



# Hydrological distribution of physicochemical parameters and heavy metals in surface water and their ecotoxicological implications in the Bay of Bengal coast of Bangladesh

Md. Saiful Islam<sup>1</sup> · Abubakr M. Idris<sup>2,3</sup> · Abu Reza Md. Towfiqul Islam<sup>4</sup> · Mir Mohammad Ali<sup>5</sup> · Md. Refat Jahan Rakib<sup>6</sup>

Received: 8 June 2021 / Accepted: 5 July 2021 / Published online: 17 July 2021  
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2021

## Abstract

Accumulation of heavy metals in the coastal ecosystem has become a prodigious problem in any developing countries like Bangladesh. The impact of human activities on some physicochemical parameters and heavy metals was studied in surface water of the Bengal coast, Bangladesh. For ease of description, the fourteen study stations were categorized into four regions of the coastal sites of Bangladesh to determine physicochemical parameters and nine heavy metals like chromium (Cr), nickel (Ni), copper (Cu), arsenic (As), cadmium (Cd), lead (Pb), iron (Fe), manganese (Mn), and zinc (Zn) in water samples. The mean concentrations for water physico-chemistry are temperature ( $27.7 \pm 1.2$  °C), pH ( $7.4 \pm 0.27$ ), electrical conductivity (EC) ( $41.8 \pm 6.6$  mS/cm), dissolved oxygen (DO) ( $6.7 \pm 0.69$  mg/L), turbidity ( $58.5 \pm 12.0$  NTU), fluoride ( $1.4 \pm 1.2$  mg/L), chloride ( $126 \pm 66.3$  mg/L), sulfate ( $120 \pm 90.5$  mg/L), nitrate ( $4.7 \pm 2.5$  mg/L), and phosphate ( $4.7 \pm 2.5$  mg/L). While the mean concentrations of Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn were  $150 \pm 58.3$ ,  $40.2 \pm 10.1$ ,  $186 \pm 114$ ,  $77.3 \pm 31.3$ ,  $32.7 \pm 20.7$ ,  $66.7 \pm 32.5$ ,  $871 \pm 268$ ,  $178 \pm 41.4$ , and  $222 \pm 100$  µg/L, respectively. As a whole, average concentration of studied metals in surface water followed the decreasing order of  $Fe > Zn > Cu > Mn > Cr > Pb > As > Ni > Cd$ . Heavy metals in water samples were much higher than the water quality guidelines for freshwater quality criteria for protection of aquatic life and drinking, indicated that the water of the study areas may create health hazard. The outcomes of the contamination factor (CF), pollution load index (PLI), Nemerow's pollution index (NPI), degree of contamination ( $C_d$ ), and modified degree of contamination ( $mC_d$ ) varied spatially and most of the water samples were moderately to heavily polluted.

**Keywords** Water quality; Heavy metals · Bengal coast · Contamination factor · Pollution index

Responsible Editor: V. V.S.S. Sarma

✉ Md. Saiful Islam  
msaifulpstu@yahoo.com

- <sup>1</sup> Department of Soil Science, Patuakhali Science and Technology University, Dumki, Patuakhali 8602, Bangladesh
- <sup>2</sup> Department of Chemistry, College of Science, King Khalid University, Abha, Saudi Arabia
- <sup>3</sup> Research Center for Advanced Materials Science (RCAMS), King Khalid University, Abha, Saudi Arabia
- <sup>4</sup> Department of Disaster Management, Begum Rokeya University, Rangpur 5400, Bangladesh
- <sup>5</sup> Department of Aquaculture, Sher-e-Bangla Agricultural University, Dhaka 1207, Bangladesh
- <sup>6</sup> Department of Fisheries and Marine Science, Noakhali Science and Technology University, Noakhali 3802, Bangladesh

## Introduction

Waters are the essential requisite for all life forms on the earth (Bytyci et al. 2018) and are also known as the most important irreplaceable natural resource on which the socio-economic growth and sustainable development of a country depends to a large extent (Pobi et al. 2019; Proshad et al. 2020). However, despite its importance to the human being, water is the most poorly managed resource in the world especially in developing countries and is facing a serious threat as a result of the wide array of anthropogenic activities (Islam et al. 2014; Ustaoglu and Islam 2020). Deterioration of the world marine ecosystems due to the introduction of different types of pollutants like heavy metals and nutrient enrichments from excessive anthropogenic activities such as marine dumping, dredging, industrial effluents and incessant municipal, agricultural waste, domestic discharges, and atmospheric depositions

has been a worldwide concern in recent years (Raknuzzaman et al. 2016; Zaher et al. 2017; Bristy et al. 2021). These activities and wastes with toxic contaminants into surface waters have negative effect on human health. In addition, bacteria, viral, and parasitic diseases like typhoid, cholera, encephalitis, hepatitis, skin infection, hair loss, liver cirrhosis, renal failure, and neural disorder are spreading through dermal and oral ingestion of metals contaminated water (Chowdhury et al. 2015; Islam 2021). According to World Health Organization (WHO) about 80% of disease are water borne, hence, surface water is a major source of infection to marine organisms and human.

Among the pollutants, heavy metals are considered as one of the most serious environmental pollutants because of their high toxicity, abundance, and ease of accumulation by various organisms (Swarnalatha et al. 2013; Islam 2021). The study of heavy metals is crucial due to their nonbiodegradable nature, accumulative properties, and long biological half-lives. Once they enter into the water body, it is difficult to remove them entirely. Therefore, heavy metals persist in the aquatic environment; gradually move through the lower food chain to upper trophic levels and bioaccumulate in the higher organisms (Aderinola et al. 2009), which can eventually lead to adverse health effects on humans due to the consumption of contaminated seafood (Wang 2002). Heavy metal contamination can affect the physical, chemical, and biological characteristics of water and its ecosystem. Therefore, physicochemical water analysis is valuable in assessing water quality and composition (Nubi et al. 2019). With the increasing use of wide variety of metals in electronics and petrochemicals industries in Bangladesh way of disposing waste indiscriminately, there is little awareness of detrimental health effect of heavy metal pollution in the coastal environment. Researchers therefore have started focusing in assessing the hydro geochemical distribution of heavy metals in the surface water with their human and ecological risks (Wang et al. 2018; Qu et al. 2018; Saleem et al. 2019; Proshad et al. 2020).

Bangladesh is a riverine country. According to Bangladesh Water development board about 230 rivers currently flow in Bangladesh with 580 km coastline of the Bay of Bengal. The Ganges is a trans-boundary river of Asia which flows through India and Bangladesh. The 2525 km length of different river rises in the western Himalayas of Uttarakhand, India, and flows south and east through the Gangetic Plain of North India into the Bay of Bengal of Bangladesh (Al-Mamun et al. 2019; Bristi et al. 2021). The Yamuna River is the second-largest tributary river of the Ganga and the longest tributary in India and flows into Bangladesh. These two rivers have been identified as the major recipients of industrial effluents through Padma and Jamuna Rivers forming the Meghna estuary (Raknuzzaman et al. 2016). In Bangladesh, Meghna estuary is the most biogeochemically active zones and is more easily affected by anthropogenic nutrient loading

and pollutants from urban expansion, untreated effluents from widespread ship breaking and port activities, excessive operation of mechanized boats, deforestation, and intensive agriculture, and aquaculture activities (Smith et al. 2012; Islam 2021; Bristi et al. 2021). The waste materials coming through these connecting tributary rivers with the Bay of Bengal are also accelerating the coastal water pollution that might contaminate the fish, crustaceans and others aquatic biota. The concerned authorities, local government, and general people of Bangladesh have not been aware about the present worse situation and no detailed study has been carried out so far in the coastal area of Bangladesh. Therefore, the objectives of the present study are to investigate the impact of human activities on some physicochemical parameters (e.g., temperature, pH, dissolve oxygen, conductivity, and turbidity), nutrient (e.g., nitrate, phosphate, sulfate, fluoride, and chloride), and heavy metals (Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn) distributions in the surface water of the coastal sea and estuarine areas using water pollution index such as contamination factor (CF), pollution load index (PLI), Nemerow's pollution index (NPI), degree of contamination ( $C_d$ ), and modified degree of contamination ( $mC_d$ ) in order to evaluate ecotoxicological effect on marine organisms and teeming population in the coastal areas of Bangladesh.

## Materials and method

### Description of the study area

In order to explore the influence of the potential sources of heavy metals, we have investigated fourteen sampling sites from four coastal areas in the southeast and southwest part of the Bay of Bengal coast of Bangladesh. These sampling sites located in Cox's Bazar, Chittagong, Meghna Estuary, and Sundarbans are shown in Fig. 1. The first site, Cox's Bazaar (Site 1), is a seaside tourist town with an unbroken 125 km world's longest natural sandy sea beach. Considering two diverse ecological aspects, it was divided into two sub sites: hatchery area (CX1–CX2) and Bakkhali estuary (CX3–CX4). More than 53 shrimp hatcheries and aqua farms, fish landing centers, huge hotels for the amusement of tourists, and some industries are located in the hatchery site. Likewise, the Bakkhali estuary, regarded as an important economic part of Cox's Bazaar district with a harbor and imperative local fishery, is about 0.5 km wide and >10 m deep at its mid-point and directly influenced by semi-diurnal tides. Moreover, Maheshkhali Island is one of the important tourists attracting economic zone incorporating to Bakkhali estuary through 9 to 11 kilometer long Maheshkhali channel to Cox's Bazaar central island. Consequently, these sampling areas are mostly influenced by the municipal sewage and

