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Physicochemical Assessment of Surface and Groundwater Quality of the Greater Chittagong Region of Bangladesh

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Abstract

The study was carried out to assess surface and groundwater quality of the greater Chittagong (Chittagong and Cox's Bazar districts) and Chittagong Hill Tracts (Rangamati, Khagrachhari and Bandarban districts) of Bangladesh. To study the various physicochemical and microbiological parameters, surface water samples from the Karnafuli, Halda, Sangu, Matamuhuri, Bakkhali, Naf, Kasalong, Chingri and Mayani Rivers, Kaptai Lake and groundwater samples from almost every Upazilas, smaller administrative unit of Bangladesh, were collected and analyzed. The statistical methods of sampling were used for collecting samples. Samples were preserved using suitable preservation methods. Water samples from the freshwater resources were collected from different points and tide conditions and at different seasons for continuous monitoring during the hydrological years 2008-2009. The collected samples were analyzed for the following parameters: pH, electrical conductivity (EC), total dissolved solids (TDS), total suspended solids (TSS), total solids (TS), dissolved oxygen (DO), transparency, acidity, dissolved carbon dioxide, total alkalinity, total hardness, chloride, ammonia-N, hydrogen sulfide, sulphate-S, o-phosphate-P, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate-N, nitrite-N, total nitrite and nitrate-N, arsenic, iron, manganese, copper, nickel, chromium, cadmium, lead, calcium, magnesium, sodium and potassium using the procedure outlined in the standard methods. Average values of maximum physicochemical and microbiological parameters studied for the Karnafuli River were found higher than the World Health Organization (WHO) guideline. The maximum water quality parameters of Kaptai Lake and other Rivers of Chittagong region were existed within the permissible limits of WHO guideline. The data showed the water quality slightly differs in pre-monsoon and post-monsoon than monsoon season. The concentration of different constituents of most of the groundwater samples were within the permissible limits of BSTI drinking water quality guideline except As, Fe, and Mn. Results of water quality assessment identified the problem areas in respect of arsenic. The results also provided data to understand and quantify the threat of the impact of climate change on freshwater resources of this region. The results also provided data for water quality of surface and groundwater resources of Chittagong region to match national and international standards for drinking, agricultural, industrial and livestock requirements.

Keywords: Physicochemical assessment, Freshwater resources, Greater Chittagong region.

Introduction

Chittagong region consists of Chittagong, Cox's Bazar, Bandarban, Rangamati and Khagrachhari districts. This region is quite different from other parts of Bangladesh for its unique natural beauty

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characterized by hills, rivers, lakes, sea, forests and valleys. Main rivers of this region are the Karnafuli, Halda, Sangu, Matamuhuri, Bakkhali, Naf, Kasalong, Chingri, Mayani and Kaptai lake. The main seaport of Bangladesh is located at the estuary of the Karnafuli River. Chittagong is also called the commercial capital of Bangladesh. A large number of chemical and fertilizer industries have been established since the independence on both the banks of the Karnafuli. Effluents from these industries are reportedly being directly discharged into this river. Huge amount of solid wastes and effluents are discharged through Chaktai, Sundari, Noakhal, Mazirghat, Gupta, Mohesh, Shikalbhaha and Ferighat canals into the Karnafuli River; as a result pollution of this river is increasing day by day. Leaking and leaching of oil from ships and boats are also polluting the water of the Karnafuli River. Due to the climate change during flood, soil erosion and land slide increases the suspended solids, metallic and other pollutants. Halda, a tidal river, is the only natural breeding ground for carps of Bangladesh, affected by the polluted water of the Karnafuli river. Due to the sea level rise, during the dry season, sea water intrusion into the Halda, Karnafuli, Sangu and Naf rivers will destroy the biodiversity of these rivers for increasing salinity. Kaptai Lake is the largest artificial freshwater reservoir in Bangladesh. Though created for power generation, it contributes to produce significant quantity of freshwater fishes, navigation, flood control, household, agriculture etc. and thus water of this lake getting polluted. Boating activities for fishing and boat repairing activities may also cause the contamination; this phenomenon is also reported in literature for evaluation of pollution in other Lakes [1]. Heavy metal contamination in water is an increasing worldwide environmental concern. At present the underground water is not safe for drinking purpose because of arsenic contamination [2]. Degradation of water quality, depletion of water resources and loss of aquatic biodiversity are prominent features of the environmental landscape requiring urgent attention at global and national scales [3]. Therefore, physicochemical assessment and monitoring of surface and groundwater resources of this region using simple and rapid methods is of paramount importance.

