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RESEARCH ARTICLE

Variability of water quality and metal pollution index in the Ganges River, Bangladesh

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Abstract

The Ganges River is one of the biggest transboundary streams in the Indian sub-continent. The significant part of this waterway channel drains one of the most densely populated areas on the planet so it is unequivocally influenced by human activities. Unprecedented high-temporal-resolution samples were collected for investigating the seasonal variability of water quality. Water quality index (WQI) reveals large seasonal variation among three major seasons and also indicates that the river water is not suitable for drinking and other household uses. The dominant water facies is bicarbonate (HCO_3^-). The water quality indices, %Na, Kelley's ratio (KR), sodium adsorption ratio (SAR), and magnesium adsorption ratio (MAR), reveal that the water is appropriate for irrigation. The permeability index (PI) indicated that the water is moderate to poorly useable for agricultural purposes. Heavy metals concentrations demonstrated significant seasonal variations with high concentrations during the monsoon due to flushing of pollutants from catchment areas by intense monsoonal precipitations. In addition, local activities such as oil spills from the boat, vehicle washing water, and agricultural runoff may also added pollutants. The single-factor pollution index (*Ii*) and Nemerow pollution index (Ni) exhibits minor pollution. The values of heavy metal pollution index (HPI) are far below than the critical limit (100) for the studied month, although relatively higher HPI values found for April, August, and November than other months might come from domestic wastes and agricultural activities. The heavy metal evaluation index (HEI) values of all the months indicated a low degree of pollution. Even though the river water pollution level is low, the authority should take proper management and monitoring strategy for sustainable use.

Keywords River Ganga · Water quality index (WQI) · Heavy metal · Temporal variation · Public health · Drinking and irrigation

Introduction

Water is the synonym of life and access to freshwater is essential for the public health and welfare of society. Most of the civilizations of the world are inextricably linked with rivers where all civilizations originated and developed. The river catchment generally underpins a wide assortment of biodiversity and furthermore makes a varied ecosystem composed of ecologically delicate and interrelated, chemical, physical, and biological entities (VishnuRadhan et al. 2017). The river is one of the major water resources for industry, agriculture, households, and also the source of food, transportation, and habitat for many organisms. Humans and other living inhabitants are abundant in the side of the river pathway. However, recently, river water in Bangladesh is worsened by anthropogenic activities and going to be unsuitable for uses (Hasan et al. 2019).

It is necessary to monitor the river water quality where the individuals utilized this water for their household purposes

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especially drinking, bathing, and cooking (Ahmad et al. 2010). Previous studies showed that the Ganges River water is polluted to some extent where organic and inorganic pollutant comes from agriculture runoff, industrial effluent, municipal sewage, and religious activity (Namrata 2010; Rai et al. 2010; Singh 2002). Among the inorganic pollutants, heavy metals are of genuine concern due to its diligent nature and regularly gather through the trophic level causing unsafe organic impact (Aktar et al. 2010). Either natural or anthropogenic sources are a common pathway for metal pollution in the river (Akoto et al. 2008; Giri and Singh 2014). Usually, when the environments are pristine condition and/or not affected by any anthropogenic activities, the metal concentration is low and weathering and mineralogy is the main source of the heavy metals (Karbassi et al. 2008). Anthropogenic activities including mining, discard poorly treated or untreated effluent comprising harmful metals from various industries, e.g., battery industries, tannery, steel plants, thermal power plants, the utilization of heavy metal-containing compost, and pesticides in farming fields (Ammann 2002; Nouri et al. 2008) might be major sources of heavy metals in the Ganges river.

Surface water quality evaluation is an extremely perplexing procedure because of its need for multiple parameters that can be equipped for causing different weights on in general water quality. The water quality index (WQI) is an exceptionally compelling strategy for surveying water quality for both surface and groundwater and found as a useful tool for policymakers who are concern about water resources management. Several researchers have proposed mathematical tools for water quality assessment (Brown et al. 1970; Horton 1965; Joung et al. 1979; Tiwari and Mishra 1985). This study used “weighted arithmetic index” method, a well-accepted and universally applied mathematical tools for evaluating the water quality index (Brown et al. 1972; Sharma and Kansal 2011; Bhutiani et al. 2016; Bora and Goswami 2017). The WQI provides simplified results with translations of a list of parameters into a single value that translates their existing concentrations in a sample into a single value. These values are used for understanding the nature of water and appropriateness for different uses like irrigation, drinking, fishing, and so on (Abbasi and Abbasi 2012). However, recently, pollution evaluation indices got attention for the assessment of heavy metal pollution in surface water and groundwater (Bodrud-Doza et al. 2019a). The single-factor pollution index, heavy metal pollution index, Nemerow pollution index, and the degree of contamination are involved for pollution evaluation indices explanation. Moreover, pollution evaluation indices are necessary for understanding the pollution level because WQI alone is not sufficient to assess the water quality appraisal.

Currently, a great deal of work has been completed all through the Ganga River pathway concerning physicochemical parameter investigation, water quality assessment, heavy metal pollution using principal component analysis, correlation analysis, and other related techniques to uncover the connection of mass portion and to recognize the wellspring of substantial metals in the river water (Bhutiani et al. 2016; Chaturvedi and Kumar Pandey 2006; Gupta et al. 2009; Meher et al. 2015; Mishra 2010; Sarkar et al. 2007; Sharma et al. 2014; Aktar et al. 2010). Considering the background, an investigation has been carried out to assess the seasonal variations of water quality and heavy metals along the lower Ganges River in Bangladesh for judging it suitability for different uses.

Materials and methods

Study site

Monthly field surveys were conducted along the lower Ganges River at Hardinge Bridge point (24° 03′ 57.04″ N, 89° 01′ 42.85″ E) between Bheremara, Kushtia, and Paksey, Pabna district of Bangladesh (Fig. 1). The sampling point is roughly 160 km down from the Farakka Barrage, West Bengal, India, and the river courses about 110 km along the Indo-Bangladesh outskirt involving the region of two nations (Haque 2008). The river water discharge, level, and velocity rate fluctuated from season to season during the study period, particularly in the monsoon season (Fig. 2). The average water discharge, level, and velocity for pre-monsoon were 970.56 m^3s^{-1}, 4.73 m, and 0.58 ms^{-1}; for monsoon were 14,186 m^3s^{-1}, 9.76 m, and 1.64 ms^{-1}; and post-monsoon were 1998 m^3s^{-1}, 5.63 m, and 0.69 ms^{-1}, respectively (Bangladesh Water Development Board). The monitoring location is downstream of the Ganges, as a transboundary River, but considered as upstream for Bangladesh. The Ganges River originates from southern slopes of the Great Himalayas. The mainstream and various tributaries of the Ganges drain a variety of geologic source rocks which are observed in its catchment areas (Kuehl et al. 2005). The river pathway consists of Precambrian metamorphics (high-grade schists, gneisses, quartzites, and metamorphosed limestones), felsic intrusives, and Paleozoic to Mesozoic sandstones, shales, and limestones (Huizing 1971; Heroy et al. 2003; Kuehl et al. 2005). The river flows south and east through the Gangetic Plain of North India into Bangladesh, and finally, it empties into the Bay of Bengal. Bangladesh has a humid monsoon climate with huge variations in precipitation and temperature all through the country. According to the FAO report (2014), Bangladesh has three primary seasons including the pre-monsoon during February–May, the most noteworthy temperatures and encounters the greatest force of cyclonic tempests, particularly in May; the monsoon during June–September, the heft of precipitation happens; and the post-monsoon during October–January, similar to the pre-monsoon season, is set by tropical cyclones on the coast.