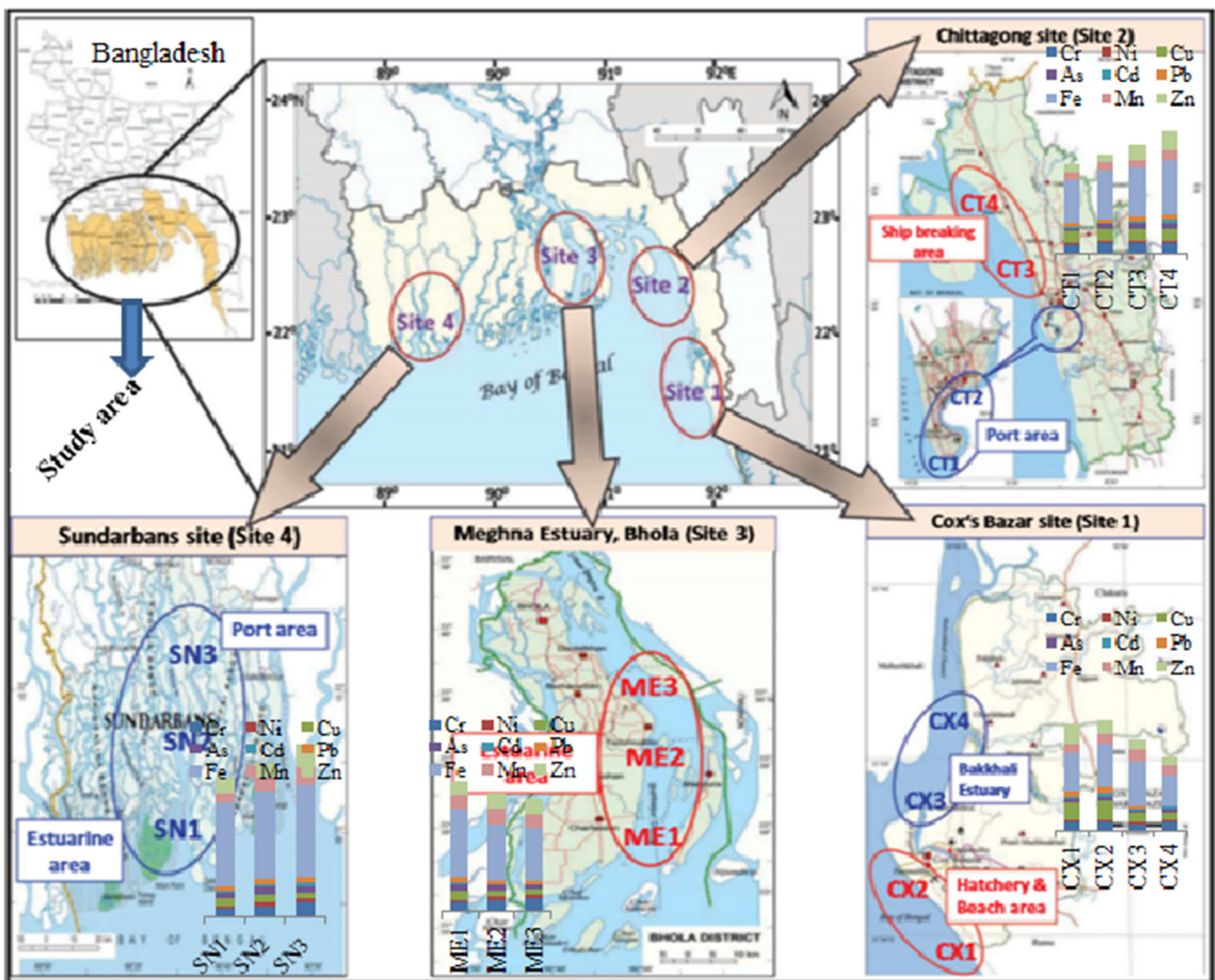


Fig. 1. Study area map of different locations of coastal sea and estuarine area in Bangladesh

industrial waste discharged from these unplanned industries, hatcheries, and aquaculture farms (Al-Mamun et al. 2019).

The second site, Chittagong (Site 2), is located near the Chittagong port (CT1–CT2) and ship breaking area (CT3–CT4). This is the southeastern principal seaport region of the country, where a significant ecological change is pronounced due to huge discharges of untreated or semi treated domestic and municipal sewage as well as effluents from multifarious industries (namely, paper and pulp, tanneries, textile, chemicals, pharmaceuticals, rubber and plastic, oil refinery, steal rerolling, leather, jute, tobacco, fish processing plants, paint, coal-based thermal power plants, fertilizer, rechargeable batteries, jewelry, plating, automobile engine, and electronics industries, etc.) as well as contaminated mud disposal from harbor dredging. Besides, Chittagong ship breaking yard is world’s second largest ship breaking area confined to 18 km<sup>2</sup> areas along the coast of Sitakunda Upazilla, particularly

Bhatiary to Kumira in Chittagong division. While dismantling the ships, the industry generates huge organic and inorganic wastes which is discharged into the nearby area and thus polluting the coastal water and sediment.

The third site (ME1–ME3), Meghna Estuary (Site 3), is an estuarine area where the main rivers mix together to the Bay of Bengal. This site is influenced mainly by the domestic and industrial effluents carried by the inland rivers from the country and trans-boundary countries. The fourth site, Sundarbans (Site 4), is located near the southwest part of the coastal area which is regarded as a large mangrove ecosystem in Bangladesh. This sampling area (SN1–SN3) is also mostly influenced by different anthropogenic and industrial activities like cement factories, export processing zone, sea port, paper industries, oil refinery industries, steal rerolling, fertilizer industry, hatcheries and aqua farms, fish processing industries, leather industries, dyeing industries, paint industries in Khulna and Mongla area. An elaborative description of the study area

is given in the Supplementary information (Table S1). All the industrial activities were observed during the sampling campaign of the present study.

### Sample collection, preparation, and quality assurance

A total of 42 composite surface water samples were collected during the transition of summer and rainy season starting from early September to end of November in 2020. The reasonable and adequate ground for the selection of seasons were to estimate the fluctuation of heavy metals in surface water in relation to the variation of the physicochemical properties, as the industrial and agricultural activities like fish processing, hatcheries, crop cultivation, and ship dismantling activities are vigorously increased in the sampling sites during this particular period. The tide in the coastal and estuarine area was semidiurnal and the samples were collected during the period of low tide. Unfiltered surface water samples were collected from fourteen coastal sampling stations. Immediately after collection, the samples were transferred into 100 mL polypropylene bottles which were previously washed with dilute nitric acid and deionized water. Then the samples were stored in refrigerator in the Department of Soil Science, Patuakhali Science and Technology University, Dumki, Patuakhali, Bangladesh.

Water samples were filtered (0.45  $\mu\text{m}$  filters, cellulose nitrate, Millipore) into polypropylene tubes using a plastic syringe (BD Plastipak, 50 mL) for dissolved heavy metals concentrations. Samples were acidified to 0.24 M with  $\text{HNO}_3$  (65% supra pure, Merck) and kept at 4 °C in the dark until analysis. The concentrations of As, Cd, Pb, Cr, Ni, Cu, Fe, Mn, and Zn in surface water samples were measured using inductively coupled plasma-mass spectrometry (ICP-MS, Agilent, 7700). The detection limits for Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn by ICP-MS analysis were 0.2, 0.05, 0.1, 0.05, 0.02, 0.02, 0.1, 0.02, and 0.3 ng/mL, respectively. The calibration curves with  $R^2 > 0.999$  were accepted for concentration calculation. Multielement solution (Agilent Technologies, USA) 1.0  $\mu\text{g/L}$  was used as tuning solution covering a wide range of masses of elements. All test batches were evaluated using an internal quality approach and validated if they satisfied the defined Internal Quality Controls (IQCs). Quality assurance and quality control for water samples were carried out using triplicates, method blanks, and standard reference material (STD TMDA-70.2). The percent recovery for all heavy metals ranged from 99.1 to 101.9% (Table S2). Comparison is made with the certified values, which in both cases confirmed that the sample preparation and instrumentation conditions provided good levels of accuracy and precision.

### Physicochemical parameters analysis

Analysis of common inorganic anions like fluoride, chloride, and sulfate was done using Ion Chromatography (IC). The physicochemical parameters such as pH, conductivity, dissolved oxygen (DO), turbidity, and temperature of water samples were measured immediately after sample collection by multi water quality checker (U-50, Horiba, Ltd., Kyoto, Japan). Water samples collected for dissolved nutrients were analyzed for Nitrate and Phosphate. Nitrates were determined using ammonium chloride. Phosphates were determined using the molybdenum-blue method. All the dissolved inorganic nutrient analyzes followed the methods of Parsons et al. (1984) using UV/VIS spectrophotometer at 410 and 820 nm for nitrate and phosphate, respectively. The common laboratory apparatus which were used during the study include; different sized beakers flasks, funnels, volumetric flasks, block digester, fume hood, droppers, glass pipettes, spatula, measuring cylinders, vinyl gloves, analytical balance, and conical flasks.

### Water pollution index

Most studies about the water quality assessment use a water quality index (Popoola et al. 2015; Yingran et al. 2017; Tanjung et al. 2019). The water pollution index is often used to understand and evaluate the level of water pollution in the coastal areas. The pollution index results can give an advice to the decision makers in order to know the quality of waters and make policy that would prohibit the deterioration of water quality if there is a quality reduction due to the existence of pollutants (Tanjung et al. 2019). A coupling of specific and combined approaches was used to appraise of heavy metal pollution level. Contamination factor (CF: Hakanson 1980), and Nemerow's pollution index (NPI) were adopted for the specific appraisal of heavy metal pollution (Dan et al. 2014), whereas the degree of contamination ( $C_d$ : Hakanson 1980), modified degree of contamination ( $mC_d$ : Abraham and Parker 2008) index, pollution load index (PLI: Tomlinson et al. 1980). All The mathematical equations, brief description and physical significances of these indices are shown in Table S3.

### Statistical analyzes

The data produced from this study were statistically analyzed using the statistical package, SPSS 16.0 (SPSS, USA). The means and standard deviations and inferential statistics (one-way ANOVA and correlation) of heavy metal concentrations in surface water samples were calculated. The data were compared by one-way ANOVA to determine if the difference was significant using 95% confidence interval ( $P\text{-value} < 0.05$ ). Correlation matrix analysis was used to identify possible significant relationships among physicochemistry, nutrients, and

heavy metals in surface water at both 0.01 and 0.05 significant levels. Multivariate post hoc Tukey test was performed to detect significant differences in concentration of physico-chemical parameters and risk index for different sampling sites. Other calculations were performed by Microsoft Excel 2010. A multivariate method in terms of principal component analysis (PCA) was used to obtain the detailed information of the data-set and gain insight into the distribution of heavy metals by detecting similarities or differences in samples. The PCA was performed using Varimax normalized rotation on the data-set.