Experimental section

Collection and preservation of samples

A survey work was conducted for the identification of sampling spots and the current quality conditions for a large part of the rivers, lakes and groundwater sources of the this region. Sampling spots were so selected that we get a clear picture of the water quality conditions of this region. For the Karnafuli River, seven sampling spots at different distances from the estuary were selected. These are Estuary, Cement factory gate, Sadarghat, Chaktai, Kalurghat, Chandraghona and Kaptai. For the Halda River, three sampling spots, Modunaghat, Sattarghat and Nazirhat at different distances were selected. Upstream samples of the Karnafuli River were collected at the intervals of 0, 17, 20, 23, 80 and 95 km from the estuary and for the Halda at the intervals of 23, 33 and 40 km from the estuary of the Karnafuli River. The Karnafuli and Halda River water samples were collected at high and low tide according to the tide table collected from the Department of Hydrography of Chittagong Port Authority. For Kaptai Lake two sampling stations, Rangamati and Kaptai, were selected. Sangu River samples were collected from Dohazari and Bandarban points. Samples of the Matamuhuri River were collected from Chakaria and Lama points. For other rivers such as Bakkhali, Naf, Kasalong and Chingri water samples were collected from Ramu, Tek Naf, Marisha and Khagrachhari points, respectively. Groundwater samples from almost every Upazilas of the five districts were collected. Samples were so collected that they represent the conditions existing at the sampling spot. The sampling spots were chosen carefully so that a representative sample of the water to be tested is obtained. Samples for different analytical purposes were collected in separate plastic container rinsed with concentrated nitric acid and distilled water and finally rinsed with the sample water to be collected. Statistical methods of sampling were used for collecting samples. Multiple samples were collected from the same spot at different tide conditions. The samples were also collected in different seasons to study the seasonal variation of the results. The surface water samples were collected in the boat if possible in the middle of the flow. Two to four sub samples of equal volume were collected from vertical section. The water

samples were collected within 3-9 inches from the surface of the water. Groundwater samples were collected from tube wells after discarding water for the first 2 minutes. The samples were mixed well and a sample of 1.0-1.5 L was transferred to an amber coloured clean plastic bottle for analysis in the laboratory. Samples were preserved using suitable preservation techniques [4, 5].

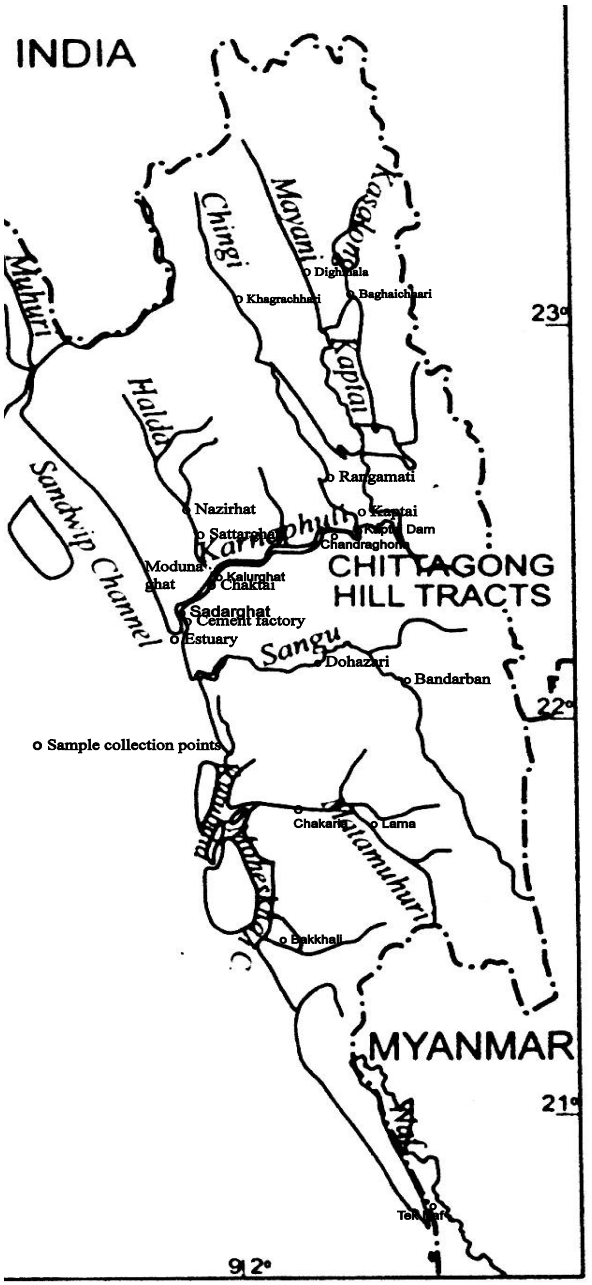

Figure 1. **Surface water sample collection points of the greater Chittagong region.**