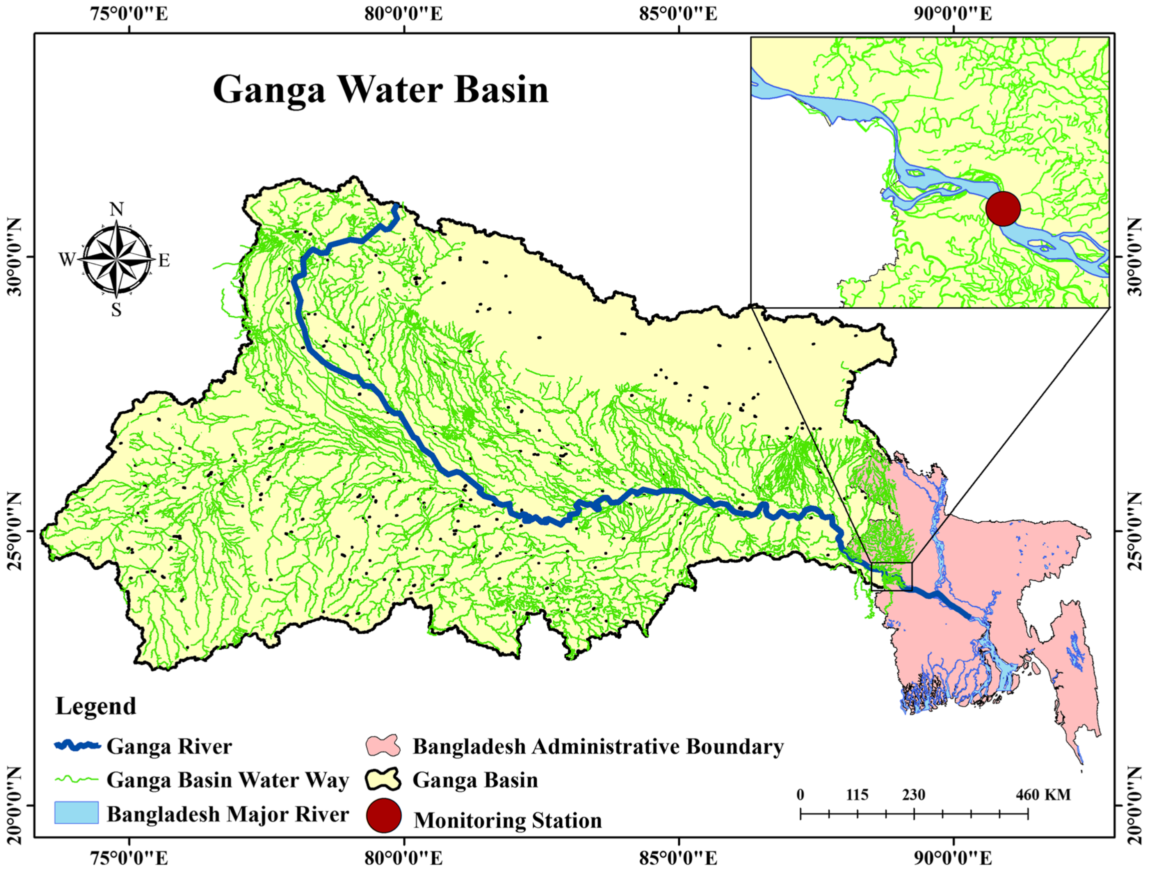


Fig. 1 Map showing monthly sampling location in the River Ganga with Ganges Basin, Ganges Basin water way, Bangladeshi Major River, and Bangladesh Administrative Boundary

Sampling

Monthly field surveys were conducted at the Hardinge bridge site in the Lower Ganges River, Bangladesh, from 2018 May to 2019 April. In monthly sampling, water samples were collected from a depth of 10–20 cm below the water surface in the study site. High-density polyethylene acid pre-washed (keep bottles in 10% HCl for ~ 24 h) bottles used for collecting a water sample and which was rinsed with a copious amount of distilled water before sampling. The samples were filtered using pre-combusted (470 °C for 4 h) 0.45-μm Whatman GF/F glass fiber filter. Usually, we collected two sets of the

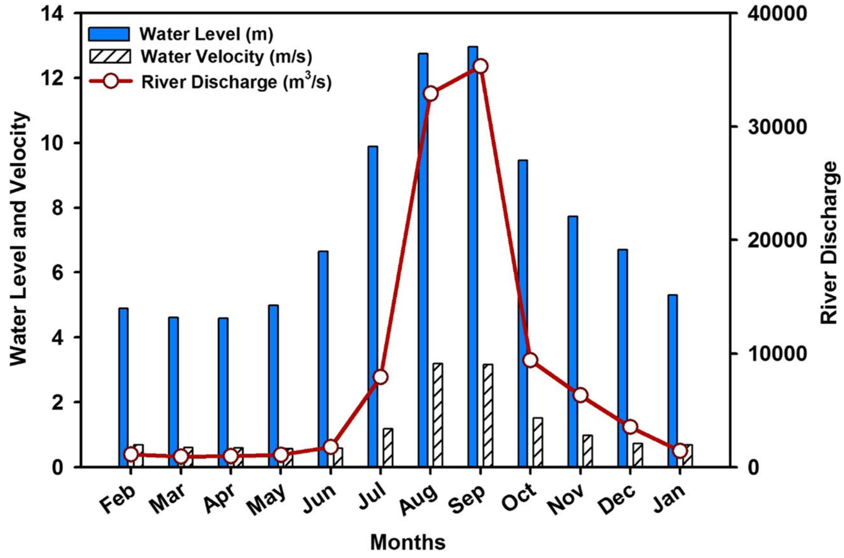


Fig. 2 Annual water level, velocity, and discharge of the lower Ganges River during study period

sample where one for cation and anion analyses and another for metals analyses. After filling the bottle, one set of samples was shipped to Atomic Energy Center, Dhaka, for determination of cations and anions. For measurement of metal concentrations, another set of samples were acidified with concentrated nitric acid and preserved in fridge condition (4 °C) until delivery to Gwangju Institute of Science and Technology (GIST), the Republic of Korea for analyses.

Analysis

A water quality monitoring multimeter (6920 V2-1 Multiparameter Water Quality Sonde, Xylem Analytics, USA) was used for *in situ* measurements of physicochemical parameters including dissolved oxygen (DO), pH, total dissolved solids (TDS), water temperature, electrical conductivity (EC), and salinity. Total hardness was calculated by (2.497Ca $^{2+}$ + 4.115 Mg^{2+}), according to Todd (1980). Ions dissolved in water including anions (F$^-$, Cl$^-$, SO$_4$$^{2-}$, NO$_3$$^-$, and PO$_4$$^{3-}$) and cations (Na+, K+, Mg^{2+}, and Ca^{2+}) were analyzed by ion chromatography (Dionex DX-3000, USA). Alkalinity (HCO$_3$$^-$) was determined by titrimetric method at Hydrobiogeochemistry and pollution control Laboratory, Department of Environmental Sciences, Jahangirnagar University. Elemental analysis (e.g., Al, As, Ba, Cr, Cu, Cd, Fe, Mn, Ni, Pb, Se, and Zn) was done by inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7500ce). For the ICP-MS method, multi-element stock calibration standard solutions containing 10 μg/mL of each component and ICP-MS tuning solution were acquired from Agilent (Agilent, Santa Clara, CA, USA). We prepared 0–100 μg/L ranges analytical calibration standards for all elements by suitable serial dilutions of multi-element stock solution in 2% (v/v) HNO$_3$$^-$. The SRM 1640 was acquired from the National Institute of Standards and Technology, MD, USA. The samples were reanalyzed with a new calibration curve when the recovery rate was exceeded the recommended range (90–110%). The recovery rates of Al (99%), As (97.9%), Ba (107.9%), Cr (97.1%), Cu (98.1%), Cd (98.6%), Fe (95.5%), Mn (92.5%), Ni (97.5%), Pb (93.2%), Se (100.3%), and Zn (119.9%) were in good covenants with the certified values.

WQI determination

Water quality index calculation was carried out by one of the popular method named "weighted arithmetic index method" (Brown et al. 1970) (Eq. (1)).

$$\mathrm{WQI} = \frac{\sum Q_n W_n}{\sum W_n} \tag{1}$$

Where, Q_n = the water quality rating of nth parameter,
W_n = the unit weight of nth parameter.

The quality rating Q_n and the unit weight (W_n) is calculated by standard procedure (Brown et al. 1970). The water quality status according to WQI is shown in Table S1.

Suitability for agricultural purposes

The appropriateness of surface water for agricultural purposes was evaluated by calculating the soluble sodium percentage (%Na), Kelly's ratio (KR), sodium adsorption ratio (SAR), magnesium adsorption ratio (MAR), and permeability index (PI). The %Na, KR, SAR, MAR, and PI were calculated using Eqs. (5) to (9) (Ehya and Moghadam 2017).

$$\%\mathrm{Na} = \frac{\mathrm{Na} + \mathrm{K}}{\mathrm{Ca} + \mathrm{Mg} + \mathrm{K} + \mathrm{Na}} \times 100 \tag{2}$$

$$\mathrm{KR} = \frac{\mathrm{Na}}{(\mathrm{Ca} + \mathrm{Mg})} \tag{3}$$

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{(\mathrm{Ca} + \mathrm{Mg})/2}} \times 100 \tag{4}$$

$$\mathrm{MAR} = \frac{\mathrm{Mg} \times 100}{\mathrm{Ca} + \mathrm{Mg}} \tag{5}$$

$$\mathrm{PI} = \frac{\mathrm{Na} + \sqrt{\mathrm{HCO3}}}{\mathrm{Ca} + \mathrm{Mg} + \mathrm{Na}} \tag{6}$$

Pollution evaluation indices

Single-factor pollution index (I_i)

Single-factor evaluation can help determine main heavy metal pollutants and the degree of harm. The single-factor evaluation can be generally expresses as pollution index, that is the ratio of the measured value on heavy metal type to the corresponding evaluation standard value.

$$I_i = \frac{C_i}{S_i} \tag{7}$$

Here, I_i is the pollution index of the heavy metal i; C_i is actual concentration of heavy metal i; and S_i is the evaluation standard value of heavy metal i. When, $I_i > 1$, the content of the heavy metal exceeds the standard.