## Results and discussions

### Physicochemical parameters distribution within water column

The physicochemical parameters of surface water samples from coastal sea and estuaries in Bangladesh are shown in Table 1. A wide range of physicochemical properties in water samples were observed among the sampling sites. Factors such as salinity, DO, pH, Temp., geomorphological setup, and terrestrial runoff might have played a role in the variation of physicochemical parameters. Water temperature is important because it increases/decreases the rate of chemical reactions as well as solubility of different gasses most especially oxygen (Ali et al. 2013). Water temperature for Cox’s Bazar Coast ranged between 26.3 and 29.9 °C with a mean of 28.0 ±1.1 °C, for Chittagong Coast ranged between 26.9 and 29.6

°C with a mean of 28.4±0.75 °C, for Meghna Estuary ranged between 25.1 and 28.7 °C with a mean of 27.0±1.2 °C and for Sundarbans ranged between 25.5 and 29.71 °C with a mean of 27.1±1.3 °C, respectively. Temperature values for surface were below 35 °C standard given by FEPA (1991). The minimal temperature values recorded across the stations could be attributed to the cloudy sky that was observed during sampling. The pH is a measure of the concentration of hydrogen ion and a very critical environmental indicator which can affect the composition of the organisms in the aquatic environment and the availability of nutrients as well as the relative toxicity of certain heavy metals. The mean ± SD value of pH in surface water was 7.6±0.39, 7.2±0.07, 7.4±0.05, and 7.5 ±0.05 at Cox’s Bazar Coast, Chittagong Coast, Meghna Estuary, and Sundarbans, respectively which is slightly alkaline. The pH values obtained are typical of the brackish water tidal climate (Fabunmi et al. 2015). Generally the alkaline nature of the study area could be due to the presence of carbonates and bicarbonates in the water bodies (Murhekar 2011). Higher value of alkalinity recorded at harbor area could be attributed to the buffering effect of the sea and it is an indicator of environmental condition closeness to the sea in agreement with the study of Onyema and Popoola (2013). The pH values recorded across the sample stations were within the permissible limit (6.5–8.5) set by WHO (1993). The pH values were well within the susceptible range for optimal aquatic productivity (6.5–9.0) and livable range of 5.5–10.0 (Wetzel 2001).

Electrical conductivity (EC) is a measure of water capacity to convey electric current through the water and it signifies the

**Table 1** Physicochemical parameters distribution within water column at different locations of the coastal sea and estuarine area in Bangladesh and comparison with the standard limit (n=3)

Sampling sites		Temperature (°C)	pH	EC (mS/cm)	Dissolved oxygen (DO) (mg/L)	Turbidity (NTU)	Fl <sup>-</sup> (mg/L)	Cl <sup>-</sup> (mg/L)	SO <sub>4</sub> <sup>2-</sup> (mg/L)	NO <sub>3</sub> <sup>-</sup> (mg/L)	PO <sub>4</sub> <sup>3-</sup> (mg/L)
Cox’s Bazar Coast	Mean±SD	28.0±1.1 <sup>a</sup>	7.6 ±0.39 <sup>a</sup>	44.2±5.6 <sup>a</sup>	6.8±0.71 <sup>a</sup>	56.8±10.9 <sup>a</sup>	1.6±1.2 <sup>a</sup>	168±63.5 <sup>a</sup>	176±108 <sup>a</sup>	5.1±2.4 <sup>a</sup>	3.4±0.96 <sup>a</sup>
	Range	26.3-29.9	6.9-7.9	30.8-50.7	5.2-7.7	45.1-76.2	0.18-3.4	50.5-255	46.3-351	1.9-8.9	1.9-5.0
Chittagong Coast	Mean±SD	28.4±0.75 <sup>a</sup>	7.2 ±0.07 <sup>a</sup>	42.0±5.5 <sup>a</sup>	6.8±0.60 <sup>a</sup>	57.6±13.8 <sup>a</sup>	1.3±1.3 <sup>a</sup>	98.9±52.7 <sup>b</sup>	77.2±43.1 <sup>b</sup>	6.5±2.4 <sup>a</sup>	3.9±1.3 <sup>a</sup>
	Range	26.9-29.6	7.0-7.3	34.7-48.9	5.5-7.8	40.1-72.5	0.11-3.3	39.9-195	38.5-138	2.5-9.2	2.0-5.5
Meghna Estuary	Mean±SD	27.0±1.2 <sup>a</sup>	7.4 ±0.05 <sup>a</sup>	43.6±5.8 <sup>a</sup>	6.4±0.84 <sup>a</sup>	54.1±9.9 <sup>a</sup>	1.8±1.1 <sup>a</sup>	154±54.9 <sup>a</sup>	161±83.7 <sup>a</sup>	2.9±1.3 <sup>b</sup>	2.6±1.0 <sup>b</sup>
	Range	25.1-28.7	7.3-7.4	33.1-51.8	5.2-7.6	42.9-71.6	0.22-3.5	66.8-216	42.3-285	1.2-4.8	1.2-4.1
Sundarbans	Mean±SD	27.1±1.3 <sup>a</sup>	7.5 ±0.05 <sup>a</sup>	36.4±7.7 <sup>b</sup>	6.6±0.63 <sup>a</sup>	66.2±10.8 <sup>b</sup>	0.6±0.9 <sup>b</sup>	79.3±55.2 <sup>b</sup>	56.9±42.0 <sup>b</sup>	3.7±1.8 <sup>b</sup>	2.6±0.54 <sup>b</sup>
	Range	25.5-29.1	7.5-7.6	25.0-49.5	5.4-7.6	41.8-78.5	0.11-2.9	34.2-198	26.9-136	1.3-5.6	2.1-3.4
Standard limit		35 (FEPA 1991)	6.5-8.5 (WHO 1993)	1.0 (WHO 1993)	5.0 (FEPA 1991)	10 (FEPA 1991)	1.5 (WHO 2007)	200 (WHO 2007)	400 (WHO 2007)	20 (FEPA 1991)	5.0 (FEPA 1991)

Note: In a column, different letters a and b indicates statistically significant difference among the station ( $p < 0.05$ ) NTU (Nephelometric turbidity units)

amount of total dissolved salts (APHA 2005). The EC values at the surface water varied from 30.8 to 50.7 mS/cm ( $44.2 \pm 5.6$  mS/cm) at Cox's Bazar Coast, 34.7 to 48.9 mS/cm ( $42.0 \pm 5.5$  mS/cm) at Chittagong Coast, 33.1 to 51.8 mS/cm ( $43.6 \pm 5.8$  mS/cm) at Meghna Estuary, and 25.0 to 46.5 mS/cm ( $36.4 \pm 7.6$  mS/cm) at Sundarbans, respectively (Table 1). The value of EC in all the sampling stations were above the maximum limit (1.0 mS/cm) given by WHO (1993). High value of EC in the study area could be attributed to the intrusion of seawater and stormy suspension of sediment particle by the ocean and others from effluents of conducting species such as chloride, phosphate, and heavy metals present in the sampling stations (Okorafor et al. 2013). EC showed a significant ( $p < 0.01$ ) positive correlation with fluoride ( $r = 0.864$ ), chloride ( $r = 0.888$ ), and sulfate ( $r = 0.767$ ) and negatively correlated with turbidity ( $r = -0.861$ ) (Table 4). The value of EC showed a significant difference ( $p < 0.05$ ) for Sundarbans with the other three sampling sites.

Dissolved oxygen (DO) is an important parameter in the aquatic system since it is virtually required by all organisms for their metabolism. Chapman (1996) stated that DO levels below 5.0 mg/L adversely affect the aquatic life while concentration below 2.0 mg/L may lead to death for most fishes. The mean  $\pm$  SD value of DO in surface water was  $6.8 \pm 0.71$ ,  $6.8 \pm 0.60$ ,  $6.4 \pm 0.84$ , and  $6.6 \pm 0.63$  mg/L at Cox's Bazar Coast, Chittagong Coast, Meghna Estuary, and Sundarbans, respectively (Table 1). The level of DO in water samples were higher than the permissible limit ( $\geq 5.0$  mg/L) recommended by Chapman (1996) and FEPA (1991) throughout the sample stations which could be as a result of influx of fresh water from the Bakkhali estuary, Ganges, Yamuna, Padma, Jamuna, and Karnaphuli Rivers as well as precipitation to the sea and estuaries of the Bengal coast of Bangladesh. The inflow of fresh water and sea water makes the sea a more productive natural habitat, resulting in high of nutrients (DO inclusive) in the water column. Turbidity is an important parameter for maintaining water quality that can indicate the presence of dispersed suspended solids, organic materials, algae, microorganisms and many more. The mean  $\pm$  SD value of turbidity at the surface water was  $56.8 \pm 10.9$ ,  $57.6 \pm 13.8$ ,  $54.1 \pm 9.9$ , and  $66.2 \pm 10.8$  NTU for Cox's Bazar Coast, Chittagong Coast, Meghna Estuary, and Sundarbans, respectively (Table 1). Turbidity values recorded from the sample stations were above the permissible limit (10 NTU) given FEPA (1991) which could be attributed to the presence of suspended matter such as silts, clay, finely divided inorganic, and organic matter from heavy dredging activities, residential discharges, and disposal of waste from hatchery and port area. Turbidity showed significant ( $p < 0.01$ ) negative correlation with fluoride ( $r = -0.803$ ), chloride ( $r = -0.807$ ) and sulfate ( $r = -0.666$ ).

Nitrate is known to be the most stable and predominant inorganic form of nitrogen in seawater which are produced naturally as part of the nitrogen cycle. The mean  $\pm$  SD value

of nitrate ( $\text{NO}_3^-$ ) in this investigation was  $5.1 \pm 2.4$ ,  $6.5 \pm 2.4$ ,  $2.9 \pm 1.3$ , and  $3.7 \pm 1.8$  mg/L for Cox's Bazar Coast, Chittagong Coast, Meghna Estuary, and Sundarbans, respectively (Table 1). Generally, the concentrations of nitrate at all the sample stations were within the permissible limit set by FEPA (20 mg/L) and could be due to utilization by phytoplankton or to the neritic water dominance, which contained negligible amount of nitrate (Govindasamy et al. 2000; Ramalingam et al. 2011). Phosphates are essential for the growth of organisms so they could be considered as a limiting nutrient for the growth of phytoplankton. The cycling of phosphorus within the aquatic water body is dynamic and complex; involving adsorption and precipitation reactions, interchange with sediments and uptake by aquatic biota (Mohamed 2005). The mean  $\pm$  SD value of phosphate ( $\text{PO}_4^{3-}$ ) in this investigation was  $3.4 \pm 0.96$ ,  $3.9 \pm 1.3$ ,  $2.6 \pm 1.0$ , and  $2.6 \pm 0.54$  mg/L for Cox's Bazar Coast, Chittagong Coast, Meghna Estuary, and Sundarbans, respectively (Table 1). Phosphate levels in the study area are likely to result from rock weathering and sand dredging activities that release soluble alkali phosphate together with inputs from domestic sewage and industrial effluents (Balogun and Ajani 2015). Phosphates values are within the maximum limit (5 mg/L) prescribe by FEPA (1991) in all the sample stations.

