169 (111 ± 57.68)	10–428 (173.3 ± 154.8)	10–428 (107.74 ± 103.86)
TDS (mg L^{-1})	221–661 (427.73 ± 105.85)	346–1051 (573.2 ± 276.11)	216–1279 (465.8 ± 308.89)	188–1279 (450.58 ± 205.13)
BOD (mg L^{-1})	2.43–140 (43.41 ± 41.39)	5–80 (50.6 ± 29.64)	8–162 (53.1 ± 49.52)	2.43–162 (47.61 ± 41.2)
COD (mg L^{-1})	8–299 (127.23 ± 90.48)	24–216 (137.8 ± 79.69)	33–456 (156 ± 136.37)	8–456 (137 ± 100.11)
PO_4-P (mg L^{-1})	0.09–5.19 (1.58 ± 1.15)	0.93–2.3 (1.36 ± 0.56)	0.28–3.15 (1.31 ± 1.13)	0.09–5.19 (1.45 ± 1.07)
NO_3-N (mg L^{-1})	0.01–0.3 (0.05 ± 0.07)	0.02–0.05 (0.04 ± 0.02)	0.01–30.24 (3.33 ± 9.48)	0.01–30.24 (0.91 ± 4.9)
Cl^- (mg L^{-1})	19–233 (57.64 ± 44.55)	52–398 (131 ± 149.81)	24–366 (71.9 ± 104.06)	19–398 (70.19 ± 82.68)
Flow (10^3 m^3 d^{-1})	0.46–1192 (171.66 ± 319.34)	49.27–581.53 (247.2 ± 221.27)	2.37–996.3 (116.73 ± 309.4)	0.46–1192 (163.29 ± 297.58)
BOD flux (Mg O_2 d^{-1})	0.01–85.83 (7.76 ± 18.99)	2.71–14.62 (7.77 ± 5.29)	0.05–18.93 (3.12 ± 5.81)	0.01–85.83 (6.38 ± 14.86)
COD flux (Mg O_2 d^{-1})	0.01–200.26 (21.87 ± 47.67)	6.16–39.92 (22.63 ± 14.11)	0.14–68.75 (10.47 ± 21.07)	0.01–200.26 (18.49 ± 38.1)
PO_4-P flux (Mg d^{-1})	0.01–3.04 (0.39 ± 0.85)	0.07–0.56 (0.32 ± 0.24)	0.01–0.48 (0.08 ± 0.15)	0.01–3.04 (0.29 ± 0.67)
NO_3-N flux (Mg d^{-1})	0.01–0.08 (0.01 ± 0.02)	0.01–0.03 (0.02 ± 0.02)	0.01–1.71 (0.19 ± 0.54)	0.01–1.71 (0.06 ± 0.28)
TSS flux (Mg d^{-1})	0.03–184.32 (22.34 ± 57.14)	8.18–31.01 (17.77 ± 8.36)	0.01–85.83 (10.22 ± 19.66)	0.01–184.32 (14.28 ± 32.44)

was observed at the ITC Triveni drain (from the upstream drains) (2.4 mg L^{-1}), whereas, the highest was found at the Kamarhati drain (162 mg L^{-1}) (from the downstream drains). A significant increase in the BOD discharge was observed over a period of 15 years. The overall BOD discharge from the drains during the present study period was 2.49 times higher than the discharge estimated in 2003 (97.32 Mg O_2 d^{-1}) (https://www.wbpcb.gov.in/writereaddata/files/Waste_water_Hooghly%20River.pdf).

The concentration of COD varied from 8.32 to 456.21 mg L^{-1} with an average of 137 ± 100.11 mg L^{-1}. The highest average concentration of COD was observed in the downstream (156 mg L^{-1}) whereas the lowest was found in upstream (127.23 mg L^{-1}) drains. Irrespective of the concentration, the average discharge of COD was found to be high from the midstream drains (22.63 Mg O_2 d^{-1}) followed by upstream (21.87 Mg O_2 d^{-1}) and downstream (10.47 Mg O_2 d^{-1}). The COD to BOD ratio for the drains varied from 2.0 to 14.8 with an average of 3.75, indicating that the organic loads receiving by the BHR system are partially non-biodegradable. This might be due to the anthropogenic activities, associated with inadequate wastewater treatment facilities [48].