Materials and Methods

Different water quality parameters were determined using the following methods

A glass thermometer was used for the measurement of temperature. Transparency was measured by Sacchi disc. pH, EC and TDS were measured at the sampling site by Hanna Combo meter, Model – HI 98129. TS and TSS were measured by drying and weighing method. Measurement of DO was done by Jenway 970 DO_2 meter at the sampling site. BOD was measured from the differences of initial and 5 day, DO by DO_2 meter. COD was determined by titrimetric method after 2 hours open reflux. Acidity and dissolved carbon dioxide were measured by titrimetric method using standard 0.02 M NaOH. Total and phenolphthalein alkalinity were measured by titrimetric method using phenolphthalein and methyl orange as indicators. Hardness was measured by complexometric titration method. Dissolved hydrogen sulphide was measured by iodimetric method using standard iodine solution [6]. Ammonia-N was measured by colorimetric nesslerization method after distillation of samples. Total nitrate and nitrite-N was measured by colorimetric nesslerization method after reducing samples by Deverda's alloy [7]. o-phosphate-P was measured by colorimetric vanadomolybdophosphoric acid method. Sulphate-S was measured by colorimetric barium chloride turbidimetric method. Nitrite-N was determined by colorimetric method after formation of a reddish purple azo dye produced at pH 2.0 to 2.5 by coupling diazotized sulfanilamide with N-(1-naphthyl)-ethylenediamine dihydrochloride (NED dihydrochloride). Nitrate-N was determined by colorimetric method in the ultraviolet range. Chloride was determined by argentometric method in a neutral or slightly alkaline solution using potassium chromate as indicator by standard silver nitrate as titer. Iron was determined by colorimetric method using 1,10-phenanthroline as chelating agent. Manganese was determined by colorimetric per-sulfate oxidation method. In colorimetric methods a Shimadzu, Model-1800 UV-Vis spectrophotometer was used. Zinc, copper, lead, cadmium, cobalt, nickel and chromium were determined by Varian Model-AA240FS fast sequential atomic absorption spectrophotometer (AAS). For the analysis of metals by UV-Visible

Spectrophotometry and atomic absorption spectrophotometry samples were digested according to the wet-digestion method [8]. Coli form was measured by MPN method [9]. Data were analysed by Excel 2000 software. SPSS 11.5 software was used for statistical analysis, such as, seasonal variation and Pearson correlation. Pearson correlation establishes relationship between the parameters of water quality i.e. whether a parameter increases or decreases with the increase and decrease of other parameters.

Reagents and solutions

All chemicals used were of analytical - reagent grade or the highest purity available. Doubly distilled de-ionized water was used throughout this study.

Results

The results of surface water resources are shown in Table 1 and 3 and seasonal variation shown in Table 2 and groundwater resources shown in Table 4. The results of Pearson Correlations among the different parameters of the Halda, Karnafuli River and groundwater are shown in Table 5, 6, 7, respectively.

Table 1. **Water quality of the Halda and Karnafuli river.**

Parameters	Halda		WHO Standard	Karnafuli	
	Present study	Previous study [10]		Present study	Previous Study [11]
Ambient temp/^{0}C	22.30-35.50	ND	-	18.25-35.00	ND
Water temp/^{0}C	20.30-36.10	22-30	-	19.50-34.30	ND
pH	7.03-8.60	5.65-7.34	NYS	6.36-9.86	7.01-8.24
EC./µScm^{-1}	72.00-414.00	ND	800-1000	90.00-45600.00	100-26150
TDS/mgL^{-1}	30.00-200.00	ND	--	45.00-20000.00	ND
TSS/mgL^{-1}	20.00-653.00	ND	--	14.40-5100.00	ND
TS/mgL^{-1}	100.00-740.00	ND	--	46.00-27700.00	ND
DO/mgL^{-1}	3.02-9.90	ND	4-6	0.00-7.91	3.20-7.20
Transparency/cm	8.00-39.00	ND	--	1.50-150.00	ND
Acidity/mgL^{-1}	2.12-35.36	ND	--	1.60-52.25	ND
CO_2/mgL^{-1}	1.87-16.61	ND	6	1.41-49.98	ND
P.alkalinity/mgL^{-1}	0.00	ND	--	0.00	ND
T.Alkalinity/mgL^{-1}	6.28-90.78	22-72	--	5.64-121.00	32.10-84.70
T. Hardness /mgL^{-1}	9.00-380.00	30-62	80-120	10.00-4500.00	39.50-3700.00
Chloride/mgL^{-1}	2.41-73.50	3.00-7.00	600	2.09-13147.70	1.50-10196.84
H_2S/mgL^{-1}	0.21-1.60	ND	--	0.00-6.39	ND
NH_3^--N/mgL^{-1}	.00	0.51-0.49	0.2-5	0.01-0.08	BDL-7.91
BOD/mgL^{-1}	0.70-5.08	ND	6	0.21-9.17	ND
COD/mgL^{-1}	14.78-49.28	ND	NYS	11.39-179.87	6.00-6480.00