Nemerow pollution index

The Nemerow pollution index (NI) is featured by the simple and clear mathematical process (Xiong et al. 2019). It is a comprehensive method to determine how sampling site is polluted by different heavy metals. The NI combines single-factor pollution index, the extreme value, and the maximum and minimum pollution degree. The calculation formula as follows:

$$\mathrm{NI} = \sqrt{\left(\frac{[(1/n)\sum(C_i/S_i)]^2 + [\max(C_i/S_i)]^2}{2}\right)} \tag{8}$$

Here, n is the number of indices, C_i is the actual concentration of heavy metal i; and S_i is the evaluation standard value of heavy metal i. We compared the NI result with groundwater pollution NI scale. NI divided by 6 degree of pollution like no pollution ≤0.5,clean 05–0.7, warm 0.7–1.0, polluted 1.0–2.0, medium pollution 2.0–3.0, and severe pollution > 3.0 (Bodrud-Doza et al. 2019b)

Heavy metal pollution index

The heavy metal pollution index (HPI) for water samples was determined utilizing the method of Edet and Offiong 2002.

$$\mathrm{HPI} = \frac{\sum_{i=1}^{n} Q_i W_i}{\sum_{i=1}^{n} W_i} \tag{9}$$

Where, Q_i is the sub index of the ith parameter, W_i is the unit weight of the ith parameter, and n is the number of parameters considered. Therefore, the subindex (Q_i) of the parameter is determined by

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i(-)I_i\}}{(S_i - I_i)} \times 100 \tag{10}$$

Here, M_i is the examined heavy metal value of the ith parameter, I_i is the ideal heavy metal value of the ith parameter, and S_i is the standard heavy metal value of the ith parameter. According's to Prasad and Bose (2001), the critical pollution index for drinking water is 100. Conversely, an adjusted scale utilizing three classes has been used in the current investigation. The three classes are low < 15, medium 15–30, and high > 30 for HPI values.

Heavy metal evaluation index

The heavy metal evaluation index (HEI) provides a general quality of the water concerning heavy metals (Prasad and Jaiprakas 1999) and calculated by the following equation:

$$\mathrm{HEI} = \sum_{i=1}^{n} {}^{H_c}/_{H_{\mathrm{mac}}} \tag{11}$$

Here, H_c is the monitored value of the ith parameter and H_{mac} is the maximum permissible concentration (MAC) of the ith parameter.

The degree of heavy metal index was classified into three divisions like low HEI ≤ 10, medium HEI (10–20), and high HEI > 20 (Bodrud-Doza et al. 2019a; Edet and Offiong 2002).

Results and discussion

Water chemistry of the Ganges River

Temporal variations of the physicochemical parameters of river water, e.g., temperature, pH, EC, TDS, DO, salinity, total hardness (TH), and alkalinity, are shown in Table 1. The water temperature varied from 18.42° to 30 °C during the winter to the summer season, and the average temperature was 26 ± 4.07 °C. The pH of the river water is a slightly alkaline condition which ranges from 7.8 to 8.5 with a mean value of 8.2 ± 0.23. This result indicates the presence of biodegradable organic compounds which makes the water alkaline in post and pre-monsoon season; on the other hand, due to upstream water input and heavy rainfall, river water pH remains neutral in monsoon season. The DO values were ranging from 6.3 to 11.2 mg L^{-1} with a mean of 8.5 ± 1.47 mg L^{-1}. Average DO value exceeded the permissible limit which recommended by DoE (1997), Bangladesh and WHO (2011). A marked increase in DO was documented in the mid of post-monsoon months to early pre-monsoon months, due to photosynthetic activity of aquatic plants. The level of water was decreasing gradually from monsoon to post-monsoon which results in the aquatic plants were significantly exposed to intense sunlight than that of monsoon season and consequently enhancing photosynthesis to produce more DO. The range of EC value of water was 174 to 361 μS cm^{-1} with a mean value of 289 ± 70.15 μS cm^{-1} which is fall within the permissible limits of all standard. Afterward, TDS ranged from 113 to 234 mg L^{-1} with an average value of 188 ± 45.60 mg L^{-1}. The higher TDS value was found in late post-monsoon and pre-monsoon season. The highest TDS desirable value is 500 mg L^{-1} recommended by WHO (2011) and the maximum permissible limit is 1000 mg L^{-1}, suggested by DoE (1997). All of the months of the study site are within the permissible limit of TDS. The salinity of the river water ranges from 0.08 to 0.17 ppt and not varied with season throughout the monitoring time. Saline water intrusion is one of the major causes of freshwater salinity in the coastal area of Bangladesh where excessive withdrawal of groundwater, construction of the Farakka Barrage might be played a major role on the changes of the hydrodynamic variability of the Ganges River (Abedin et al. 2013). Alkalinity ($\mathrm{HCO_3}^-$) of the Ganges River water was found in the range of 152–348 mg L^{-1} with an average value of 265.5 ± 56.50 mg L^{-1}. The highest value observed in the pre-monsoon season and the lowest value found during monsoon season. Excluding pre-monsoon months rest of months, the water sample exceeded the permissible limit set by WHO (2011), indicates that the presence of the high amount of bicarbonates, which may be coming from weathering of carbonate mineral at upper catchments, mostly from the Himalayan.

Table 1 Statistical summary of the measured physicochemical parameters, major cations, and anions of the lower Ganges River water samples and their comparison with drinking water standards

Month	Water temperature (°C)	pH	DO (mg/l)	EC (µS/cm)	TDS (mg/l)	Salinity (ppt)	Total hardness (mg/l)	Total coliform (TC) (CFU/mL)*	Alkalinity (HCO_3^-) (ppm)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l	Cl^- (mg/l)	F^-(mg/l)	SO_4^{2-}(mg/l)	NO_3^-(mg/l)	PO_4^{3-}(mg/l)
February	23.03	8.34	8.72	342.95	222.92	0.16	44.60	775	302.73	9.98	2.24	6.42	6.97	12.37	0.12	7.72	3.49	< 0.04
March	25.80	8.30	8.79	344.74	224.08	0.16	72.90	1330	347.54	18.56	3.54	11.35	10.85	20.27	0.07	17.52	< 0.03	< 0.04
April	25.82	8.33	9.33	360.69	234.44	0.17	81.50	1425	302.74	23.03	4.12	13.11	11.89	27.59	0.14	20.01	11.65	< 0.04
May	29.09	8.44	9.62	353.93	230.05	0.17	65.00	1520	318.00	17.48	4.47	6.15	10.12	22.68	0.19	18.27	4.25	0.33
June	29.83	8.02	7.27	192.05	124.84	0.10	49.60	1480	286.00	10.73	4.77	8.94	6.64	11.21	0.17	14.14	5.67	< 0.04
July	29.22	7.99	7.37	174.07	113.14	0.08	20.00	520	222.00	0.75	0.79	5.80	1.35	0.40	0.11	2.47	0.64	0.50
August	29.04	7.80	6.29	212.68	138.24	0.10	29.70	320	152.00	3.19	1.94	6.50	3.28	2.78	0.14	6.67	0.48	< 0.04
September	30.07	7.84	6.57	222.81	144.82	0.10	23.20	950	222.10	1.12	0.49	7.24	1.25	0.66	0.06	2.54	1.01	< 0.04
October	27.94	8.13	7.71	278.62	181.10	0.13	30.30	590	231.06	6.02	1.94	5.29	4.17	7.15	0.15	8.41	0.79	0.71
November	24.04	8.32	8.72	303.11	197.02	0.14	33.30	790	231.06	5.48	1.61	6.27	4.31	5.84	0.09	7.81	< 0.03	< 0.04
December	19.09	8.31	10.11	330.48	214.82	0.16	60.70	970	248.98	7.78	1.75	12.08	7.43	6.89	0.07	11.20	< 0.03	0.29
January	18.42	8.48	11.18	351.56	228.52	0.17	70.90	970	322.10	17.36	3.77	11.08	10.53	20.80	0.18	16.83	< 0.03	0.46
DoE (1997)	20–30	6.5–8.5	6	700	1000	–	200–500	–	–	200	12	30–35	75	150–600	1	400	10	6
WHO (2011)	–	6.5–8.5	5	1000	500	–	200	50	300	200	12	75	50	250	1.5	250	50	10
BIS (2012)	–	6.5–8.5	5	300	500	–	200–600	–	200–600	–	–	75	30	250	1	200	45	–

*Total coliform data collected from previous work of Tareq et al. (2013)

The average concentrations and ranges of Na^+, K^+, Ca^{2+}, and Mg^{2+} throughout the year were observed at 10.12 (0.75–23.03), 2.62 (0.49–4.77), 8.35 (5.29–13.11), and 6.57 (1.25–11.90) mg L^{-1}, respectively and major cations of all samples fall within the permissible limit of DoE (1997) as well as WHO (2011) (Table 1). Among the major cations, the contribution of Ca^{2+} and Na^+ ions concentration remained prevailing in the water of Ganges during the pre- and post-monsoon period. Meher et al. (2015) found the contribution of Ca^{2+} and Na^+ also dominated during the post-monsoon period at Rishikesh to Allahabad in the Ganges River. The average concentration of major cations in the Ganges River showed a decreasing trend which followed the order as $Na^+ > Ca^{2+} > Mg^{2+} > K^+$; Sharma et al. (2014) found the same order in upstream of the Ganges River.