### Distribution of heavy metals in waters of the Bengal coast

The distribution of heavy metal concentrations in the Bay of Bengal coast are presented in Table 2. Average concentration of heavy metals in waters followed the decreasing order of  $\text{Fe} > \text{Zn} > \text{Cu} > \text{Mn} > \text{Cr} > \text{Pb} > \text{As} > \text{Ni} > \text{Cd}$ . Considering Cr concentration in surface water, elevated level of Cr was observed CT3 site ( $257 \pm 35.5$   $\mu\text{g/L}$ ) of Chittagong coast followed by CT4 site ( $234 \pm 19.0$   $\mu\text{g/L}$ ) of the Chittagong coast. During our sampling period we observed huge amount of Cr was used in stainless steel for polished silvery mirror coating, chrome plating, metal ceramics, shiny finish in dyes and paints, and leather tanning in the ship breaking area of the Chittagong coast. In the natural water systems virtually all chromium ore is processed via hexavalent chromium, specifically the salt sodium dichromate which is toxic and in higher concentration to be carcinogenic (ATSDR 1998; Ustaoglu and Tepe 2019; Ustaoglu 2021; Tokatlı and Ustaoglu 2020; Islam 2021). The mean concentration of Cr in waters of the Bay of Bengal coast was far higher than the drinking water quality criteria and freshwater quality criteria for the protection of aquatic life (USEPA 2020 a,b; Ustaoglu et al. 2020a, b) (Table 3). Nickel has been reported to be associated with the effluents from electroplating, breakdown of old batteries, land disposals, sewage sludge, paint and dyes, effluents from crude oil transportations, fertilizers application, and vehicular emissions (Popoola et al. 2015; Tokatlı 2017, 2019, 2021; Aydin

**Table 2** Heavy metals concentration (µg/L) in water sample collected from the coastal sea and estuarine areas of Bangladesh (mean±SD, from each station, n=3)

Sampling sites	site	Cr	Ni	Cu	As	Cd	Pb	Fe	Mn	Zn
Cox's Bazar Coast	CX1	132±20.7	35.4±1.6	337±8.3	73.0±20.1	41.8±5.8	89.7±15.8	694±48.5	187±15.5	353±6.1
	CX2	132±10.4	49.9±3.1	358±31.2	92.5±28.4	45.0±9.0	104±6.6	823±77.6	175±14.0	256±7.4
	CX3	128±9.6	28.2±12.1	159±25.9	61.5±21.9	39.3±5.1	18.8±6.1	820±236	226±10.6	174±32.9
	CX4	130±2.1	42.3±2.4	143±21.0	69.4±13.3	34.7±7.5	21.5±4.3	568±44.0	195±27.5	139±20.0
Chittagong Coast	CT1	219±15.6	39.0±1.1	257±28.0	76.7±19.3	31.3±21.2	80.8±15.8	1084±75.8	195±64.6	169±56.9
	CT2	224±15.3	62.2±6.0	300±46.9	116±4.7	31.3±23.1	94.7±7.4	1194±63.6	177±15.5	166±49.1
	CT3	257±35.5	50.8±5.0	280±27.0	119±11.3	63.8±7.5	109±10.4	1189±123	185±14.4	380±34.0
	CT4	234±19.0	45.0±5.6	317±31.7	138±5.6	70.7±11.1	114±9.2	1328±283	259±25.1	443±8.5
Meghna Estuary	ME1	83.0±1.0	33.9±4.4	101±7.9	55.1±3.6	17.0±10.7	50.4±19.0	695±145	141±22.1	143±4.0
	ME2	109±27.7	35.4±2.2	68.2±0.75	45.5±18.4	8.2±0.89	37.9±19.1	566±21.7	162±5.7	166±45.7
	ME3	133±10.4	38.6±1.0	53.5±4.1	33.2±6.2	4.9±3.7	52.7±4.7	520±71.2	142±20.6	160±28.7
Sundarbans	SN1	82.0±3.6	28.9±4.4	71.8±20.5	62.4±12.7	15.1±1.6	43.1±12.4	867±33.6	116±16.1	159±12.4
	SN2	104±9.0	33.5±3.7	97.3±12.8	66.8±4.7	19.9±1.3	57.0±5.5	910±46.5	141±4.0	151±18.8
	SN3	136±19.3	33.9±9.9	63.6±20.5	74.1±17.1	34.3±8.4	61.3±7.5	943±64.9	188±24.0	245±2.1

et al. 2021). At the Cox's Bazar Coast, the mean±SD concentration of Ni was observed as 35.4±1.6, 49.9±3.1, 28.2±12.1, and 42.3±2.4 µg/L for CX1, CX2, CX3, and CX4,

respectively; in the Chittagong Coast, Ni was observed as 39.0±1.1, 62.2±6.0, 50.8±5.0, and 45.0±5.6 µg/L for CT1, CT2, CT3, and CT4, respectively; in the Meghna Estuary,

**Table 3** Comparison of heavy metals concentration (µg/L) in water samples of this study with other reservoir and international guidelines value

Locations	Cr	Ni	Cu	As	Cd	Pb	Fe	Mn	Zn	References
Coastal sea area, Bangladesh										
Cox's Bazar Coast	130.4	39.0	249.5	74.1	40.2	58.4	726.2	195.8	230.8	This study
Chittagong,	233.6	49.3	288.3	112.3	49.3	99.6	1198.6	203.8	289.7	This study
Meghna Estuary	108.6	36.0	74.3	44.6	10.0	47.0	593.3	148.2	156.6	This study
Sundarbans	107.2	34.1	77.6	67.8	23.1	53.8	906.8	148.4	185.1	This study
Freshwater quality criteria for protection of aquatic life										
USEPA, CMC, acute	0.016	470	NA	0.34	0.0018	0.082	NA	NA	0.12	USEPA 2020a
USEPA, CMC, chronic	0.011	52	NA	0.15	0.00072	0.0032	NA	NA	0.12	USEPA 2020a
Drinking water quality criteria										
DWSB	0.05	100	1	0.05	0.005	0.05	0.3-1.0	0.1	5	DoE 1997
European Community	0.05	20	2	0.01	0.005	0.01	0.2	0.05	NA	EC 1998
WHO	0.05	70	2	0.01	0.003	0.01	NA	0.5	3	WHO 2011
USEPA (MCLG)	0.1	NA	1.3	0	0.005	0	NA	NA	NA	USEPA 2020b
USEPA (MCL)	0.1	NA	NA	0.01	0.005	0.015	NA	NA	NA	USEPA 2020b
Danjiangkou Reservoir, China	0.0063	NA	0.0133	0.0111	0.0117	0.0106	0.0191	0.00569	0.00202	Li et al. 2008
Three Gorges Reservoir, China	NA	NA	0.00894	0.00233	0.00102	0.01121	NA	NA	0.01304	Gao et al. 2016
Chah nimeh reservoir, Iran	0.0624	NA	0.0225	0.0095	0.0106	0.0291	0.312	NA		Rajaei et al. 2012
Catalan River, Spain	2.4	2.7	1.3	2.9	1.2	2.2		NA	1.9	Carafa et al. 2011
Hawkesbury-Nepean River, Australia	NA	0.26	0.81	NA	0.045	0.111	268	52	0.88	Markich and Brown 1998
Trinity River, USA	NA	2.07	1.15	NA	0.008	0.026	5.8	4.15	NA	Warnken and Santschi 2009

Ni was observed as  $33.9\pm 4.4$ ,  $35.4\pm 2.2$  and  $38.6\pm 1.0$   $\mu\text{g/L}$  for ME1, ME2, and ME3, respectively and in the Sundarbans, Ni was observed as  $28.9\pm 4.4$ ,  $33.5\pm 3.7$ , and  $33.9\pm 9.9$   $\mu\text{g/L}$  for SN1, SN2, and SN3, respectively (Table 2). Nickel values at all the sampling sites in water samples are below the maximum limit of 470  $\mu\text{g/L}$  (acute) and 52  $\mu\text{g/L}$  (chronic) as prescribed by (USEPA 2020a, b) (Table 3). In water samples, Ni showed a significant positive correlation with other metal except Zn and Mn (Table 4).

Copper is a very common element that occurs naturally but Cu in the aqueous systems received attention mostly because of its toxic effects on biota. In water, even at very low concentrations, Cu can be toxic. It is known to cause brain damage in mammals (Fatoki et al. 2002; Ustaoğlu and Aydın 2020). The descending order of mean Cu concentration ( $\mu\text{g/L}$ ) in the sampling sites were of CX2 (358) > CX1 (337) > CT4 (317) > CT2 (300) > CT3 (280) > CT1 (257) > CX3 (159) > CX4 (143) > ME1 (101) > SN2 (97.3) > SN1 (71.8) > ME2 (68.2) > SN3 (63.6) > ME3 (53.5). Among the four sampling sites, elevated level of Cu was observed at the Cox's Bazar Coast and the Chittagong Coast which might be due to the effects from hatchery operation, electrical, and metal processing, antifouling paints in the marine environment, used as coatings for ships, buoys, underwater, and decking pollutants (Raknuzzaman et al. 2016). During the sampling campaign, we observed that the local peoples are commonly used form as copper sulfate, which is available either as a crystal or a powder often known as "Bluestone" or "Blue powder" (Watson and Yanong 1989; Shamsuzzaman and Biswas 2012).

Arsenic is a ubiquitous element in the environment and is mobilized through a combination of natural processes such as weathering reactions, biological activity, and volcanic emissions. In the natural environment, As can occur in several oxidation states (-3, 0, +3, and +5) but in the natural water systems it is mostly found in inorganic form as oxyanions of trivalent arsenite [As(III)] or pentavalent arsenate (As(V)). Among fourteen sampling points of four coastal sites, elevated levels of As was observed at three stations of Chittagong sea port area like CT2 ( $116\pm 4.7$   $\mu\text{g/L}$ ), CT3 ( $119\pm 11.3$   $\mu\text{g/L}$ ), and CT4 ( $138\pm 5.6$   $\mu\text{g/L}$ ), respectively). During sampling campaign, we observed the movement ships for loading and unloading of containers, huge application of arsenical pesticides for crop production besides the Chittagong sea port connecting Karnaphuli River (Shao et al. 2016), used chromated copper arsenate (CCA) for wood treatments to protect from rotting due to insects and microbial agents (Pravin et al. 2012; Islam 2021) and arsenic (III) sulfide to make infrared-transmitting glass, pigments, electrical semiconductors, and tanning agents (Bhuiyan et al. 2011; Aydın et al. 2021) at the Chittagong sea port area. The concentration of As in water samples of the Bengal coast was higher than the freshwater and drinking water quality criteria (USEPA 2020

a,b) (Table 3) indicating As in water may create ecological and health risks to the entire coastal ecosystems of the Bay of Bengal.