Table 1. **Water quality of the Halda and Karnafuli river (continued).**

Parameters	Halda		WHO Standard	Karnafuli	
	Present study	Previous study [10]		Present study	Previous Study 11]
NO_2^--N/mgL^{-1}	BDL-0.87	ND	0.03	0.00-5.18	BDL-0.09
NO_3^--N/mgL^{-1}	0.00	ND	NYS	0.00-1.63	BDL-1.45
NO_2^-+NO_3^--N/mgL^{-1}	0.14-04.90	0.61-1.11	--	0.54-14.60	ND
PO_4^{3-}-P/mgL^{-1}	0.73-4.28	0.09-0.40	0.8	0.12-4.94	BDL-7.60
SO_4^{2-}-S/mgL^{-1}	BDL-95.52	ND	--	9.26-977.08	8.50-1250.70
Zn/mgL^{-1}	0.04-.80	ND	--	0.01-0.04	0.02-0.45
Cu/mgL^{-1}	BDL-0.07	ND	<0.4	0.01-0.03	0.02-4.23
Co/mgL^{-1}	0.01-0.04	ND	--	BDL	BDL-0.02
Cr/mgL^{-1}	BDL-0.01	ND	NYS	BDL-0.01	0.02-0.35
Cd/mgL^{-1}	BDL	ND	NYS	BDL	BDL-0.01
Pb/mgL^{-1}	BDL-0.07	ND	0.05	BDL-0.02	BDL-0.11
Fe/mgL^{-1}	0.25-5.94	0.99-2.5	NYS	0.06-3.24	0.01-9.35
Mn/mgL^{-1}	0.122.93	ND	0.1-1	BDL-0.92	0.02-2.59
%NaCl	BDL-0.40	ND	--	0.20-19.10	ND
Coliform/100mL	≥1600	ND	5000	≥1600	ND

BDL= Below Detection Level, ND= Not Done

Table 2. **Seasonal variation of the Halda and Karnafuli river water quality.**

Parameters	Seasons	Halda		Karnafuli	
		Min.	Max.	Min.	Max.
pH	Pre-monsoon	7.03	8.60	7.15	8.12
	Monsoon	7.25	7.93	6.36	9.86
	Post-monsoon	7.10	7.95	7.20	8.40
EC	Pre-monsoon	106.10	194.50	90.00	36325.00
	Monsoon	72.00	172.00	99.00	25300.00
	Post-monsoon	78.00	414.00	93.00	45600.00
DO	Pre-monsoon	3.02	8.32	.00	6.33
	Monsoon	3.34	7.15	2.15	6.50
	Post-monsoon	4.05	9.90	3.25	7.91
Carbon dioxide	Pre-monsoon	1.87	11.09	1.41	13.31
	Monsoon	3.70	12.46	4.47	13.40
	Post-monsoon	3.17	16.61	3.12	49.98
Total alkalinity	Pre-monsoon	6.28	90.78	5.64	119.00
	Monsoon	23.60	89.60	16.29	104.00
	Post-monsoon	30.60	64.40	24.00	121.00
Total hardness	Pre-monsoon	10.00	84.00	16.00	4000.00
	Monsoon	9.00	380.00	10.00	2380.00
	Post-monsoon	17.00	88.00	22.00	4500.00
Chloride	Pre-monsoon	3.56	36.30	2.09	13147.70
	Monsoon	7.34	39.02	3.21	10125.94
	Post-monsoon	2.41	73.50	7.00	12120.20
BOD	Pre-monsoon	1.37	5.08	0.22	9.17
	Monsoon	1.42	3.12	0.21	6.22
	Post-monsoon	0.70	2.88	11.39	122.46
Nitrite-N	Pre-monsoon	0.09	0.87	1.01	3.89
	Monsoon	0.00	0.59	.00	5.18
	Post-monsoon	0.16	0.17	1.60	14.60
o-Phosphate-P	Pre-monsoon	1.52	4.28	2.00	3.37
	Monsoon	0.43	0.64	0.12	4.94
	Post-monsoon	0.73	0.97	9.26	212.81
Sulphate-S	Pre-monsoon	8.64	95.52	152.08	974.10
	Monsoon	0.00	6.62	28.55	977.08
	Post-monsoon	4.48	12.59	9.26	32.87
Fe	Pre-monsoon	0.51	4.66	0.06	2.30
	Monsoon	0.79	4.05	0.40	2.72
	Post-monsoon	0.25	5.94	0.23	3.24
Mn	Pre-monsoon	0.12	2.37	0.01	0.92
	Monsoon	0.33	2.93	0.22	0.45
	Post-monsoon	0.22	2.36	0.01	0.24