3.2. Spatio-temporal distribution of the biogeochemical variable in BHR system

3.2.1. Distribution of conductivity, pH, temperature and TSS:

The human settlement along the BHR system may affect the material inputs and sediment loads, and ultimately cause changes in the water quality; especially in the case of the midstream which has severe anthropogenic runoff. The mean water quality for the BHR system for the monsoon and post-monsoon of 2017 and pre-monsoon of 2018 are shown in Table 2. The results of one-way ANOVA revealed no significant spatial variation ($p > 0.05$) in the hydro-chemical parameters (conductivity, temperature, pH, TSS, DO, BOD, COD and nitrate) during the entire sampling period. Whereas, a significant temporal variation ($p < 0.05$) was showed in hydro-chemical parameters except BOD and COD. The surface water temperature varied from 20.9°C to 32.5°C with an average of 27.78 ± 3.2°C. Relatively warmer waters were observed during pre-monsoon season (Figure 2, Table 2) when compared with the other two seasons [49]. The higher

Table 2. Seasonal statistics of physicochemical parameters along the surface waters of the BHR system.

Parameter	Pre-monsoon 2018	Monsoon-2017	Post-monsoon-2017	Total
BOD (mg L^{-1})	1.95–7 (2.84 ± 1.36)	2.23–6 (3.14 ± 1.25)	1.5–4 (2.38 ± 0.82)	1.5–7 (2.79 ± 1.18)
DO (mg L^{-1})	4.3–7.1 (5.69 ± 1.05)	2.9–7.3 (6.07 ± 1.28)	6.2–9 (7.35 ± 0.8)	2.9–9 (6.37 ± 1.26)
EC (µs cm^{-1})	165–388 (344.92 ± 58.73)	170.7–308 (245.76 ± 47.4)	346–392 (370.59 ± 13.35)	165–392 (320.42 ± 69.47)
pH	7.3–8.06 (7.7 ± 0.23)	7.3–7.85 (7.56 ± 0.2)	7.58–8.13 (7.91 ± 0.16)	7.3–8.13 (7.72 ± 0.24)
Temp. (°C)	28–31.26 (29.64 ± 1.05)	27.8–32.5 (29.79 ± 1.69)	20.9–26.4 (23.91 ± 2.01)	20.9–32.5 (27.78 ± 3.2)
COD (mg L^{-1})	9–26 (12 ± 4.75)	10–21 (14.67 ± 3.32)	7–19 (11.42 ± 3.73)	7–26 (12.7 ± 4.12)
TSS (mg L^{-1})	14–130 (58.09 ± 30.81)	26–110 (81.34 ± 22.45)	12–70 (42.03 ± 16.54)	12–130 (60.49 ± 28.47)
Nitrate (mg L^{-1})	0.04–0.37 (0.2 ± 0.1)	0.22–1.37 (0.51 ± 0.33)	0.05–2.57 (0.8 ± 0.86)	0.04–2.57 (0.5 ± 0.58)