Cadmium (Cd) is used in phosphate fertilizers, in PVC products, nickel-cadmium rechargeable battery and pigment alloys which are not recycled but discarded along with household waste, and create deleterious effect on the aquatic organisms and human health (Ekere et al. 2014). It has been established that chronic renal failure is associated with Cd exposure (Hellstrom et al. 2001). The descending order of Cd concentration ( $\mu\text{g/L}$ ) in the sampling sites were of CT4 (70.7) > CT3 (63.8) > CX2 (45.0) > CX1 (41.8) > CX3 (39.3) > CX4 (34.7) > SN3 (34.3) > CT1 (31.3) > CT2 (31.3) > SN2 (19.9) > ME1 (17.0) > SN1 (15.1) > ME2 (8.2) > ME3 (4.9). Among the four sites, elevated level of Cd was observed at the Cox's Bazar Coast and the Chittagong Coast which might be due to the effects from different electroplating industries, ship repairing, and battery dumping. Besides, weathering of rocks, manures, municipal sewage sludge, fossil fuel combustion, artificial phosphate fertilizers, and pesticides as  $\text{CdSO}_4$  also contribute significant amount of Cd in this area (Sheppard et al. 2009; Raknuzzaman et al. 2016).

Lead is a nonessential component for plants and animals and it is often an accumulative poison for the living organisms. It has been a potentially hazardous to most forms of life (USEPA 1986). However, in the water systems, Pb can be carried either dissolved or as waterborne particles where a few Pb compounds dissolve readily in water, though a significant amount is then precipitated and becomes incorporated into sediments at the base of the watercourse. Among the sampling sites, the highest mean $\pm$ SD concentration of Pb ( $114\pm 9.2$   $\mu\text{g/L}$ ) was observed in water samples of the Chittagong Coast (CT4 site) followed by CT3 site ( $109\pm 10.4$   $\mu\text{g/L}$ ) (Table 2). The high concentration of Pb in the Chittagong Coast site might be attributed to the acid drainage from the industrial wastes and different chemical activities of hatcheries, fish processing, paint, and ship repairing industries.

Iron, Mn, and Zn are the essential micronutrient for most living organisms and human beings. Among them Fe is a constituent of proteins and many enzymes, including hemoglobin and myoglobin. These essential elements are typically more common in the marine environment than other metals due to its high prevalence on Earth (Edokpayi et al. 2016). The highest mean $\pm$ SD concentration of Fe ( $1328\pm 283$   $\mu\text{g/L}$ ) was observed in water samples of the Chittagong Coast (CT4 site) followed by CT2 site ( $1194\pm 63.6$   $\mu\text{g/L}$ ); for Mn was ( $259\pm 25.1$   $\mu\text{g/L}$ ) at (CT4 site) followed by CX3 site ( $226\pm 10.6$   $\mu\text{g/L}$ ), and for Zn was ( $443\pm 8.5$   $\mu\text{g/L}$ ) at (CT4 site) followed by CT3 site ( $380\pm 34.0$   $\mu\text{g/L}$ ) (Table 2). During our sampling campaign, we observed huge tourist presence in this town with longest sandy sea beach, 53 fish hatcheries operation, a fish landing center, activities from ship and boat making



**Table 4** Pearson correlation for physicochemical parameters and heavy metals at the surface water collected from the coastal and estuarine areas of Bangladesh

Parameters	Temperature	pH	EC	DO	Turbidity	fluoride	Chloride	Sulphate	Nitrate	Phosphate	Cr	Ni	Cu	As	Cd	Pb	Fe	Mn	Zn		
Temperature	1																				
pH	-0.113	1																			
EC	0.137	0.045	1																		
DO	0.061	0.008	0.148	1																	
Turbidity	-0.18	0.192	-0.861**	-0.069	1																
Fluoride	0.284	0.061	0.864**	0.168	-0.803**	1															
Chloride	0.206	0.17	0.888**	0.101	-0.807**	0.857**	1														
Sulphate	0.165	0.198	0.767**	0.113	-0.666**	0.777**	0.890**	1													
Nitrate	0.303	0.057	0.018	-0.01	0.026	-0.042	-0.058	-0.074	1												
Phosphate	0.424**	-0.042	0.112	0.095	-0.076	0.109	0.064	0.052	0.28	1											
Cr	0.371*	-0.481**	0.066	0.184	-0.097	0.011	-0.207	-0.192	0.462**	0.415**	1										
Ni	0.205	-0.285	0.168	0.078	-0.197	0.054	0.005	-0.092	0.314*	0.521**	0.611**	1									
Cu	0.381*	0.029	0.269	0.262	-0.068	0.227	0.121	0.137	0.585**	0.526**	0.629**	0.528**	1								
As	0.23	-0.148	-0.076	0.179	0.21	-0.146	-0.341*	-0.334*	0.536**	0.425**	0.708**	0.553**	0.697**	1							
Cd	0.381*	-0.046	0.174	0.237	-0.041	0.09	-0.045	-0.016	0.3	0.19	0.616**	0.359*	0.638**	0.669**	1						
Pb	0.216	0.036	0.106	0.232	0.062	0.081	-0.13	-0.087	0.476**	0.339*	0.668**	0.585**	0.756**	0.654**	0.591**	1					
Fe	0.22	-0.278	-0.201	0.19	0.275	-0.181	-0.461**	-0.476**	0.385*	0.258	0.699**	0.429**	0.478**	0.777**	0.563**	0.618**	1				
Mn	0.268	-0.124	0.156	0.136	-0.112	0.074	0.02	0.005	0.497**	0.047	0.503**	0.207	0.451**	0.459**	0.642**	0.294	0.356*	1			
Zn	0.089	0.143	0.081	0.221	0.142	-0.038	-0.125	-0.002	0.433**	0.126	0.547**	0.244	0.613**	0.641**	0.744**	0.692**	0.499**	0.510**	1		

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

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

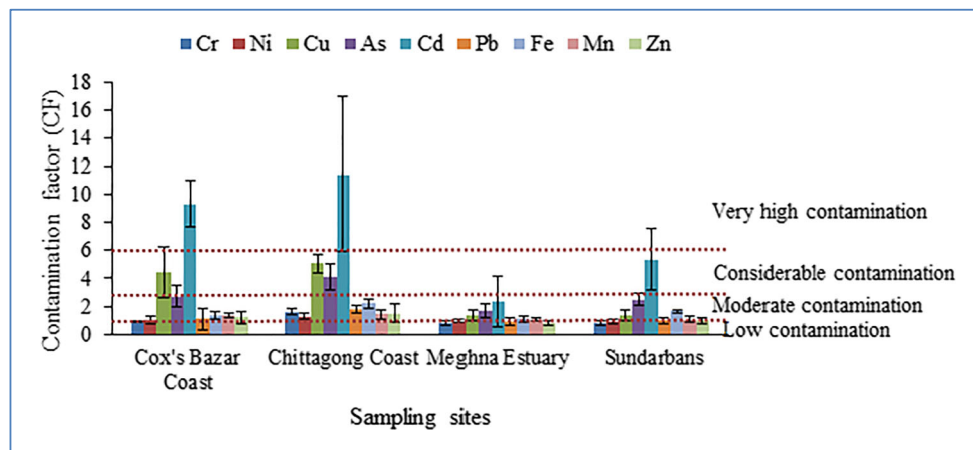
industries, paint industries, salt industries, fish processing, unplanned urbanization, and many hotels at the coast of Chittagong and Cox's Bazar. Therefore, elevated levels of the studied heavy metals were observed in these areas.

The observed concentrations of all studied heavy metals in surface waters from the coast and estuaries of the Bay of Bengal were much higher than the guideline values for freshwater quality criteria (DoE 1997; EC 1998; WHO 2011; USEPA 2020a, b) (Table 3) indicated that the waters of the Bengal coast may create health hazard. Apart from freshwater quality criteria, the mean concentrations of heavy metals in water samples were much higher than the USEPA maximum contaminant level (MCL) and maximum contaminant level goal (MCLG) (Table 3), indicated that waters from the Bay of Bengal coast might pose potential threats to the surrounding coastal ecosystems.

### Pollution assessment of heavy metal in surface water

Contamination factor (CF), pollution load index (PLI), Nemerow's pollution index (NPI), degree of contamination ( $C_d$ ), and modified degree of contamination ( $mC_d$ ) of the study area is shown in Figs. 2 and 3. At the Cox's Bazar coast, the mean values of CF in waters were 0.90, 1.01, 4.42, 2.70, 9.35, 1.06, 1.32, 1.36, and 1.20 for Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn, respectively. At the Chittagong coast, CF values were 1.61, 1.27, 5.10, 4.10, 11.5, 1.81, 2.17, 1.42, and 1.50 for Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn, respectively. At the Meghna estuary, the CF values were 0.75, 0.93, 1.31, 1.63, 2.34, 0.85, 1.07, 1.03, and 0.81 for Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn, respectively and at the Sundarbans area, the mean values of CF were 0.74, 0.88, 1.37, 2.47, 5.37, 0.98, 1.364, 1.03, and 0.96 for Cr, Ni, Cu, As, Cd, Pb, Fe, Mn, and Zn, respectively. Following the Hakanson (1980) classification scheme, the heavy metals ranged from low to very high contamination, with Cd showed very high contamination class for the coast of Chittagong and Cox's Bazar ( $CF > 6.0$ ), while other elements recorded low to moderate contamination level

**Fig. 2.** Contamination factor (CF) of heavy metal in water samples collected from the coastal sea and estuarine area in Bangladesh. Horizontal dot lines indicate the standard limit of contamination level