Table 3. **Water quality of other rivers of the greater Chittagong region.**

Parameters	Sangu	Kaptai Lake	Matamu-huri	Naf	Bakkhali	Kasalong	Chingri
pH	7.66	7.90	7.71	7.73	9.55	7.69	7.31
EC./μScm^{-1}	270.90	85.87	237.50	49300.00	353.00	235.90	170.90
TDS/mgL^{-1}	135.32	41.33	118.55	24700.00	171.00	117.70	85.50
DO/mgL^{-1}	5.83	6.85	5.64	7.56	6.96	5.36	4.91
Transparency/cm	35.00	82.00	64.00	26	16.00	66	47
Acidity/mgL^{-1}	3.09	10.08	ND	ND	ND	ND	ND
T.Alkalinity/mgL^{-1}	146.52	53.62	113.55	153.52	146.85	128.16	96.12
T. Hard ness/mgL^{-1}	160.00	27.62	84.00	5840.00	220.00	84.00	60.00
Chloride/mgL^{-1}	14.35	3.96	13.88	21720.92	62.96	8.61	6.70
BOD/mgL^{-1}	2.24	1.27	3.60	6.92	7.40	2.34	2.79
NO_2^--N/mgL^{-1}	0.01	0.01	ND	ND	ND	ND	ND
NO_3^--N/mgL^{-1}	0.25	0.44	ND	ND	ND	ND	ND
o-PO_4^{3-}-P/mgL^{-1}	1.13	2.36	2.85	0.43	1.50	0.64	0.32
SO_4^{2-}-S/mgL^{-1}	4.66	6.79	7.41	1411.73	1.54	3.09	3.09
Ni/mgL^{-1}	ND	BDL	ND	ND	ND	ND	ND
Zn/mgL^{-1}	ND	0.037	ND	ND	ND	ND	ND
Cu/mgL^{-1}	ND	BDL	ND	ND	ND	ND	ND
Co/mgL^{-1}	ND	BDL	ND	ND	ND	ND	ND
Cr/mgL^{-1}	ND	0.004	ND	ND	ND	ND	ND
Cd/mgL^{-1}	ND	BDL	ND	ND	ND	ND	ND
Pb/mgL^{-1}	ND	BDL	ND	ND	ND	ND	ND
Fe/mgL^{-1}	0.60	1.71	1.47	0.52	2.05	BDL	1.65
Mn/mgL^{-1}	0.37	0.82	0.02	1.01	0.84	0.50	0.06
%NaCl	0.49	0.60	0.45	96.40	0.09	0.05	0.30