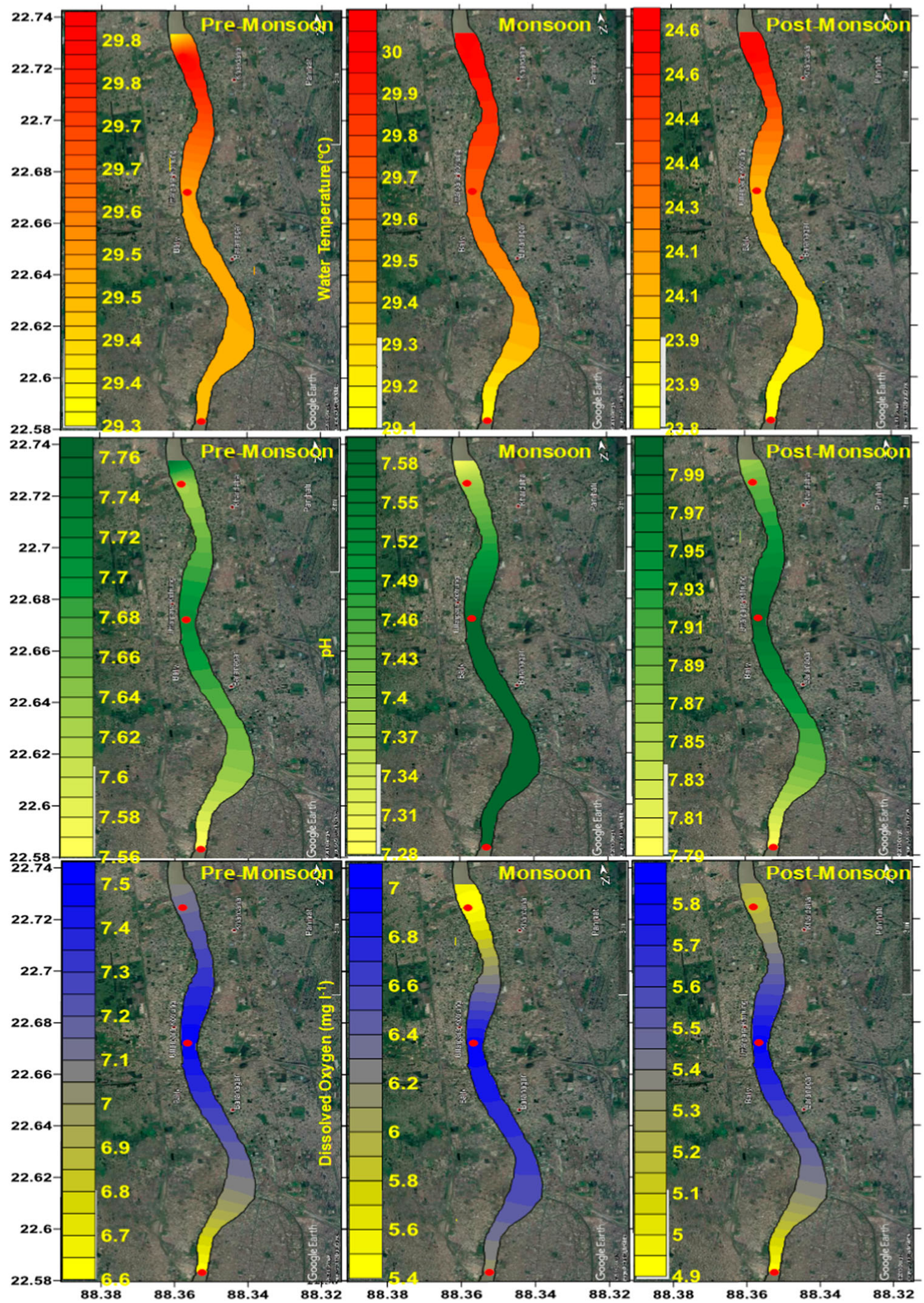

Figure 2. Spatio-temporal distribution of Temperature, pH and Dissolved Oxygen (DO) along the Bhagirathi-Hooghly Riverine (BHR) system.

temperatures during pre-monsoon might be due several factors including intensity of solar radiation, atmospheric temperature, humidity, evaporation rate and exchange of water due to a tidal effect [50,51]. The seasonal variations of pH and TSS in the study