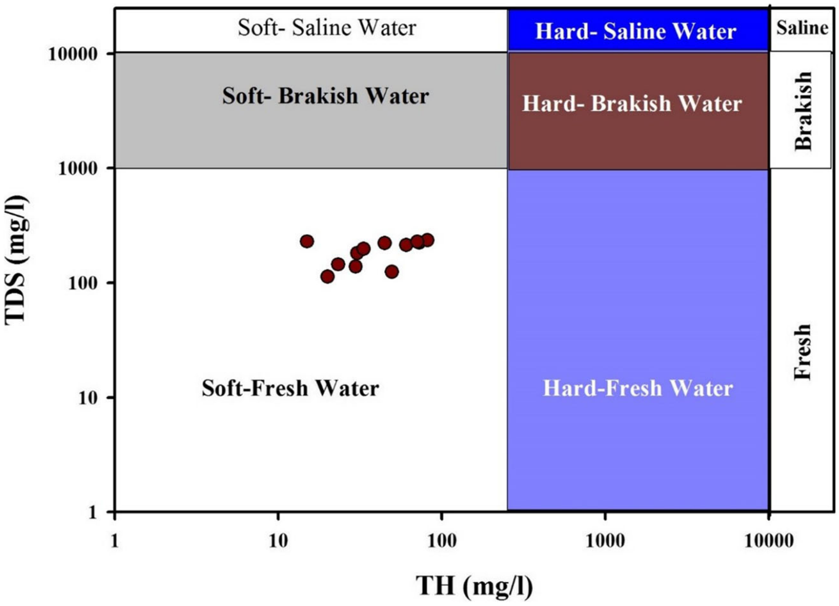
The range of chloride (Cl^-) concentration was 0.40 to 27.59 mg L^{-1} with a mean of 11.55 ± 9.20 mg L^{-1}. The maximum permissible limit of Cl^- in drinking water is 250 mg L^{-1}, recommended by WHO (2011), and 150–600 mg L^{-1}, suggested by DoE (1997). As chloride found in nature as different salts which might be increased due to anthropogenic activities and leaching into the river water. The average concentration of F^- was 0.12 ± 0.04 mg L^{-1} with ranges from 0.06 to 0.19 mg L^{-1} and which within the permissible limit (Table 1). The average concentration of sulfate (SO_4^{2-}), nitrate (NO_3^-), and phosphate (PO_4^{3-}) is 11.14 ± 6.10, 3.50 ± 1.80, and 0.45 ± 0.20 mg L^{-1} respectively, and concentrations range within the permissible limits of DoE. Among them, the highest value of SO_4^{2-} and NO_3^- was observed in pre-monsoon season which indicated possibility of nutrient leaching from the local agricultural land. Nutrient concentrations in several months of pre and post-monsoon were below than detection limit, which indicated biological utilization of nutrients by aquatic plants during low level of water. The low values of PO_4^{3-} observed throughout the year might be due to the utilization of PO_4^{3-} by phytoplankton. Among anions, the average concentration trend was found $Cl^- > SO_4^{2-} > NO_3^- > PO_4^{3-} > F^-$. The nutrients in the Ganges River were mostly derived from household sewage, industrial wastewater, agricultural runoff, and aquaculture (Dwivedi et al. 2018).

Hydrochemical facies

Total hardness (TH) in the river water varies from 15 to 81.5 mg L^{-1} with an average of 44.31 ± 21.20 mg L^{-1}, which is much lower than the desirable allowable limit. The maximum permissible and desirable limit of TH in drinking water is 500 and 100 mg L^{-1}, respectively (WHO 2011). Monsoonal runoff might be decreased the hardness of water by about 50% of the pre-monsoon times. The river water quality classification determined based on TDS and TH (Thakur et al. 2015) is shown in Fig. 3. The result showed that all the samples were classified as soft freshwater.

A Piper (1944) diagram for the water samples is shown in Fig. 4. This diagram contains two triangles, where one for anions and another for cations. The anions and cations fields are consolidated to show a solitary point in a diamond-shaped field from which induction is drawn based on the hydrogeochemical facies idea (Bodrud-Doza et al. 2019b). The results showed that the majority of the samples belong to the HCO_3^- (75%) type followed by the Na^+, Mg^{2+}, HCO_3^- (17%), and Mg^{2+}, HCO_3^- (8%) types in the lower Ganges River (Fig. 4). However, the plots reveal that HCO_3^- is the predominated facies. Rai et al. (2019) investigate the water type of the upstream of the Ganges River and found similar results.

Fig. 3 The Ganges River water classification based on TDS and TH



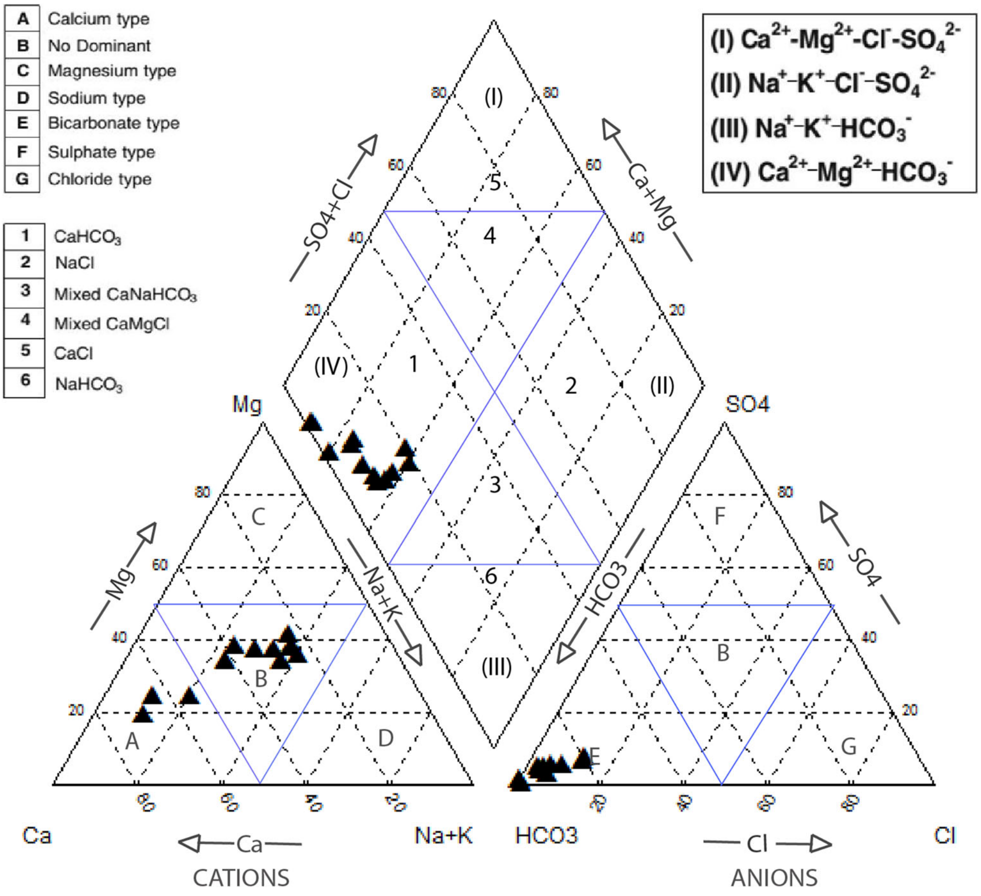


Fig. 4 Piper diagram displaying ion composition of the Ganges River water

Durov (1948) plots give more information on the hydrochemical process to distinguish the water types. It showed some geochemical forms used to specify the nature of water and its assessments. The anions and cations values are used to create two individual triangular plots and the information focuses are anticipated onto a square grid at the base of each triangle. The way that mixed water type denotes in the study area was supported by data plotted on the graph (Fig. 5), where two samples (16.67%) within the field 3 of Durov plot along with the disintegration or blending line. Because of the arrangement of Lloyd and Heathcote (1985), this pattern can be ascribed to HCO_3^- and Na dominated, typically shows particle traded water, although the generation of CO_2 at profound part can produce HCO_3^- where Na^+ is dominant under definite environments. In addition to this, 10 samples (83.33%) fall in the field 6 which showed SO_4^{2-} predominant or anion separate and Na^+ prevailing, is a water type that is not frequently encountered and indicates probable mixing or uncommon dissolution influences (Bodrud-Doza et al. 2019a).