Table 4. **Groundwater quality of the greater Chittagong region.**

Parameters	Khagrachhari	Rangamati	Cox's Bazar	Bandarban	Chittagong	BSTI Standard
Ambient Temp./^{0}C	31.75	28.32	33.00	29.90	27.53	--
Water Temp./^{0}C	26.63	25.72	27.08	26.85	27.15	--
pH	5.86	6.26	7.19	6.55	7.38	6.4-7.4
EC./μScm^{-1}	205.38	107.60	1646.86	534.50	2822.13	--
TDS/ mgL^{-1}	102.88	53.80	823.86	266.93	787.00	Max 500
% NaCl	0.40	0.18	3.01	1.05	2.54	--
DO/ mgL^{-1}	2.34	3.70	2.27	2.00	1.75	Max 6
Acidity/ mgL^{-1}	28.80	20.61	20.56	23.03	40.55	--
T. Alkalinity/ mgL^{-1}	64.08	54.67	283.63	113.52	355.83	--
T. Hardness/ mgL^{-1}	60.00	39.50	243.75	92.00	224.59	Max 500
Chloride/ mgL^{-1}	15.79	12.55	404.63	35.41	378.28	Max 600
NO_2^--N/mgL^{-1}	ND	0.002	0.09	0.010	0.14	Nil
NO_3^--N /mgL^{-1}	ND	0.534	0.925	0.107	2.47	Max 4.5
o-PO_4^{3-}-P/mgL^{-1}	0.35	1.19	2.02	2.58	3.35	Max 6
SO_4^{2-}-S/mgL^{-1}	3.63	1.41	404.99	6.40	88.67	Max 400
Ni/mgL^{-1}	BDL	BDL	BDL	BDL	0.020	--
Zn/mgL^{-1}	BDL	BDL	BDL	BDL	0.015	Max 5
Cu/mgL^{-1}	BDL	BDL	BDL	BDL	0.010	Max 1
Co/mgL^{-1}	BDL	0.009	0.005	0.009	0.008	---
Cr/mgL^{-1}	BDL	BDL	BDL	BDL	0.005	Max 0.5
Cd/mgL^{-1}	BDL	BDL	BDL	BDL	0.011	0.005
Pb/mgL^{-1}	0.050	0.053	0.045	0.047	0.049	Max 0.05
As/mgL^{-1}	0.100	BDL	BDL	BDL	0.413	Max 0.05
Fe/mgL^{-1}	4.28	0.41	2.80	5.21	1.67	0.3-1.0
Mn/mgL^{-1}	0.61	0.11	0.52	1.27	0.19	Max 0.1

BSTI= Bangladesh Standards and Testing Institute

Table 5. **Pearson correlations among the different parameters of the Halda river water.**

	pH	EC	DO	Acidity	T.A	T.H	Cl^-	PO_4^{3-}-P	SO_4^{2-}-S	Fe	Mn
pH	1	-.108	.663(**)	-.298	.360(*)	-.145	-.451(**)	-.252	-.225	.346	-.235
EC	-.108	1	.285	.049	.260	.135	.804(**)	-.479	-.122	.264	.169
DO	.663(**)	.285	1	-.100	.181	-.040	-.082	-.894	-.292	.312	-.366
Acidity	-.298	.049	-.100	1	-.032	.622(**)	.255	-.733	-.225	-.118	.092
TA	.360(*)	.260	.181	-.032	1	.113	.134	.632	-.046	.112	.023
T.H	-.145	.135	-.040	.622(**)	.113	1	.489(**)	-.992(*)	-.160	-.134	.374
Cl^-	-.451(**)	.804(**)	-.082	.255	.134	.489(**)	1	-.998(*)	.028	-.190	-.032
PO_4^{3-}P	-.252	-.479	-.894	-.733	.632	-.992(*)	-.998(*)	1	.679	-.538	-.578
SO_4^{2-}S	-.225	-.122	-.292	-.225	-.046	-.160	.028	.679	1	-.094	-.851(*)
Fe	.346	.264	.312	-.118	.112	-.134	-.190	-.538	-.094	1	.685(**)
Mn	-.235	.169	-.366	.092	.023	.374	-.032	-.578	-.851(*)	.685(**)	1

**Correlation is significant at the 0.01 level (1-tailed),
*Correlation is significant at the 0.05 level (1-tailed).
TA= Total Alkalinity, TH= Total Hardness

Table 6. **Pearson correlations among the different parameters of the Karnafuli river water.**

	pH	EC	DO	Acidity	T.A	T.H	Cl^-	PO_4^{3-}-P	SO_4^{2-}- S	Fe	Mn
pH	1	.280(*)	.196	.310(*)	.335(**)	.432(**)	.255(*)	-.246	.614(**)	.076	-.403
EC	.280(*)	1	.250(*)	.379(**)	.279(*)	.972(**)	.964(**)	-.552(*)	.899(**)	-.099	-.545(*)
DO	.196	.250(*)	1	.075	-.073	.266(*)	.244(*)	-.180	.509(*)	-.017	-.580(*)
Acidity	.310(*)	.379(**)	.075	1	.204	.335(**)	.274(*)	.417	-.134	-.085	.671(**)
T.A	.335(**)	.279(*)	-.073	.204	1	.379(**)	.292(*)	.026	.180	-.290(*)	-.032
T.H	.432(**)	.972(**)	.266(*)	.335(**)	.379(**)	1	.980(**)	-.505(*)	.905(**)	-.025	-.768(**)
Cl^-	.255(*)	.964(**)	.244(*)	.274(*)	.292(*)	.980(**)	1	-.482(*)	.887(**)	.043	-.739(**)
PO_4^{3-}P	-.246	-.552(*)	-.180	.417	.026	-.505(*)	-.482(*)	1	-.433	.296	.633(*)
SO_4^{2-}S	.614(**)	.899(**)	.509(*)	-.134	.180	.905(**)	.887(**)	-.433	1	-.007	-.243
Fe	.076	-.099	-.017	-.085	-.290(*)	-.025	.043	.296	-.007	1	-.296
Mn	-.403	-.545(*)	-.580(*)	.671(**)	-.032	-.768(**)	-.739(**)	.633(*)	-.243	-.296	1