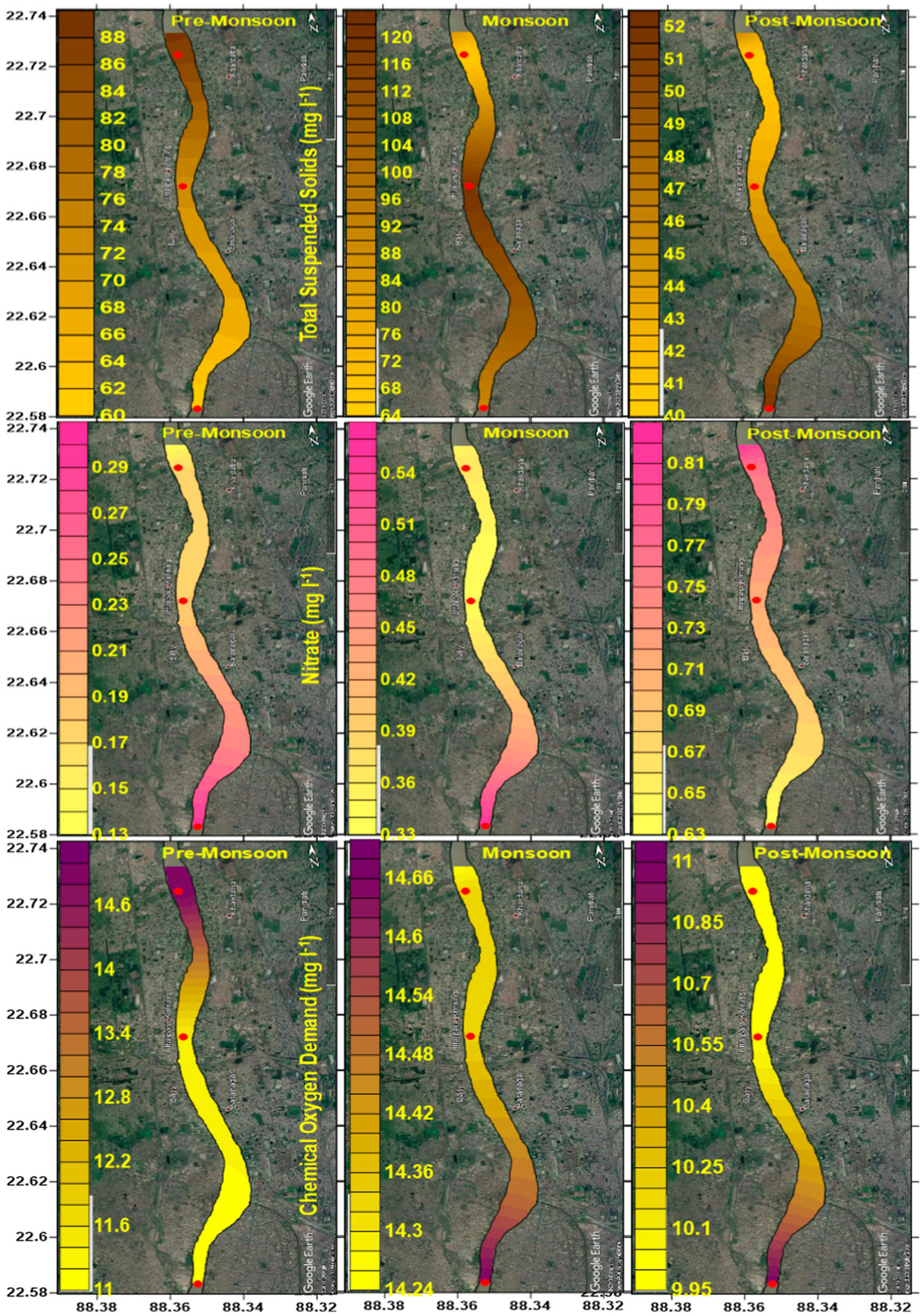

Figure 3. Spatio-temporal distribution of Total Suspended Solids (TSS), Nitrate and Chemical Oxygen Demand (COD) along the Bhagirathi-Hooghly Riverine (BHR) system.

region was shown in Figures 2 and 3 respectively. The electrical conductivity of water varied from 165 to 392 µs cm^{-1} with an average of 320 ± 69.47 µs cm^{-1} during the entire study period.