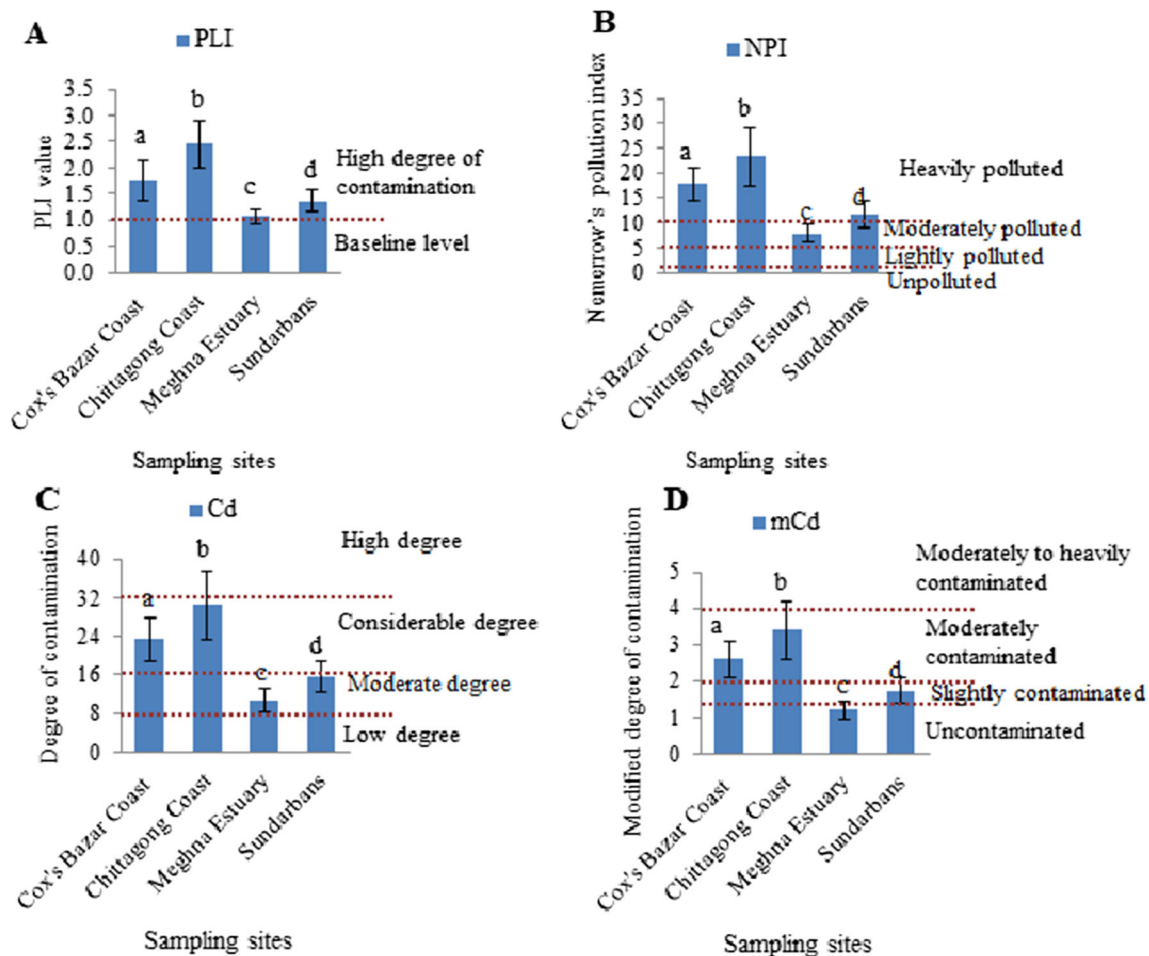


(Fig. 2). High CF value for Cd for the coasts of Chittagong and Cox's Bazar could be due to heavy dredging activities, sea port activities, marine debris, and construction of dredgers at the shore sites.

The calculated pollution load index (PLI) values of heavy metals in water presented in Fig. 3A. The PLI values were ranged from 0.85 to 2.96 that the water of the studied coastal area was base line level to the high degree of pollution ( $PLI > 1$ ). Elevated levels of PLI were observed in three sampling sites of the Cox's Bazar coast, Chittagong coast, and Sundarbans Fig. 3A which might be attributed to the discharge of different salts and chemicals from hatcheries, fish processing industries, ship breaking activities, and some aqua farms through their underground pipeline outlets to the sea without treatment at these sites (Raknuzzaman et al. 2016; Bristi et al. 2021), vehicle and sugarcane farming activities at these sites. The mean values of Nemerow's pollution index (NPI) of the study area were 17.8, 23.2, 7.8, and 11.6 for the Cox's Bazar coast, Chittagong coast, Meghna Estuary, and Sundarbans, indicated moderately to heavily polluted water (Fig. 3B). For computing  $C_d$   $mC_d$  (Table S3), the guideline values of heavy metals can be suggested on the basis of various standard values. For evaluating the level of heavy metals contamination  $mC_d$  was used which revealed that because of examining the contamination by heavy metals using the  $mC_d$ , three studied sites contained waters that surpassed the contamination threshold limit ( $mC_d=1.5$ ). The sites including Cox's Bazar coast (2.6), Chittagong coast (3.4), and Sundarbans (1.7) sites were evaluated as contaminated (Fig. 3D). The  $C_d$  value of heavy metals showed moderate to considerable degree of contamination (Fig. 3C). The descending order of the pollution status of the study area is in the order of Chittagong coast > Cox's Bazar coast > Sundarbans > Meghna Estuary.

### Source analysis of heavy metals

After acquiring the dataset based on centered log-transformed algorithm, Spearman correlation and Principal component



**Fig. 3.** Distribution of risk index value; **A** Pollution load index (PLI), **B** Nemerow's pollution index (NPI), **C** Degree of contamination (Cd) and **D** Modified degree of contamination (mCd) due to heavy metal

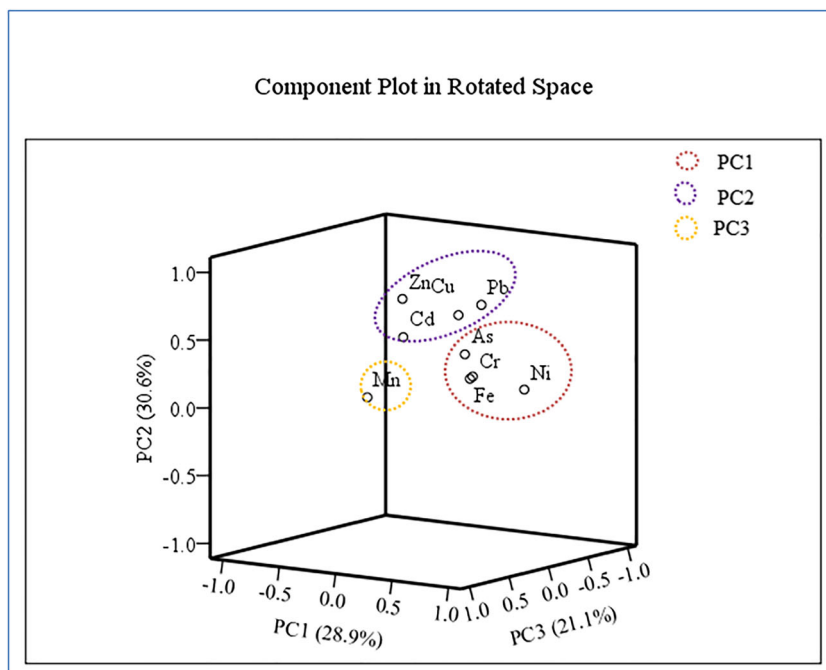
analysis (PCA) were adopted to elucidate the inter-elements association, Euclidean differences, and possible sources concerning the geochemical relationship of studied heavy metals in surface water samples of the Bengal coast, Bangladesh. With the communality method Varimax rotation was coupled which was employed to confirm the PCA to get a basic expression of the heavy metals except changing the coordinate system of the elements. Three principal components (PCs) were extracted from 9 elements in water samples and the three PCs together contributed 80.7% of the total variance. In surface waters for Rotated Component Matrix, As, Fe, Cr, and Ni had high loadings in PC1, and can explain 28.9% of the variance (Fig. 4 and Table S4). Iron is typically more common in the marine environment than other metals due to its high prevalence on Earth (Edokpayi et al. 2016; Wang et al. 2017). The weathering of calcite and chlorite in loess can provide an amount of Fe to the surface water of the coastal sea and estuaries (Yokoo et al. 2004). Application of arsenic-based pesticides/herbicides during agricultural activities, different industrial activities of stainless steel, ship breaking and repairing, rechargeable batteries, metal ceramics, dyeing, and

contamination in water collected from the coastal sea and estuarine areas in Bangladesh. Horizontal dot lines indicate the level of contamination for different risk index

leather industries, plating and gas turbine factories, export import zones in the Chittagong and Mongla port areas (Wang et al. 2019).

Principal component 2 (PC2) explained about 30.6% of the total variance with the factor loadings of Zn, Cu, Pb, and Cd which were mainly from anthropogenic input such as industry effluents and domestic sewage (Islam et al. 2015, 2018). The source identification of the present study findings are consistent with previous study by Genthe et al. (2013) where industries like textiles effluents have been identified as prime sources of metallic components (i.e., Cd, Cu, Pb, and Zn) either as suspended or dissolved forms in the natural water. Furthermore, another study by Kibria et al. (2012), applied laboratory prepared synthetic mussels for the detection of heavy metals in the natural waters and found that industrial and agricultural/aquaculture discharges are potential source for higher levels of Cd, Cu, and Pb (Emenike et al. 2020; Islam et al. 2020). Principal component 3 (PC3) explained about 21.1% of the total variance with the loadings of Mn (Fig. 4) which was mainly from the breakdown of parent material through weathering and pedogenic processes. In the

**Fig. 4.** Principal Component Analysis (PCA) of heavy metals in surface water collected from the coastal sea and estuarine areas in Bangladesh



natural water systems, Fe and Mn may be released via the reductive dissolution and precipitation of Fe-Mn-Oxyhydroxide and releases Fe and Mn contents from pyroclastic sediments (Kumar et al. 2016; Islam et al. 2017). This suggests that changes in pH and redox state may cause by seasonal groundwater level fluctuations dissolve Mn complexes and release arsenic adsorbed on them into ground and surface water (Gan et al. 2014; Díaz et al. 2016).