WQI of the Ganges River

The initial phase in figuring of WQI following the "weighted arithmetic index" technique includes the approximation of "unit weight" allocated to each physicochemical parameters reflected for the count. By allotting unit-weights, all of the respective parameters of various units and measurements are changed to a typical scale (Table S2). Greatest weight, i.e., 0.518 is allocated to F^- because of the standard value of F^- is lowest compare to other parameter and along these lines proposing the key criticalness of the water quality appraisal and its impressive effect on the index. The summery of 12 months WQI of the lower Ganges River water is presented in Fig. 6. The results revealed that 33.33% of water samples were within good water quality category ($26 < \mathrm{WQI} < 50$) and 58.33% samples were within poor water quality category ($51 < \mathrm{WQI} < 75$) and 8.33% of the water sample fall under very poor water quality category ($76 < \mathrm{WQI} < 100$). The highest WQI value (75.78) was recorded in June and the lowest WQI value (36.00) was recorded in August.

The results showed that the variabilities of WQI uncovered a comparative distribution pattern with rainfall (Fig. 6). At the pre-monsoon season, the WQI was varied from 50.59 to 71.88 which indicates poor water quality but suitable for industrial and agricultural purposes. In the first part of the pre-monsoon seasons, the rainfall was observed to a certain extent and the peak was observed in April (Fig. 2). Some extent of rainfall flushed out local agricultural land, vehicle washing pollutant and also domestic waste which mixed with water and responsible for water quality deterioration where baseflow was the

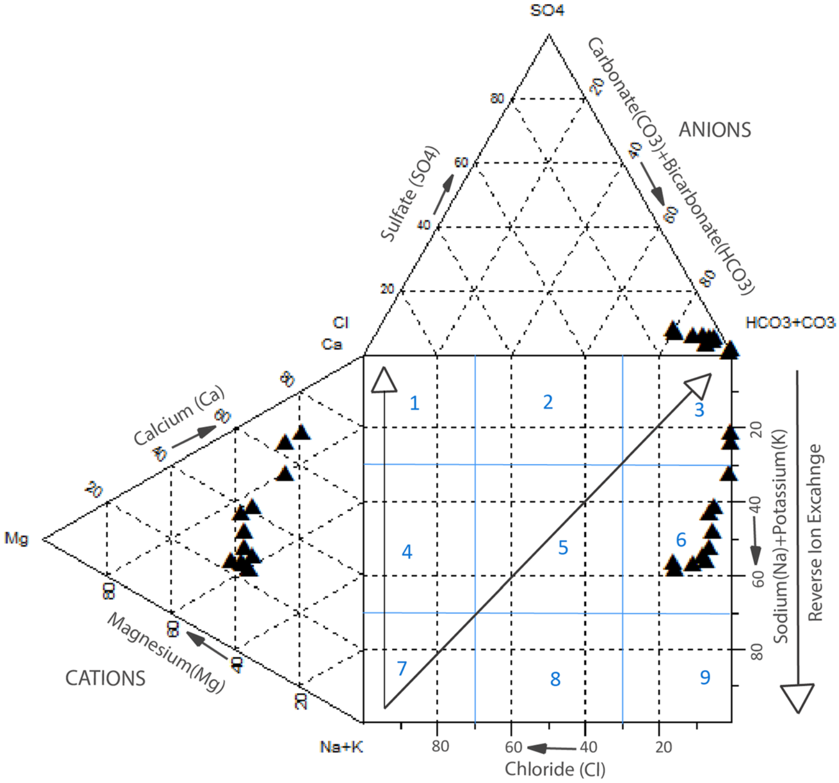


Fig. 5 Durov diagram showing hydrochemical processes in river water samples

predominant source of the riverine water. During monsoon season, the highest average rainfall and the water level was observed. The catchment area of the Ganges River is 1,087,300 km^2 (Hossain et al. 2016); due to the long catchment, the water discharged rate was increased gradually from pre-monsoon to monsoon and the pollutant was flushed out from upstream to downstream. On the other hand during monsoon season, an intense amount of rainfall dilutes the pollution level and makes it suitable for uses. The WQI for monsoon was ranged from 36.00 to 75.78, which indicates good to very poor water quality. The water quality gradually increased with increasing water discharge and also noted that high water velocity and low retention time caused for non-mixing of pollutants into the water column. At post-monsoon season, the WQI was varied from 45.82 to 56.78 which indicates good to poor water quality. The water quality was started to deteriorate at the beginning of the post-monsoon to the end. The water level, water discharge, and rainfall were decreasing gradually with the water quality. Because of the monsoonal flood, a flushed pollutant from catchment could easily be mixed with the water column and deteriorate the water quality.

Among the sampling period, most of the months water of the lower Ganges River is unacceptable for drinking, however, is appropriate for irrigation and industrial

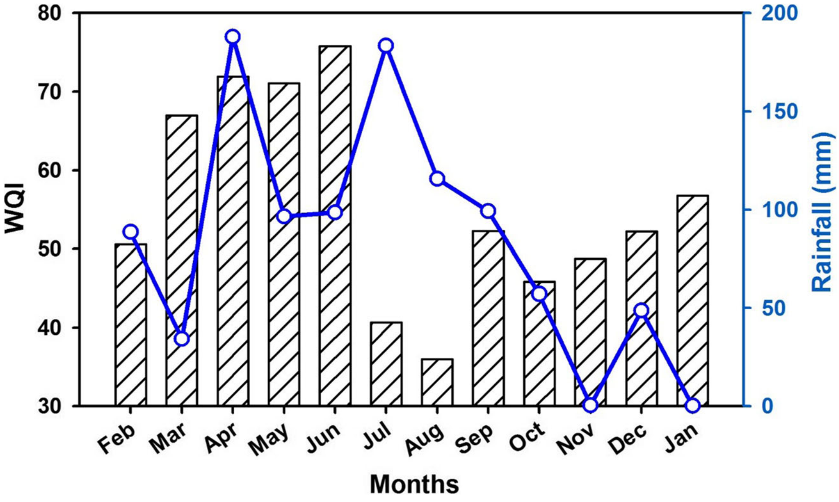


Fig. 6 Monthly average rainfall and WQI rating of various sampling months of the lower Ganges River

purpose according to Brown et al. (1972) WQI category. Bora and Goswami (2017) found the WQI in the Kolong River is unsatisfactory during the monsoon season which is essentially credited by expanded surface runoff from the contiguous urban accumulations and direct release from storm water depletes along streets nearby the river. The Ganges is one of the largest rivers in the world and the river path is mostly urbanized (Meybeck and Helmer 1989). Before entering the Bangladesh boundary, the Ganga passes along 29 class I urban areas, 23 class II urban communities, 70 towns, and a huge number of villages which also extend along the river banks (Bhutiani et al. 2016; Paul 2017). This large number of people living in urban areas of along the Ganges river bank are producing a huge amount of pollutants, e.g., approximately 1.3 billion liters sewage water for every day legitimately mixed into the river (Bhardwaj et al. 2010). In the monsoon period, heavy rainfall and runoff washed out pollutants from the catchment into the river. So that the water chemistry partially changed during the wet season compared to the dry season. Sharma et al. (2014) estimated the water quality index at upstream (India) of the Ganges River at Allahabad and found the range from 86.20 to 157.69. The studied sampling site at the downstream of Ganges in Bangladesh compared to Allahabad and observed with a slight difference among pre-monsoon, monsoon, and post-monsoon water quality. This study suggests that the water quality of the lower Ganges River at Hardinge Bridge point is inappropriate for drinking and may be suitable for irrigation and industrial purpose.

Correlation analysis of the hydrochemical parameters

The correlation is commonly used to build up the connection between two variables. From this analysis, we can understand how one variable foretells the other (Bodrud-Doza et al. 2019a). The correlation among different hydrochemical parameters is presented in Table 2. The results indicated that the correlations among pH, DO, EC, TDS, salinity, hardness, alkalinity, Na^+, Mg^{2+}, Cl^-, and $SO_4{}^{2-}$ are significantly positive ($p < 0.01$). This investigation demonstrated that DO and pH were significantly correlated ($r = 0.935$) from which pH may likewise consider as the main factor for the dissolution of oxygen in the water. Variations in pH and DO are both affected by several factor like algal photosynthesis, water temperature, aquatic respiration, and oxidative decomposition of organic matter (Scholz 2006; Zang et al. 2011). However, a high value of pH inhabit algal photosynthesis under certain conditions that might be decreased DO level (Zang et al. 2011; Sharma et al. 2014). The strong positive correlation was found between salinity and pH ($r = 0.914$), EC ($r = 0.993$), and TDS ($r = 0.993$), which indicated that salinity could be ascribed to the variability of pH, EC, and TDS. The significantly positive correlations among Na^+ and K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^{2-} are shown that these ions are acquired from the same source of water. Sulfate concentrations are unequivocally corresponded to the proximity of Na^+ ($r = 0.963$), K^+ ($r = 0.912$), Mg^{2+} ($r = 0.961$), and Cl^- ($r = 0.945$), the plausible explanation may be that the dissolution of evaporate minerals and the ion are likewise positive and significant. Chloride and magnesium ($r = 0.960$) showed a strong relationship between them which