3.2.2. Distribution of dissolved oxygen and nitrate

The DO concentration in the surface waters of rivers and lakes is a global concern [52]. Influenced by several factors like temperature, organic matter degradation, primary production, respiration and [53–55], DO plays a crucial role in maintaining life in aquatic ecosystems [56–60]. The average concentrations of DO in the BHR system was found to be highest (7.35 ± 0.8 mg L^{-1}) during the post-monsoon when compared with the other two seasons (Figure 2, Table 2). The lowest and highest DO records were observed during monsoon at the stations WB 27 (2.9 mg L^{-1}) and WB 23 (9.0 mg L^{-1}) respectively. The prevalence of high DO values during the post-monsoon might be due to the favourable temperature and greater intensity of solar radiation which facilitates the maximum phytoplankton growth in the BHR system [61,62]. The current observations are in agreement with the results of the Hooghly estuarine system [49] and indicates that the waters are above the hypoxia threshold values [63–65]. According to ISI-IS: 2296–1982, the observed pH and DO values (Table 2) varied between classes A to C. In addition, the pH values are within the prescribed limits of WHO and BIS standards (6.5–8.5) [40,66], suggesting that the BHR waters have a possible use for drinking purposes after conventional treatment and disinfection.

The nitrate concentrations varied from 0.04 to 2.57 mg L^{-1} with an average of 0.5 ± 0.5 mg L^{-1} during the entire study period (Figure 3). The values obtained in the present study are similar to the values reported from the tide-influenced Saigon River, Vietnam [67]. The mean concentration of nitrate was found to be highest during post-monsoon followed by monsoon and pre-monsoon (Table 2). The elevated concentrations of nitrate might be due to domestic and agricultural (the excess usage of NPK fertilisers) runoff along the BHR system [68]. The observed mean values of the present study are ∼10 fold higher than the values reported elsewhere during 2014 to 2015 from the estuarine region of BHR system [49]. The results of nitrate from the present study are significantly lower the values reported from the midstream (Kanpur) of the Ganges and also the annual mean value is approximately 24 and 16 fold lower than the values reported from Gomati, and Sai rivers (tributaries of river Ganges), respectively [69]. The nitrate concentrations observed from the BHR system are well below 2.5 mg L^{-1}. Comparing these values to the European standard of water quality (Water Framework Directive (WFD), 2000) reveals that the health of the BHR system is equivalent to good (0.5–2.5 mg N L^{1}) and high status (<0.5 mg N L^{-1}) (WFD, 2000).

3.2.3. Distribution of BOD and COD:

BOD and COD are the key indicators of surface water pollution [70]. BOD is the quantity of oxygen required for the metabolic activities of aerobic microorganisms during the degradation of organic matter [71]. The BOD concentrations varied from 1.5 to 7.0 mg L^{-1} with a mean of 2.79 ± 1.18 mg L^{-1}. The highest mean concentration of BOD were observed during monsoon 2017 followed by pre-monsoon 2018 and post-monsoon 2017 (Figure 4, Table 2). This might be due the huge amount of allochthonous organic matter from the upstream to BHR system during monsoon. The mean concentration from the present study region are within the range (2.2 to 5.95 mg L^{-1}) reported for the Babughat region during 2002 to 2003 [72]. Irrespective of the season, the concentration of BOD was found to be high at WB 21. This might be due to domestic and the jute industrial waste discharges into the BHR system without treatment [72] from the Serampore region of Hooghly district.