Table 7. **Pearson Correlations among the different parameters of groundwater.**

	pH	EC	DO	Acidity	T.A	T.H	Cl^-	PO_4^{3-}-P	SO_4^{2-}-S	As	Fe	Mn
pH	1	.186	-.040	.145	.542(**)	.326(*)	.544(**)	.102	.321(*)	.477	-.286(*)	-.165
EC	.186	1	-.055	.367(*)	.379(*)	.219	.942(**)	.044	.049	.194	-.033	-.097
DO	-.040	-.055	1	.339	.017	-.514	.444	-.442	.078	-.655	-.098	.054
Acidity	.145	.367(*)	.339	1	.484(**)	.250	.459(**)	.028	.099	-.460	-.182	.155
T.A	.542(**)	.379(*)	.017	.484(**)	1	.689(**)	.681(**)	.184	.357(*)	-.231	-.069	.140
T.H	.326(*)	.219	-.514	.250	.689(**)	1	.333(*)	.050	.083	.479	.073	.068
Cl^-	.544(**)	.942(**)	.444	.459(**)	.681(**)	.333(*)	1	.453(**)	.549(**)	-.084	-.170	-.289
PO_4^{3-}P	.102	.044	-.442	.028	.184	.050	.453(**)	1	.305(*)	-.132	-.038	-.085
SO_4^{2-}S	.321(*)	.049	.078	.099	.357(*)	.083	.549(**)	.305(*)	1	.736(*)	-.130	-.111
As	.477	.194	-.655	-.460	-.231	.479	-.084	-.132	.736(*)	1	.060	-.323
Fe	-.286(*)	-.033	-.098	-.182	-.069	.073	-.170	-.038	-.130	.060	1	.296(*)
Mn	-.165	-.097	.054	.155	.140	.068	-.289	-.085	-.111	-.323	.296(*)	1

Discussion and Conclusions

From the present physicochemical study of the water quality of the Chittagong region, it can be concluded that the condition of the Karnafuli River is critical and Halda River may be affected by the polluted Karnafuli River water. Decreasing trend of DO of the Karnafuli River water was observed from the present and previous study [11]. Minimum DO value found for the Karnafuli River was as low as 0 mgL^{-1}. This indicates the critical condition of this River. Similar situation was observed by Gasim [12]. Alam et al. [13], reported DO values in the range (2.74-5.12 mgL^{-1}) and (3.95-5.97 mgL^{-1}) for river water samples and (3.73-5.01 mgL^{-1}) and (5.04-5.49 mgL^{-1}) for lake water samples in the dry and rainy seasons, respectively. Only tidal cycle is keeping the Karnafuli River alive. If there were no tidal cycle, the Karnafuli would have been turned into a dead River like Buriganga and Turag of Dhaka. The development of strong institutional mechanisms is necessary to facilitate the sustainable management of resources and to prevent further deterioration of the environment [14].

The Karnafuli and Halda River water quality significantly varied with seasons, tide conditions and locations. From the location dependent variation it can be concluded that effect of sea water reaches up to the Kalurghat point. So there is possibility of destroying biodiversity of the Halda River by the intrusion of polluted Karnafuli River water in the pre-monsoon period at high tide. Due to this, spawning of carps are decreasing gradually and lesser quantities of fish eggs are being harvested nowadays.

Toxic metals pollution is not predominant in the Karnafuli and Halda River water as the toxic metals were found within the acceptable limit for surface water. Manganese content of the Halda and Karnafuli River was found slightly higher than the permissible limit. The average values of manganese in Turag, Buriganga and Shitalakhya were reported by Hossain [15] as 63.10, 33.10 and 192.27 $\mu g\ L^{-1}$, respectively. Maximum EC, TDS, Hardness, chloride and sulphate-S values of the Karnafuli River water were found at the estuary and decreases gradually with the distance from the estuary. Phenolphthalein alkalinity was not detected in any of the samples analyzed. So alkalinity of the Halda, Karnafuli, Sangu, Kaptai Lake and also for groundwater samples is mainly for carbonates and bicarbonates [16]. Mean pH value of the Naf River water (Table 3) was found in the alkaline range. Similar pH values 7.5-8.5 were reported by Chowdhury et al. [17], for the Naf River.