Table 2 Pearson correlation of the hydrochemical parameter of the lower Ganges River water

	pH	DO	EC	TDS	Salinity	Hardness	Alkalinity	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	F^-	SO_4^{2-}
pH	1													
DO	0.935**	1												
EC	0.895**	0.836**	1											
TDS	0.895**	0.836**	1.000**	1										
Salinity	0.914**	0.869**	0.993**	0.993**	1									
Hardness	0.737**	0.764**	0.775**	0.775**	0.821**	1								
Alkalinity	0.768**	0.681*	0.686*	0.686*	0.715**	0.805**	1							
Na^+	0.728**	0.679*	0.758**	0.758**	0.793**	0.954**	0.845**	1						
K^+	0.509	0.447	0.430	0.430	0.509	0.788**	0.714**	0.852**	1					
Ca^{2+}	0.399	0.562	0.480	0.480	0.517	0.808**	0.508	0.659*	0.450	1				
Mg^{2+}	0.790**	0.768**	0.815**	0.815**	0.857**	0.983**	0.842**	0.977**	0.828**	0.703*	1			
Cl^-	0.742**	0.677*	0.766**	0.766**	0.797**	0.924**	0.840**	0.993**	0.845**	0.583*	0.960**	1		
F^-	0.240	0.211	0.083	0.083	0.156	0.259	0.227	0.395	0.665*	−0.127	0.348	0.454	1	
SO_4^{2-}	0.686*	0.664*	0.684*	0.684*	0.740**	0.949**	0.776**	0.963**	0.912**	0.662*	0.961**	0.945**	0.457	1

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

**Correlation is significant at the 0.01 level (2-tailed) affirms their equivalent inception. Magnesium and calcium are also positively correlated ($r = 0.703$ and $p < 0.05$), which indicated these ions come from agricultural practices (Potasznik and Szymczyk 2015) or silicate weathering. The correlations among $K^+ - Mg^{2+}$, $K^+ - Cl^-$, $K^+ - F^-$, Ca^{2+} -Mg^{2+}, Ca^{2+} -Cl^-, and Ca^{2+}-SO_4^2 are also positive and significant.

Suitability for agricultural purposes

The potential usability of irrigation water can depend on the concentration of TDS, EC, Ca^{2+}, Mg^{2+}, Na^+, and HCO_3^- (Table 3). SAR is a proportion of the degree to which Na^+ ions in the water systems may be consumed by the soil. Mainly, high SAR value caused sodium hazard on plant development. The SAR for the lower reach of the Ganges River range from 0.40 to 6.51 with an average value of 3.44 ± 2.10. According to Richards (1954) classification, the river water is excellent for agricultural purposes. The high substance of salts, predominantly Na^+ ion in the irrigation water stimuli the soil structure, diminishes air circulation and porousness, as well as bringing basic soil, which can distress plant development (Asare-Donkor et al. 2018). SAR and % Na are persuaded the sodium hazard by an excessive Na^+ ion in the irrigation water. High Na^+ concentrations can be adversely influenced soil physical properties (e.g., soil particle dispersion) (Alam 2014; Bob et al. 2017; Ehya and Moghadam 2017).

The %Na in water is vital for irrigation. The formation of alkaline or saline soils was caused by mixed of sodium with CO_3^{2-} or Cl^-. The %Na value ranged from 15.94 to 57.43, with a mean value of 41.09 ± 13.38. Henceforth, most of the months, river water is appropriate for irrigation according to Wilcox (1955) classification. The water quality of the Ganges river was also assessed using Kelley's ratio (KR), calculated according to Kelley (1963). KR is the amount of Na^+ ions estimated against Ca^{2+} and Mg^{2+}. If the KR value exceeds 1, the sodium concentration is too high whereas the value below 1 indicates waters suitable for irrigation. Apparently, all of the water samples KR value was lower than one where only the May month sample exceeded the permissible limit which was unsuitable for irrigation due to salts distress plant development by expanding soil osmotic pressure and to obstruction with plant sustenance. The ability of plants to acquire water is reduced due to high salt concentration in soil solution, which is alluded to as the osmotic or water-shortage impact of saltiness (Machado and Serralheiro 2017).

Table 3 Computed values of SAR, %Na, KR, PI, and MAR in the lower Ganges River

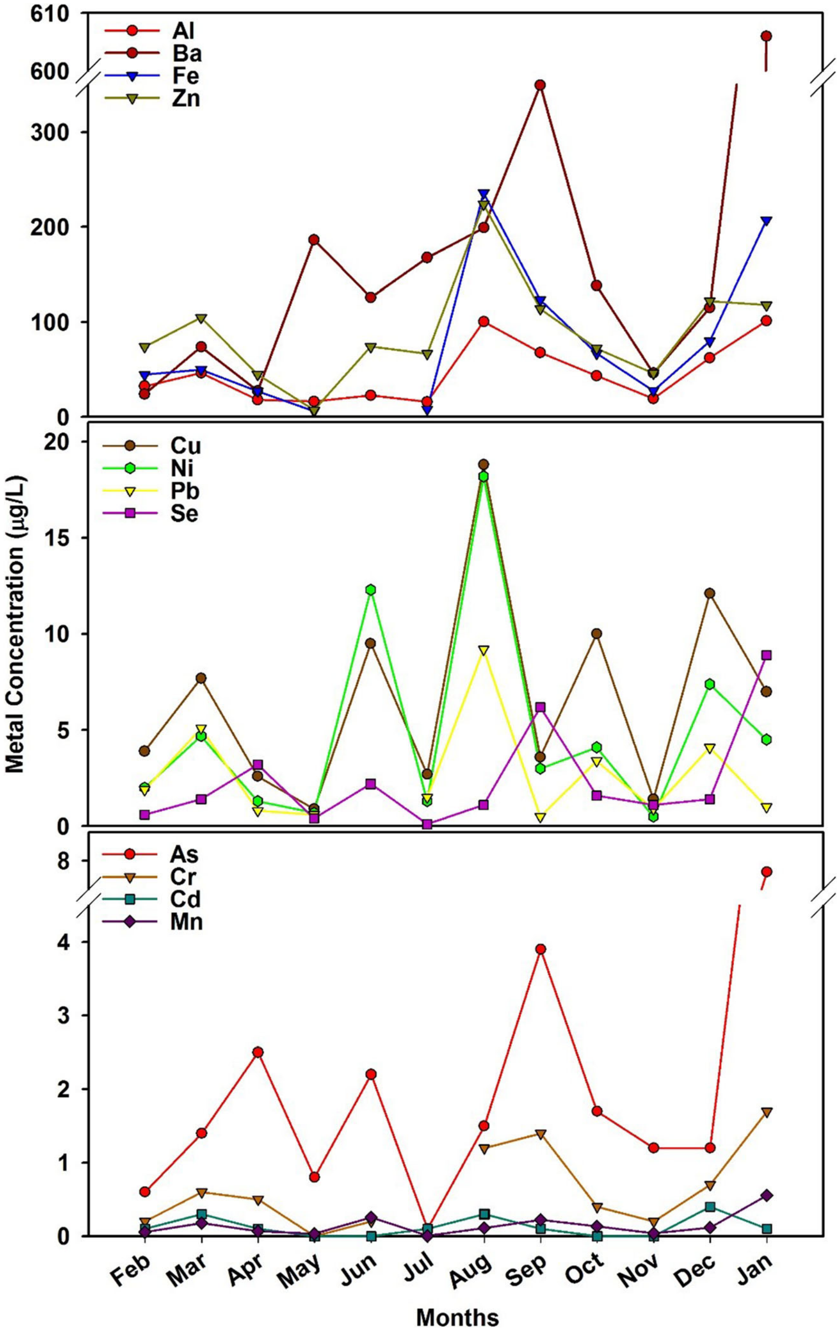
Months	SAR	%Na	KR	PI	MAR
February	3.86	47.72	0.75	117.16	52.05
March	5.57	49.89	0.84	91.27	48.87
April	6.51	52.06	0.92	84.18	47.56
May	6.13	57.43	1.07	104.63	62.20
June	3.84	49.87	0.69	105.06	42.62
July	0.40	17.72	0.10	198.10	18.88
August	1.44	34.41	0.33	119.65	33.54
September	0.54	15.94	0.13	166.73	14.72
October	2.77	45.69	0.64	137.08	44.08
November	2.38	40.12	0.52	128.77	40.74
December	2.49	32.82	0.40	86.33	38.08
January	5.28	49.44	0.80	90.60	48.73

Soil permeability is dependent on Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- whereas prolonged irrigation might be reduced the permeability. The PI value ranged from 84.18 to 198.10 with a mean of 119.13 ± 34.66. According's to Ehya and Moghadam (2017) PI classification, 33% sample was moderately useable and 67% sample was poorly useable for irrigation. The relationship between Ca^{2+} and Mg^{2+} in the surface water is expressed by the magnesium adsorption ratio. However, high Mg^{2+} concentrations may have negative effects on soil quality, because the soil becomes alkaline and results in infiltration problems (Asare-Donkor et al. 2018). According to Ayuba et al. (2013), water is unsuitable for irrigation when the MAR value is greater than 50. The MAR value of the present study ranged from 14.12 to 62.20 with a mean of 41.01 ± 13.45. All the month water samples were below the acceptable limit of 50, except February and May. Where these two months water indicates it was not suitable for irrigation. Due to excess MAR, previous study also concluded the visible signs of stress and injury across the leaf and stem structures of plants and also poses infiltration problems (Gupta and Gupta 1997).