## Conclusions

In this study, base line information, identification of source and mobilization mechanisms of physicochemical parameters and heavy metals in surface waters from the Bengal coast of Bangladesh were determined. Among the fourteen sampling sites of the Bengal coast, ship breaking, and sea port areas of Chittagong and hatchery site of Cox's Bazaar were severely polluted where elevated concentrations of Cu, As, Cd, and Pb were observed. The concentrations of physicochemical parameters such as EC, DO, turbidity,  $\text{F}^-$ ,  $\text{Cl}^-$ , and  $\text{PO}_4^{3-}$  and heavy metals were higher than the safe recommended values, which suggested that waters of the Bengal coast are polluted by heavy metals and might create an adverse effect on these coastal ecosystems. The CF, PLI, NPI,  $C_d$ , and  $mC_d$  established that the surficial waters were polluted by heavy metals to different levels. PCA showed that essential and toxic elements originated from both anthropogenic and natural sources. This study suggests that integrated aspects could be explored in the future, for instance, the identification of heavy metals in the aquatic water bodies and their distribution and

how they contribute to accumulate in the human body through different exposure pathways.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s11356-021-15353-9>.

**Acknowledgements** The author is thankful to the authority of Patuakhali Science and Technology University (PSTU), Dumki, Patuakhali-8602, Bangladesh for sample collection and processing and the University of Tokyo, Japan for sample analysis.

**Author contribution** Md. Saiful Islam and Mir M. Ali collected water samples from the coastal area of Bangladesh. Md. Saiful Islam and Abu Reza Md. Towfiqul Islam designed the total experiment. Abubakr Mustafa Idris and Md. Saiful Islam analyzed the data. Md. Saiful Islam and Md. Refat Jahan Rakib wrote, revised, and improved the manuscript. All authors reviewed and approved this manuscript.

**Funding** The authors extend their appreciation to the Deanship of Scientific Research at King Khalid University for funding this work through Group Research Project under grant number (R.G.P2/114/41).

**Data availability** Not applicable.

## Declarations

**Ethical approval** Not applicable.

**Consent to participate** Not applicable.

**Consent to publish** Not applicable.

**Conflict of interest** The authors declare no conflict of interest.

## References

- Abraham G, Parker R (2008) Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. *Environ Monit Assess* 136(1–3):227–238
- Aderinola OJ, Clarke EO, Olanrinmoye OM, Kusemiju V, Anatekhaiand MA (2009) Heavy metals in surface water, sediments, fish and periwinkles of lagos lagoon. *American-Eurasian J Agric Environ Sci* 5(5):609–617
- Ali A, Serkan S, Dilek F, Ufuk A, Bayram Z, Muhammed BK (2013) Physico-Chemical Characteristics and Nutrient Levels of the Eastern Black Sea Rivers. *Turkish J Fisheries Aquat Sci* 13:847–859
- Al-Mamun MH, Ahmed MK, Islam MS, Tokumura M, Masunaga S (2019) Occurrence, distribution and possible sources of polychlorinated biphenyls (PCBs) in the surface water from the Bay of Bengal coast of Bangladesh. *Ecotoxicol Environ Saf* 167:450–458
- American Public Health Association (APHA) (2005) Standard methods for examination of water and wastewater, 21st edn. APHA, AWWA, WPCF, Washington
- ATSDR (1998) Toxicological Profile for Chromium. Agency for Toxic Substances and Disease Registry. U.S. Department of Health and Human Services, Atlanta
- Aydm H, Ustaoglu F, Tepe Y, Soylu EN (2021) Assessment of water quality of streams in northeast Turkey by water quality index and multiple statistical methods. *Environ Foren* 22(1-2):270–287
- Balogun KJ, Ajani EK (2015) Spatial and temporal variations of phytoplankton pigments, nutrients and primary productivity in water column of Badagry Creek, Nigeria. *American J Res Commun* 3(7):157172
- Bhuiyan MAH, Suruvi NI, Dampare SB, Islam MA, Quraishi SB, Ganyaglo S, Suzuki S (2011) Investigation of the possible sources of heavy metal contamination in lagoon and canal water in the tannery industrial area in Dhaka, Bangladesh. *Environ Monit Assess* 175:633–649
- Bristi MS, Sarker KK, Baki MA, Quraishi SB, Hossain MM, Islam A, Khan MF (2021) Health risk estimation of metals bioaccumulated in commercial fish from coastal areas and rivers in Bangladesh. *Environ Toxicol Pharmacol* 86:103666–103676
- Bytyci P, Fetoshi O, Durmishi B, Etemi FZ, Cadraku H, Ismaili M, Abazi AS (2018) Status assessment of heavy metals in water of the Lepenci River Basin. *J Ecol Engin* 19:19–32
- Carafa R, Faggiano L, Real M, Munné A, Ginebreda A, Guasch H, Flo M, Tirapu L, Carsten von der Ohe P (2011) Water toxicity assessment and spatial pollution patterns identification in a Mediterranean River Basin District. Tools for water management and risk analysis. *Sci Total Environ* 409:4269–4279
- Chapman D (1996) Water quality assessments—a guide to use of biota, sediments and water in environmental monitoring, E and FN Spon. Great Britain at the University Press, Cambridge
- Chowdhury S, Annabelle K, Klaus FZ (2015) Arsenic contamination of drinking water and mental health. 1-28
- Dan SF, Umoh UU, Osabor VN (2014) Seasonal variation of enrichment and contamination of heavy metals in the surface water of Qua Iboe river estuary and adjoining creeks, South-South Nigeria. *J Oceanogr Mar Sci* 5(6):45–54
- Diaz SL, Espósito ME, del Carmen BM, Amiotti NM, Schmidt ES, Sequeira ME, Paoloni JD, Nicolli HB (2016) Control factors of the spatial distribution of arsenic and other associated elements in loess soils and waters of the southern Pampa (Argentina). *Catena* 140:205–216
- DoE (Department of Environment, Government of the People’s Republic of Bangladesh) (1997) ECR (The Environment Conservation Rules). Poribesh Bhaban E-16, Agargaon, Shere Bangla Nagar Dhaka 1207, Bangladesh. pp. 179–226
- EC (1998) The quality of water intended to human consumption, Directive 1998/83/EC, Official Journal L330/05.12.1998, European Community. 32–54
- Edokpayi JN, Odiyo JO, Popoola OE, Msagati TAM (2016) Assessment of Trace Metals Contamination of Surface Water and Sediment: A Case Study of Mvudi River, South Africa. *Sustainability* 8(135):1–13
- Ekere NR, Ihedioha JN, Eze IS, Agbazue VE (2014) Health risk assessment in relation to heavy metals in water sources in rural regions of South East Nigeria. *Int J Phys Sci* 9(6):109–116
- Emenike PC, Tenebe IT, Neris JB, Omole DO, Afolayan O, Okeke CU, Emenike IK (2020) An integrated assessment of land-use change impact, seasonal variation of pollution indices and human health risk of selected toxic elements in sediments of River Atuwara, Nigeria. *Environ Pollut* 265:114795. <https://doi.org/10.1016/j.envpol.2020.114795>
- Fabunmi I, Kunbi F, Paul UJ, Samuel P, Opeyemi O, Chidinma N (2015) On the physico-chemistry and nutrient profile in the lagos harbor. *J Sci Res Rep* 8(4):1–13
- Fatoki OS, Lujiza N, Ogunfowokan AO (2002) Trace metal pollution in Umtata, River. *Water SA* 28(2):183–189
- Federal Environmental Protection Agency (FEPA) Act (1991) Guidelines and standard for Industrial effluent gaseous emissions and hazardous waste management in Nigeria. National Environmental Protection Regulations, Federal Republic of Nigeria Supplement to Gazette Extraordinary- Part B 78(42):15–31
- Gan Y, Wang Y, Duan Y, Deng Y, Guo X, Ding X (2014) Hydrogeochemistry and arsenic contamination of groundwater in the Jiangnan Plain, central China. *J Geochem Explor* 138:81–93
- Gao Q, Li Y, Cheng Q, Yu M, Hu B, Wang Z, Yu Z (2016) Analysis and assessment of the nutrients, biochemical indexes and heavy metals in the Three Gorges Reservoir, China, from 2008 to 2013. *Water Res* 92:262–274
- Genthe B, Le Roux WJ, Schachtschneider K, Oberholster PJ, Aneck-Hahn NH, Chamier J (2013) Health risk implications from simultaneous exposure to multiple environmental contaminants. *Ecotox Environ Safe* 93:171–179
- Govindasamy C, Kannan L, Azariah J (2000) Seasonal variation in physicochemical properties and primary production in the coastal water biotopes of Coromandel coast, India. *J Environ Biol* 21:1–7
- Hakanson L (1980) An ecological risk index for aquatic pollution control—a sedimentological approach. *Water Res* 14(8):975–1001
- Hellstrom L, Elinder CG, Dahlberg B (2001) Cadmium Exposure and end-stage renal disease. *Am J Kidney Dis* 3:10011008
- Islam MS (2021) Preliminary assessment of trace elements in surface and deep waters of an urban river (Korotoa) in Bangladesh and associated health risk. *Environ Sci Pollut Res* 28:29287–29303. <https://doi.org/10.1007/s11356-021-12541-5>
- Islam MS, Han S, Ahmed MK, Masunaga S (2014) Assessment of trace metal contamination in water and sediment of some rivers in Bangladesh. *J Water Environ Tech* 12:109–121
- Islam MS, Ahmed MK, Raknuzzaman M, Al-Mamun MH, Islam MK (2015) Heavy metal pollution in surface water and sediment: a preliminary assessment of an urban river in a developing country. *Ecol Indic* 48:281–292
- Islam ARMT, Ahmed N, Bodrud-Doza M, Chu RH (2017) Characterizing groundwater quality ranks for drinking purposes in Sylhet district, Bangladesh, using entropy method, spatial autocorrelation index, and geostatistics. *Environ Sci Pollut Res Int* 24:26350–26374
- Islam MS, Proshad R, Ahmed S (2018) Ecological risk of heavy metals in sediment of an urban river in Bangladesh. *Hum Ecol Risk Assess* 24:699–720