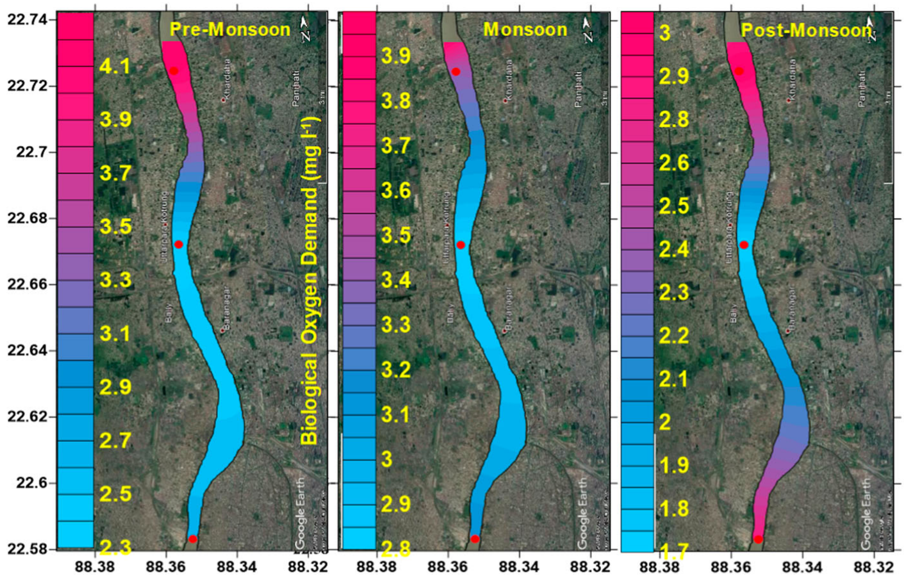

Figure 4. Spatio-temporal distribution of Biological Oxygen Demand (BOD) along the Bhagirathi-Hooghly Riverine (BHR) system.

The mean concentrations of COD during the entire study period is 12.7 ± 4.12 mg L^{-1}. Lower concentrations were found during the post-monsoon (7–19 mg L^{-1}) with a mean of 11.42 ± 3.73 mg L^{1}, whereas, the highest mean was found during the monsoon (14.67 ± 3.32 mg L^{-1}) followed by pre-monsoon (12.0 ± 4.75 mg L^{-1}) (Figure 3, Table 2). The highest COD concentration was reported at WB 21 (26 mg L^{1}) during the pre-monsoon. In addition, high concentrations of BOD and COD were observed at the downstream location when compared to upstream and midstream during monsoon and post-monsoon seasons. This pattern might be due to the localised influence of the downstream drains (i.e. highly concentrated sewage with respect to BOD and COD (Table 1)). The mean values of the COD to BOD ratio (>4.5) during the different seasons indicates that the organic matter received by the BHR system is mostly refractory/non-biodegradable. The results of the mean COD concentration are within the range reported by Sarkar et al. [72] at Babughat of the BHR system during 2002 to 2003. Thus, the results indicate that the BHR system is self-sustaining with respect to BOD and COD in the present day when compared with the results from Sarkar et al. [72]. In addition, huge loads of refractory organic matter are transported to the continental slope from the BHR system. The results of the present study revealed that the BHR system was slightly altered from the undisturbed condition with respect to physicochemical variables even though a large quantity of material fluxes is received from the drains. This might be due to the perennial runoff from the upstream, tidal incursion of seawater, dilution and assimilation capacity of the BHR system.

3.2.4. Relation between BOD and the associated physicochemical variable through statistical analysis

Correlation, multiple regression and factor analyses were performed on the entire physicochemical dataset to determine the data structure and to identify the factors controlling the

Table 3. Correlations between the physicochemical variables of the BHR system.

	All seasons							
Parameter	BOD	DO	EC	pH	Temp.	COD	TSS	Nitrate
BOD	1							
DO	−.613**	1						
EC	−.611**	.448**	1					
pH	−.602**	.671**	.709**	1				
Temp.	.302	−.596**	−.574**	−.652**	1			
COD	.622**	−.219	−.538**	−.363*	.258	1		
TSS	.622**	−.487**	−.687**	−.651**	.434**	.405*	1	
Nitrate	−.071	.356*	.091	.332*	−.577**	−.241	−.014	1