Heavy metals in river water

The concentrations of dissolved heavy metals in the pre-monsoon, monsoon, and post-monsoon are shown in Fig. 7. The temporal distribution of heavy metals at the sampling site reveals a wide scope of variabilities. These variabilities can be influenced by a segment mixing, the tidal system, and other stream design (Nasr et al. 2017). The concentrations of all heavy metals in every season water were lower than that of drinking and irrigation standard permissible level (FAO 1985; DoE 1997; WHO 2011; BIS 2012). The average concentration of Al, As, Ba, Cr, Cu, Cd, Fe, Mn, Ni, Pb, Se, and Zn of all month samples in the three-season was found 45.55, 2.05, 171.57, 0.64, 6.68, 0.13, 79.72, 0.15, 5.00, 2.64, 2.35, and 88.98 μg L^{-1}, respectively (Table 5). In the pre-monsoon season, metal concentrations were lower than the other seasons. The maximum concentration of As, Ba, Fe, Pb, and Se was very close to the maximum allowable limits of the

Fig. 7 Monthly variation of the concentration of heavy metals (μg L^{-1}) in the lower Ganges River water samples



International Standard (WHO 2011) and National Guideline (DoE 1997). The increasing pattern of these metal concentrations was recorded during monsoon and post-monsoon season which might be due to the anthropogenic activities and surface overflow during monsoon substantial rainfalls. Monsoonal water interacts with the alluvium of the Ganga plain and goes into the groundwater framework to turn into a wellspring of all tributaries of the river system (Singh et al. 2010). The maximum concentration of As was recorded as 7.60 μg L^{-1} in January whereas the maximum allowable limit is 10 μg L^{-1} (WHO 2011). In the Ganges plain, unconsolidated sediments of the alluvium are the source of Arsenic (As) and can be represented by biogeochemical forms functioning at the sediment-water interface (Tareq et al. 2003, 2013). This study found the maximum value of Ba was 606 μg L^{-1} in January during the post-monsoon period. Most of the concentration of Ba comes from the drainage basin due to the chemical weathering of various lithologies (Bluth and Kump 1994). Anthropogenic activities, e.g., fertilizer use and land-use pattern, might be influenced dissolved Ba richness in particular rivers (Dalai et al. 2002). The concentration of Fe was observed high during August at 236 μg L^{-1}, with year-round seasonal variation. Phytoplankton activity could be stimulated the seasonal variability of Fe, as this metal is fundamental for phytoplankton (Sarkar et al. 2007). The source of Pb in aquatic environments is the atmospheric fallout and this goes about as the most potential hotspot for increasing dissolved Pb concentration in the surface waters (Moore and Ramamoorthy 1984). The maximum Pb value was recorded as 9.20 μg L^{-1} in August during the monsoon period. As the Ganges River passes through the most densely populated region including some developing cities, there was a great possibility to addition of Pb from urban and semi-urban areas industrial activities. The maximum concentration of Se was recorded 8.9 μg L^{-1} in January which indicates the river water chemistry dominated by weathering of sedimentary and carbonate rock (Panigrahy and Raymahashay 2005). Natural sources contribute low concentrations of heavy metals in river water and it can be described by slow addition, while certain metals concentration can be generally augmented through anthropogenic activities (Karbassi et al. 2008; Giri and Singh 2014; Liang et al. 2018, 2019). The results revealed that the mean concentration of heavy metals followed a descending order as Ba > Zn > Fe > Al > Cu > Ni > Pb > Se > As > Cr > Mn > Cd in the Ganges river.

Heavy metals in contaminated water pose a potential risk when it is used to agricultural and fisheries activities (Gupta et al. 2009; Ahmed et al. 2019). The present study showed that the heavy metal concentrations were lower than that of irrigational standard (FAO 1985) as well as fisheries (Svobodova et al. 1993). Bangladesh is one of the agricultural based country where most of agricultural production depend on the river water especially the Ganges River. More than 90 vegetables and 60 fruits are being grown, where the leafy vegetables accumulate significant amount of metals compare to other (Alam et al. 2003; Sultana et al. 2015). The results showed that the lower Ganges River water did not have any risk for single metal pollution. In addition, toxicity of heavy metals depends on some physicochemical parameter especially the pH and DO for fish culture. The pH significantly influenced to the solubility of metals in the river water. The narrow ranges of pH values (7.5 To 8.5) indicated low solubility of metals in water column especially Pb (Svobodova et al. 1993), and the heavy metal concentrations in all seasons were lower than the international standard for fisheries set by Food and Agricultural Organization (Svobodova et al. 1993).

According to Chanpiwat and Sthiannopkao (2014), the world river water mean concentration of Al, As, Ba, Cr, Cu, Cd, Fe, Mn, Ni, Pb, and Zn is 32 μg L^{-1}, 0.6 μg L^{-1}, 23 μg L^{-1}, 0.9 μg L^{-1}, 1.5 μg L^{-1}, 0.1 μg L^{-1}, 66 μg L^{-1}, 34 μg L^{-1}, 0.8 μg L^{-1}, 0.1 μg L^{-1}, and 0.6 μg L^{-1}, respectively (Table 5). Our results showed that the average concentration of heavy metals is significantly greater than the world river average value, except Cr, Cd, and Mn. However, the concentrations of Al, Cr, Cd, Fe, and Mn are much lower than other comparable rivers in Bangladesh (Ahmed et al. 2009; Rashid et al. 2012; Islam et al. 2013; Mokaddes et al. 2013; Hassan et al. 2015; Bhuyan et al. 2019). The concentrations of As, Cu, and Pb are near to the Balu, Shitalakhya, and Turag Rivers, while other metals fluctuate considerably from the comparable river. The concentration of Zn is high compare to other rivers in Bangladesh, but the values were 3.6 and 3.1 times lower than Buriganga and Karnofully River (Table 4), respectively.

The correlation matrix for the investigated heavy metals in the lower Ganges River is shown in Table 5. The results revealed significant positive correlations between Al and other heavy metals, with the exception of Cd, Ni, and Pb. The correlation between Al and Cr is positively significant ($r = 0.908$) and the coefficient of assurance value showed Al could be credited to Cr focus in river water. The significant positive correlations between As and Ba, Cr, Fe, Mn, and Se indicate that these metals are acquired from a similar wellspring of water. The correlations between Ba and Cr, Fe, Mn, and Se are positive and significant. The correlation among Cr-Fe, Cr-Mn, Cr-Se, Cr-Zn, Cu-Cd, Cu-Fe, Cu-Ni, Cu-Pb, Cu-Zn, Cd-Pb, Cd-Zn, Fe-Mn, Fe-Ni, Fe-Zn, Mn-Se, Ni-Pb, Ni-Zn, and Pb-Zn is also positive and significant (Table 5). Among them, the strong correlation of Cu-Ni ($r = 0.912$), Cu-Pb ($r = 0.914$), and Ni-Pb ($r = 0.915$) confirms that these metals came from same origin. The statistical analyses demonstrated that these heavy metals might be originated from similar sources or were affected by the equivalent environmental factor(s) during land water interactions.

Seasonal variation of metals

This study revealed that the metal concentrations varied significantly and also it has great seasonality (Fig. 7). Significantly higher concentrations of Cu, Fe, Ni, Pb, and Zn were observed in the monsoon season than that of pre and post-monsoon season while Al, As, Ba, Cr, Cd, Mn, and Se were significantly higher in the pre-monsoon and monsoon season. The total concentrations of all the studied metals in the river water had an average of 207.15, 499.19, and 489.38 μg L^{-1} in the pre-monsoon, monsoon, and post-monsoon seasons, respectively. The metal concentration was greater in the monsoon season when contrasted with different seasons. This may be attributed to the high metal content water pass through the sampling location during monsoon. The Ganges River is one of the largest rivers in the world, with a total length and total drainage area of 2515 km and 1.05×10^6 km^2, respectively (Meybeck and Ragu 2012). During pre-monsoon season, the river catchment area ascribed to the greater vaporization and intense anthropogenic activities. During early monsoon with heavy rainfall, all of the pollutants washed out from the catchment to the stream via baseflow and interflow and made the high metal concentrations of river water. The river water flow remained high

Table 4 Comparison of the observed values of heavy metals (μg L^{-1}) in the water of the lower Ganges River with world average and other rivers of Bangladesh