- Islam ARMT, Hasanuzzaman M, Islam HMT, Mia MU, Khan R, Habib MA, Rahman MM, Siddique MAB, Moniruzzaman M, Rashid MB (2020) Quantifying source apportionment, co-occurrence and ecotoxicological risk of metals from up-mid-downstream river segments. Bangladesh. *Environ Toxicol Chem* 39:2041–2054. <https://doi.org/10.1002/etc.4814>
- Kibria G, Lau TC, Wu R (2012) Innovative ‘artificial mussels’ technology for assessing spatial and temporal distribution of metals in Goulburn–Murray catchments waterways, Victoria, Australia: effects of climate variability (dry vs. wet years). *Environ Int* 50:38–46
- Kumar M, Rahman MM, Ramanathan AL, Naidu R (2016) Arsenic and other elements in drinking water and dietary components from the middle Gangetic plain of Bihar, India: health risk index. *Sci Total Environ* 539:125–134
- Li S, Xu Z, Cheng X, Zhang Q (2008) Dissolved trace elements and heavy metals in the Danjiangkou Reservoir, China. *Environ Geol* 55:977–983
- Markich SJ, Brown PL (1998) Relative importance of natural and anthropogenic influences on the fresh surface water chemistry of the Hawkesbury–Nepean River, south-eastern Australia. *Sci Total Environ* 217:201–230
- Mohamed HA (2005) Physico-chemical characteristics of Abu Za'baal ponds, Egypt. *Egypt J Aquat Res* 31(2):1–15
- Murhekar GH (2011) Determination of physico-chemical parameters of surface water samples in and around Akot City. *Int J Res Chem Environ* 1(2):183–187
- Nubi OA, Oyatola OO, Adeleke KG, Adekunbi FO (2019) Impact of human activities on heavy metals and physicochemistry of surface and groundwater quality in Ilaje community of Ondo State, Nigeria. *Nig J Pure Appl Sci* 32(2):3525–3537
- Okorafor KA, Effanga EO, Andem AB, George UU, Amos DI (2013) Spatial variation in physical and chemical parameters and macro-invertebrates in the intertidal regions of Calabar river, Nigeria. *Green J Geol Earth Sci* 1(2):063–072
- Onyema IC, Popoola RT (2013) The Physico-chemical characteristics, chlorophyll a levels and phytoplankton dynamics of the East mole area of the Lagos Harbour, Lagos. *J Asian Sci Res* 3(10):995–1010
- Parsons TR, Maita Y, Lalli CM (1984) A manual of chemical and biological methods for seawater analysis. Pergamon Press 173
- Pobi KK, Satpati S, Dutta S, Nayek S, Saha R, Gupta S (2019) Sources evaluation and ecological risk assessment of heavy metals accumulated within a natural stream of Durgapur industrial zone, India, by using multi-variate analysis and pollution indices. *Appl water sci* 9:1–16
- Popoola SO, Nubi OA, Oyatola OO, Adekunbi FO, Fabunmi GI, Nwoko CJ (2015) Vertical profiling and contamination risk assessment of some trace metals in Lagos Lagoon axis (2015). *Int J Sci Technol Soc* 3(4):186–193
- Pravin US, Trivedi P, Ravindra MM (2012) Sediment heavy metal contaminants in Vasai Creek of Mumbai: pollution impacts. *Am J Chem* 2:171–180
- Proshad R, Islam MS, Tusher TR, Zhang D, Khadka S, Gao J, Kundu S (2020) Appraisal of heavy metal toxicity in surface water with human health risk by a novel approach: a study on an urban river in vicinity to industrial areas of Bangladesh. *Toxin Rev*:1–17. <https://doi.org/10.1080/15569543.2020.1780615>
- Qu L, Huang H, Xia F, Liu Y, Dahlgren RA, Zhang M (2018) Risk analysis of heavy metal concentration in surface waters across the rural-urban interface of the Wen-Rui Tang River, China. *Environ Pollut* 237:639–649
- Rajaei G, Mansouri B, Jahantigh H, Hamidian AH (2012) Metal concentrations in the water of Chahnimeh reservoirs in Zabol, Iran. *Bull. Environ Contam Toxicol* 89:495–500
- Raknuzzaman M, Ahmed MK, Islam MS, Al-Mamun MH, Tokumura M, Sekine M, Masunaga S (2016) Assessment of trace metals in Surface Water and sediment collected from polluted coastal areas of Bangladesh. *J Water Environ Technol* 4:247–259
- Ramalingam M, Subramanian A, Ali AHMS (2011) Seasonal variations of physico-chemical properties of the great Vedaranyam swamp, point Calimere wildlife sanctuary, south-east coast of India. *African Journal of Environmental Science and Technology* 5(9):673–681
- Saleem M, Iqbal J, Shah MH (2019) Seasonal variations, risk assessment and multivariate analysis of trace metals in the freshwater reservoirs of Pakistan. *Chemosphere* 216:715–724
- Shamsuzzaman MM, Biswas TK (2012) Aqua chemicals in shrimp farm: a study from south-west coast of Bangladesh. *Egypt J Aquat Res* 38(4):275–285
- Shao D, Zhan Y, Zhou W, Zhu L (2016) Current status and temporal trend of heavy metals in farmland soil of the Yangtze River Delta Region: field survey and meta-analysis. *Environ Pollut* 219:329–336
- Sheppard SC, Grant CA, Sheppard MI, de Jong R, Long J (2009) Risk indicator for agricultural inputs of trace elements to Canadian soils. *J Environ Qual* 38(3):919–932
- Smith J, Burford MA, Revill AT, Haese RR, Fortune J (2012) Effect of nutrient loading on biogeochemical processes in tropical tidal creeks. *Biogeochem* 108:359–380
- Swamalatha K, Letha J, Ayoob S (2013) Ecological risk assessment of a tropical lake system. *J Urban Environ Engin* 7(2):323–329
- Tanjung RHR, Hamuna B, Alianto (2019) Assessment of Water Quality and Pollution Index in Coastal Waters of Mimika, Indonesia. *J Ecol Engin* 20(2):87–94
- Tokatlı C (2017) Bio – ecological and statistical risk assessment of toxic metals in sediments of a worldwide important wetland: Gala Lake National Park (Turkey). *Arch Environ Protec* 43(1):34–47
- Tokatlı C (2019) Drinking water quality assessment of Ergene River Basin (Turkey) by water quality index: essential and toxic elements. *Sains Malaysiana* 48(10):2071–2081
- Tokatlı C (2021) Health risk assessment of toxic metals in surface and groundwater resources of a significant agriculture and industry zone in Turkey. *Environ Earth Sci* 80:156
- Tokatlı C, Ustaoglu F (2020) Health risk assessment of toxicants in Meriç River Delta Wetland, Thrace Region, Turkey. *Environ Earth Sci* 79:426
- Tomlinson L, Wilson G, Harris R, Jeffrey DW (1980) Problems in the assessments of heavy-metal levels in estuaries and formation of a pollution index. *Helgol Meeresunters* 33:566–575
- USEPA (1986) Quality criteria for water. United States Environmental Protection Agency office of Water Regulations and Standards. DC, 20460
- USEPA (2020a) National Recommended Water Quality Criteria - Aquatic Life Criteria Table. <https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-lifecriteria-table#table>, Accessed date: 08 January 2021
- USEPA (2020b) National Primary Drinking Water Regulations. <https://www.epa.gov/groundwater-and-drinking-water/national-primary-drinking-water-regulations#Inorganic>, Accessed date: 08 January 2021
- Ustaoglu F (2021) Ecotoxicological risk assessment and source identification of heavy metals in the surface sediments of Çömlekci stream, Giresun, Turkey. *Environ Foren* 22(1-2):130–142
- Ustaoglu F, Aydın H (2020) Health risk assessment of dissolved heavy metals in surface water in a subtropical rivers basin system of Giresun (north-eastern Turkey). *Desal Water Treat* 194:222–234
- Ustaoglu F, Islam MS (2020) Potential toxic elements in sediment of some rivers at Giresun, Northeast Turkey: a preliminary assessment for ecotoxicological status and health risk. *Ecol Indic* 113:106237–106251
- Ustaoglu F, Tepe Y (2019) Water quality and sediment contamination assessment of Pazarsuyu Stream, Turkey using multivariate

- statistical methods and pollution indicators. *Int Soil Water Conser Res* 7(1):47–56
- Ustaoglu F, Tepe Y, Taş B (2020a) Assessment of stream quality and health risk in a subtropical Turkey river system: a combined approach using statistical analysis and water quality index. *Ecol Indic* 113:105815. <https://doi.org/10.1016/j.ecolind.2019.105815>
- Ustaoglu F, Tepe Y, Aydin H (2020b) Heavy metals in sediments of two nearby streams from Southeastern Black Sea coast: contamination and ecological risk assessment. *Environ Foren* 21(2):145–156
- Wang WX (2002) Interactions of trace metals and different marine food chains. *Mar Ecol Prog Ser* 243:295–309
- Wang J, Liu GJ, Liu HQ, Lam PKS (2017) Multivariate statistical evaluation of dissolved trace elements and a water quality assessment in the middle reaches of Huaihe River, Anhui, China. *Sci Total Environ* 583:421–431
- Wang X, Zhang L, Zhao Z, Cai Y (2018) Heavy metal pollution in reservoirs in the hilly area of southern China: distribution, source apportionment and health risk assessment. *Sci Total Environ* 634:158–169
- Wang L, Gao S, Yin X, Yu X, Luan L (2019) Arsenic accumulation, distribution and source analysis of rice in a typical growing area in north China. *Ecotox Environ Saf* 167:429–434
- Wamken KW, Santschi PH (2009) Delivery of trace metals (Al, Fe, Mn, V, Co, Ni, Cu, Cd, Ag, Pb) from the Trinity River Watershed towards the ocean. *Estuar Coasts* 32:158–172
- Watson C, Yanong RP (1989) Use of Copper in Freshwater Aquaculture and Farm Ponds. The Fisheries and Aquatic Sciences Department, UF/IFAS Extension, <http://edis.ifas.ufl.edu> [accessed in April 2021]
- Wetzel RG (2001) *Limnology: Lake and River Ecosystems*. Academic Press, San Diego
- WHO (1993) World Health Organization. Guidelines for drinking water quality, Geneva
- WHO (ed) (2007) World Health Organization, International Drinking Water Standards, 3rd edn. WHO, Geneva
- WHO (2011) Guidelines for drinking water quality, 4th edn. World Health Organization, Geneva
- Yingran L, Hongming Y, Sun Y, Chen J (2017) Novel assessment method of heavy metal pollution in surface water: a case study of Yangping River in Lingbao City, China. *Environ Eng Res* 22(1):31–39
- Yokoo Y, Nakano T, Nishikawa M, Quan H (2004) Mineralogical variation of Sr-Nd isotopic and elemental compositions in loess and desert sand from the central Loess Plateau in China as a provenance tracer of wet and dry deposition in the northwestern Pacific. *Chem Geol* 204:45–62
- Zaher D, Houda S, Habib A (2017) Spatial distribution and source identification of heavy metals in surface waters of three coastal areas of Tunisia. *Pol J Environ Stud* 26:1057–1069

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.