Higher BOD values found at Sadarghat (9.17mgL^{-1}) and Chandraghona (6.22 mgL^{-1}) points of the Karnafuli River indicates that these two sites are severely polluted by the wastes and effluents of the industries and Chittagong City Corporation area and Karnafuli Paper Mill (KPM), respectively. o-phosphate-P of the Karnafuli and Halda was found in the range (0.73-4.28 mgL^{-1}) and (0.12-4.94 mgL^{-1}), respectively, which is higher than permissible limit. Higher values may be due to the washing out of fertilizer from agricultural fields and detergents used in household purposes which ultimately disposed off into the Rivers water. Carbon dioxide found for the Halda (max 16.61 mgL^{-1}), Kaptai Lake (max 14.00 mgL^{-1}), Karnafuli (max 49.98 mgL^{-1}) exceeds the limit (6 mgL^{-1}) of surface water. Comparison of the water quality of the Halda, Karnafuli and other rivers (Table-4) shows that Karnafuli is the most polluted among the Rivers of Chittagong region.

From the pH value of the groundwater samples it is observed that lowest value is found in samples collected from Khagrachhari districts, which is far below the permissible limit. Iron content of groundwater samples of this region (Khagrachhari 5.72 mg L^{-1}, Cox's Bazar 10.38 mgL^{-1}, Bandarban 11.53 mg L^{-1}, Chittagong 4.93 mg L^{-1}) exceeds the Bangladesh standard for drinking water (0.3-1.0 mg L^{-1}). Chittagong region groundwater also contains arsenic (max 0.5 mgL^{-1}) exceeding the BSTI limit (0.05mgL^{-1}) and WHO limit (10 μgL^{-1}) for drinking water. Miah et al. [18], reported that irrigation with high arsenic water (>100μgL^{-1}) is positively related to the high arsenic content in wetland rice. Groundwater samples of Mirsharai and Sandwip contained arsenic (max 0.5 mgL^{-1}) exceeding the WHO tolerance limit (0.01 mgL^{-1}) for drinking water. Rahman et al. [19], reported that >94% shallow tube-wells of Mirsharai and 82.7% of Sitakunda Upazilas contained arsenic above the permissible

limit. Some groundwater samples contained nitrite-N (max 0.14 mg L^{-1}) exceeding the limit of BSTI limit for drinking water.

In groundwater samples used for drinking purposes coli form should not be present but some samples contained coli form (<2-2/100mL). Nitrate-N of the groundwater samples were found for the Chittagong region (0.11-2.47 mgL^{-1}). Bashar et al. [20] reported that nitrate-N is the most prevalent form of nitrogen compound in groundwater and (1.1-1.8 mgL^{-1}) in Maddhayapara Granite mine area of Dinajpur district.

From the Pearson Correlations of the Halda (Table 5), Karnafuli (Table 6) and groundwater (Table 7) samples of this region it can be concluded that correlation of different parameters from different sources differs significantly e.g. pH of the Halda River water was found positively correlated with DO and alkalinity and negatively correlated with chloride but the Karnafuli River water pH was found positively correlated with EC, acidity, total alkalinity, total hardness, chloride and sulphate-S.

Recommendations

1. From the present study it is found that the Karnafuli River water becomes polluted from Industrial, municipal and agricultural sources. Industrial and municipal effluents must be discharged into the River after proper treatment. Many industries have effluent treatment plants, but they are not using it.
2. The Chittagong Municipal Authority and Department of Environment (DoE) should take a lead role in organizing a concrete and concerted effort with other Government and non-Government agencies in solving the problems of the Karnafuli River as soon as possible.
3. Steps must be taken to save the Halda River from getting polluted by the Karnafuli River water especially in the pre-monsoon season when flow of this River decreases. Proper law should be passed and implemented, so that authority can take necessary action against the industries and bodies responsible for polluting the Rivers. The community people should be mobilized in such efforts, because people's participation is very much fruitful in improving the environmental situation.
4. Government should take necessary steps to supply safe drinking water in the hilly regions. Arsenic prone areas such as Sandwip, Mirsharai and Sitakundu should be provided with safe drinking water from deep tube-wells.
5. Steps must be taken for using rain water, after preserving in tanks and ponds in the rainy season, as alternate source of groundwater.
6. Government of Bangladesh should be taken proper action for making new national and regional policies and appropriate preventive measures on the basis of assessment data prior further deterioration of water quality.
7. The Public awareness should be increased of the risk and affected areas so that they could ready to face the disaster due to Climate change.

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