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

BOD in the BHR system. The correlation analysis revealed that DO, conductivity and pH showed a negative correlation with BOD ($P < 0.01$), whereas, COD and TSS showed a positive correlation (Table 3). The stepwise multiple regression analysis between BOD and physicochemical variables (DO, COD, Nitrate and TSS) revealed that the independent factors all together explained the BOD variability of 67.25%. The entire variables showed a positive feedback except DO towards BOD variability and the regression equation obtained is:

$$\text{BOD} = 3.259 - 0.464\,\text{DO} + 0.1411\,\text{COD} + 0.466\,\text{Nitrate} + 0.00755\,\text{TSS}$$

FA is a significant environmetric technique that was used to evaluate the interrelations between the physicochemical variables in the BHR system. FA was executed by considering the rotated Varimax variables with Kaiser normalisation on all the physicochemical parameters like temperature, pH, conductivity, DO, TSS, Nitrate COD and BOD (Table 4). Based on the Eigen values >1.0. two factors were extracted with the cumulative loadings showing a total variability of 68.6%. Factor 1 showed strong positive loadings for TSS, BOD and COD and negative loadings for pH, DO and conductivity; factor 1 accounts for 41.29% of the total variability. Further, negatively loaded variables show a negative correlation with BOD, COD and TSS indicating that the concentrations of dissolved organic and

Table 4. Rotated varimax factor analysis of the physicochemical variables along the BHR system.

	Rotated component matrix[a]	
	Component loadings	
	Factor 1	Factor 2
BOD (mg L^{-1})	0.850	−0.107
DO (mg L^{-1})	−0.517	0.601
EC (µs cm^{-1})	−0.848	0.225
pH	−0.698	0.534
Temp. (°C)	0.363	−0.819
COD (mg L^{-1})	0.656	−0.090
TSS (mg L^{-1})	0.732	−0.118
Nitrate(mg L^{-1})	0.100	0.885
Eigen value	4.177	1.312
% of variance	41.294	41.294
% of cummulative variance	27.314	68.608

Notes: Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalisation.
[a]Rotation converged in three iterations.

particulate matter (BOD, COD and TSS) increased with the depletion of oxygen and vice--versa. This may be due to the increase in dissolved organic and particulate matter loads in the BHR system, which undergo re-mineralization by heterotrophic bacteria especially during monsoon.

The second factor shows a total variability of 27.31% with a strong positive loading for nitrate and DO and negative a loading for temperature. In addition, the temperature showed a significant inverse relation with DO and nitrate – indicating that temperature and nitrate plays a major role in controlling the DO concentration in the BHR system. This might be due to favourable temperatures, sufficient light attenuation during the post-monsoon with a significant amount of nitrate concentrations needed in the BHR system to be productive. From the results of the statistical analysis, we deduced that the autochthonous processes mainly control the organic matter dynamics in the BHR system.

4. Conclusion

As outlined above, the discharge and material fluxes (except phosphate) obtained from the drains in the BHR midstream were higher than those observed in the downstream and upstream regions of BHR system, indicating that high anthropogenic runoff is concentrated in the midstream region of high urbanisation (i.e. North 24 Paraganas). The water quality of the BHR system varied significantly between seasons, but are within the limits of WHO, 2004; BIS, 1991 and WFD, 2000, indicating that the health status of the lower stretch of the river Ganges is high to good (i.e. the system is slightly changed from the undisturbed condition with respect to physicochemical variables and slightly above the requirement for the sustainability of the biological elements). The high concentration of BOD and COD were observed during monsoon when compared with the two other seasons. The ratio of COD to BOD (>4.5) revealed that the organic matter flowing into the BHR system is mostly refractory/non-biodegradable and ultimately transported to the marine continental slope from the BHR system. The statistical analysis of the data showed that autochthonous processes (viz., heterotrophic bacterial activities like respiration and production) control the organic matter dynamics in the BHR system. Based on the observations it is observed that the system is dynamic with respect to the physicochemical characteristics, so it needs a massive exercise of data collection at least on a monthly scale across a longer period of time. This would provide a thorough understanding of the biogeochemical dynamics of the BHR system, allow for establishing the sound scientific mathematical models and will be helpful for policy development in maintaining the sustainability of the BHR system.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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