River	Al	As	Ba	Cr	Cu	Cd	Fe	Mn	Ni	Pb	Se	Zn	Reference
Ganges	45.55	2.1	172	0.7	6.68	0.1	80	0.15	5	2.6	2.35	89	This study
Old Brahmaputra	6870	–	–	10	120	1	–	1440	440	110	–	10	Bhuyan et al. (2019)
Meghna	–	–	–	34.6		3	1022	8.8	BDL	BDL	–	36.4	Hassan et al. (2015)
Balu	–	1	–	–	10	8	–	30	–	1	–	20	Mokaddes et al. (2013)
Buriganga	–	134	–	114	239	59	612	157	150	119	–	332	Bhuiyan et al. (2015)
Dhaleshwari	–	–	–	440	150	6	–		7		–		Ahmed et al. (2009)
Khiru	–	–	–		4	130	–	170	–	20	–	6	Rashid et al. (2012)
Karnofully	–	–	–	250	50	10	2060	120	–	140	–	280	Islam et al. (2013)
Shitalakhya	–	2	–	–	5	10	–	50	–	1	–	20	Mokaddes et al. (2013)
Turag	–	2	–	–	4	10	–	60	–	2	–	20	Mokaddes et al. (2013)
World average concentration	32	0.6	23	0.9	1.5	0.1	66	34	0.8	0.1	–	0.6	Chanpiwat and Sthiannopkao (2014)
WHO for drinking	–	10	700	50	2000	3	300	100	70	10	40	3000	WHO (2011)
Bangladesh standard for drinking	200	50	1000	50	1000	5	300–1000	100	100	50	10	5000	DoE (1997)
Indian standard for drinking	30–200	10 to 50	700	50	50–1500	3	300–1000	100–300	20	10	10	5000–15,000	BIS (2012)
Irrigation standard	5000	100	100	10	200	10	5000	200	200	5000	20	2000	(FAO 1985)

in the middle of the post-monsoon season compared to the end of this season due to the long catchment and pathway, correspondingly the concentration of metals was quite similar to the monsoon season. However, most of the point sources of pollution are located along the upstream stretches of the Ganges River, far away from this study site, so it could easily recognize that the river discharge plays a vital role for metal concentration variabilities.

Table 5 Pearson correlation matrix of the heavy metals in the studies samples

Parameters	Al	As	Ba	Cr	Cu	Cd	Fe	Mn	Ni	Pb	Se	Zn
Al	1											
As	0.619*	1										
Ba	0.686*	0.854**	1									
Cr	0.908**	0.784**	0.807**	1								
Cu	0.663*	0.044	0.091	0.362	1							
Cd	0.518	−0.089	−0.049	0.375	0.601*	1						
Fe	0.971*	0.628*	0.669*	0.878*	0.709*	0.369	1					
Mn	0.647*	0.924**	0.816*	0.712*	0.23	0.015	0.676*	1				
Ni	0.555	0.042	0.091	0.298	0.912**	0.444	0.773**	0.227	1			
Pb	0.520	−0.236	−0.151	0.191	0.914**	0.699*	0.519	−0.056	0.915**	1		
Se	0.584*	0.978**	0.833**	0.803**	−0.037	−0.08	0.574	0.869**	−0.035	−0.313	1	
Zn	0.857**	0.234	0.319	0.701*	0.844**	0.684*	0.861**	0.324	0.791**	0.800**	0.214	1

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

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

Pollution evaluation indices

The results of the single-factor pollution index (I_i) and the Nemerrow pollution index (NI) of heavy metals in the Ganges river water are presented in Table S3, which was computed using WHO (2011) and BIS (2012) standards. The I_i for all metals and all sampling months were < 1, indicating metal concentrations in river water was did not exceed the respective standard and no pollution was found throughout the sampling period. Besides, NI was utilized to survey how multi-components contaminate river water at a solitary sampling site. The mean value of NI was 0.30 ± 0.19 and the range was 0.09–0.67 (Table S3). The results of NI indicated that the river water is in catagory of no metal pollution to safe pollution. Most of the months indicated less metals pollution, only April and September exceed the limit (≤ 0.5). The Ganges River is a large river in the Indian subcontinent which passes many cities and villages of India and Bangladesh and carried different types of pollutants. But due to its long course and high water discharge rate the pollutant mixed with river water and after the hydro-biogeochemical process, it might be partly absorbed by clay or soil in the river. On the other hand, the Farakka Barrage plays an important role on pollution discharges. The water retention time is increased during the pre- and post-monsoon seasons when the physical, biological, and chemical process control the pollutant activity. Therefore, metal concentrations of the Ganges River were low compared to other urban peripheral rivers like Buriganga, Turag, and Bangshi in Bangladesh.

The results of the heavy metal pollution index (HPI), computed based on the global standard values (WHO 2011; BIS 2012) of metal, are showed in Fig. 8. The mean and range of HPI were 9.13 and 1.92 to 26.47, respectively. According's to Edet and Offiong's (2002) classification, 75% of samples were within the limit of low class (HPI < 15) and the rest of 25% of samples were within the medium class (HPI 15–30). The determining index values demonstrated that, as a whole, the river waters were not polluted with respect to heavy metals. It also demonstrated that 100% of the samples were below the critical limit (100) and 25% of the samples exceed the mean estimation of HPI. The major part of the samples showed a far lower values than as far as possible for the drinking water prescribed by Prasad and Bose (2001). Although the HPI of throughout the year is far below than critical index value, but index values of the April, August, and November are greater than that of other months, indicating that the river receives pollutants from local activities (oil spills from the boat, vehicle washing water, agricultural runoff) during these three months. Though the sampling location is downstream of the Ganga River, the pollution intensity gradually reduced from the source of pollution to the downstream of the river (Bhuiyan et al. 2015). Edet and Offiong (2002) introduced the heavy metal evaluation index (HEI) for better resolution of the pollution assessment. The HEI range from 0.52 to 3.35 with a mean of 1.39 ± 0.99 (Table S4). Most of the sampling months were characterized as a low degree of pollution. The result showed that 41.66% of river water samples (January, March, August, September, and December) have greater value than the mean estimation of HEI. The HPI and HEI were below their respective mean values (Table S4), and their comparing negative percent deviations demonstrated a good quality of water. A similar conclusion was drawn by other researchers (Bhuiyan et al. 2015; Edet and Offiong 2002; Prasad and Bose 2001) in the different study locations of the Ganges river.

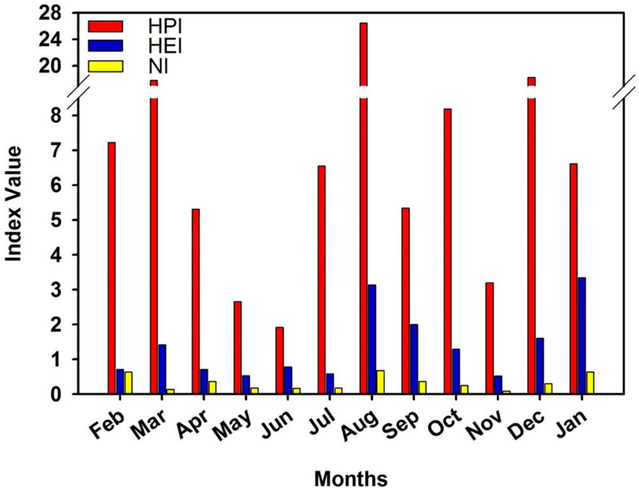


Fig. 8 Monthly variation of HPI, HEI, and NI of lower Ganges river water

Conclusion

The results of this study showed that the lower Ganges River water is polluted to some extent. Most of the investigative physicochemical parameter is within the recommended limits specified by the National and International Guidelines and Standards while DO and Alkalinity (HCO_3^-) exceeded the specified permissible limits. The hydrochemical facies showed the water is bicarbonate (HCO_3^-) dominated and the weathering process plays a vital role during transportation. The water quality index of this present study reveals significant variation among all months and also indicated the river water is not suitable for drinking but suitable for fisheries, industrial, and irrigation purposes. Different water quality indices for irrigational suitability resulted that water is appropriate for irrigation, only PI indicate 67% samples poorly useable for agricultural purposes. The concentrations of heavy metals (Al, As, Ba, Cr, Cu, Cd, Fe, Mn, Ni, Pb, Se, and Zn) along the lower Ganges River demonstrated incredible seasonality. The metal concentrations were higher in monsoon and post-monsoon season as compared to pre-monsoon season due to the influences of high discharge of monsoon floodwater. The magnificent consideration ought to be paid for As, Ba, Fe, Pb, and Se when contrasted with guidelines. The respective higher estimations of metals in the rivers water suggest surplus inputs from infrequent geochemical enhancement during monsoon and post-monsoon water discharge, which may be coming from the geological sources combined with anthropogenic contributions from the river catchments. The results of I_i and NI showed that the river water has less metals pollution. Similarly, the HPI and HEI indicate that 75% samples are within a low degree of pollution. Thus, it can be concluded that the water quality of the Ganges River deteriorated and greatly influenced by the discharge of monsoonal flood water and local anthropogenic activities. So, it is high time for doing management planning and adequate policies to control the pollution and monitoring the water quality periodically.

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