



Research

Physicochemical Characteristics of Groundwater Quality from Chittagong Area, Southeastern Bangladesh

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Abstract: Chittagong is one of the major developing cities in Bangladesh; its area is rapidly increasing and a large number of populations live in Chittagong City Corporation (CCC). Majority of the people are using the groundwater as a prime source for their domestic needs, besides the CCC is supplying them with an allocation of treated water. Our research work has been focused on various essential physical and chemical parameters including color, odor, transparency, pH, conductivity, salinity, total dissolved solids (TDS), dissolved oxygen (DO), Chemical oxygen demand (COD), sulfate, nitrate, ammonia, orthophosphate, chloride, fluoride, M. alkalinity, P. alkalinity, hardness, calcium, magnesium, arsenic, iron, potassium, manganese, chromium, nickel, cadmium, lead silver, mercury and zinc of water samples from various districts of Chittagong region. An attempt has been made in this study to evaluate the groundwater quality of Chittagong region. Groundwater samples were collected from shallow wells, deep wells and hand pumps of different heavily industrialized and domestic blocks. The work has been confined to Chittagong region and districts. Since the water quality is expected to vary with season, multiple samples have been collected from 100 sites at an interval of 2 to 3 weeks in each district before and after monsoon for hydrological year 2016 -2018. The water samples have been analyzed using standard method for physicochemical parameters as prescribed by APHA, using standard techniques and compared with WHO drinking water quality standards. The laboratory findings of water quality parameters were also compared with the recommended values set by DoE and BSTI. The concentration of different constituents of most of the groundwater samples were within the permissible limits of BSTI drinking water quality guideline except As, Cd and Pb. 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 groundwater resources of Chittagong area to match national and international standards for drinking, agricultural, industrial and livestock requirements.

Keywords: Physicochemical assessment; groundwater quality parameters; Chittagong Area

Introduction

Natural resources are the important wealth of our country, water is one of them. Water is a wander of the nature. “*No life without water* ” is a common saying depending upon the fact that water is the one of the naturally occurring sensational requirement of all life supporting activities[1].The quality of drinking water is closely associated with human health and providing safe drinking water is one of important public health priorities. Evaluation of water quality goes far beyond merely determining which constituents are present and at what concentrations. This is because identification of specific physical, chemical and biological characteristics has never been the primary goal in practical consideration of water quality. It is just mechanism by which suitability of water for attaining the goal can be judged and end point of water quality control activities defined. However, rapid industrial development, economic growth, and population growth have intensified the requirements for a vast number of materials and products, leading to an increase in the number of factories in various places across the World. Consequently, available water resources have been reduced, while the environmental pollution of open water systems has increased. However, recently, social concerns and the requirement for environmental conservation have increased across the World, with rising economic standards, which has led to the establishment of wastewater treatment facilities near the industrial complexes for the efficient control of wastewater [2]. So its quality is likely to change day by day and from source to source. Any change in the natural quality may disturb the equilibrium system and would become unfit for designated uses. The availability of water through surface and groundwater resources has become critical day to day. Estimated 80 percent of all diseases and over one third of deaths in developing countries are caused by the consumption of contaminated water, and on the average as much as one tenth of each person’s productive time is sacrificed to water- related diseases [3]. In Bangladesh, most of the population is dependent on groundwater as the only source of drinking water supply. The groundwater is believed to be comparatively much clean and free from pollution than surface water. But prolonged discharge of industrial effluents, domestic sewage and solid waste dump causes the groundwater to become polluted and created health problems [4]. For agricultural purposes ground water is explored in rural areas especially in those areas where other sources of water like dam and river or the canal is not available. During last decade, this is observed that the ground water get polluted drastically because of increased human activities. The rapid growth of urban areas has further affected groundwater quality due to over exploitation of resources and improper waste disposal practices. Hence, there is always a need for and concern over the protection and management of groundwater quality [4]. Heavy metals are priority toxic

pollutants that severely limit the beneficial use of water for domestic and industrial application. The quality of drinking water in Bangladesh is also at high risk. Problems are acute, especially in urban areas. Chittagong is one of the major developing cities in Bangladesh. Majority of the people are using the groundwater as a prime source for their domestic needs, besides the Chittagong City Corporation is supplying them with an allocation of treated water. Only 1% part is available on land for drinking, agriculture, domestic power generation, industrial consumption, and transportation and waste disposal [3, 5]. Greater Chittagong district, the important portion of Bangladesh, is one the densely populated urban and rural areas which have been suffering from inadequate supply of drinking water often associated with water quality problems too.

Besides surface water, groundwater is one of the major sources of water in Bangladesh for agriculture, drinking, municipal and industrial uses [6]. Groundwater is stored in pore space and sediments of the earth's upper crust. When rainfalls or snow melts, some of the water on the earth's surface evaporates, some used by plants and some runs over the ground into streams and lakes. The remainder seeps into pores and cracks in the underlying sediments and bed rock to become groundwater. Some groundwater emerges as surface water to supply rivers, ponds or lakes during dry month; the rest remain in the ground.

Although groundwater is not directly exposed to surface polluting activities, numerous natural and anthropogenic activities cause groundwater pollution. A number of physical, chemical and biochemical processes cause alteration of groundwater properties either by addition of new species or by increasing the existing concentrations. There are many waste products of industries which is potentially dangerous to the environment [7]. The polluted water contains various metallic ions e.g. arsenic (As), molybdenum (Mo), lead (Pb), cadmium (Cd), mercury (Hg), nickel (Ni), barium (Ba), beryllium (Be), cobalt (Co), tin (Sn), vanadium (V) etc. many of those are highly toxic.

Before the discovery of elevated amount of arsenic in Bangladesh, groundwater used to be considered a safer source of drinking water. But this is now considered the world's largest case of water pollution [6]. Groundwater in Bangladesh is also polluted by a number of anthropogenic and natural sources. The most widespread anthropogenic sources are the infiltration of industrial and urban wastes disposed of on the ground or in surface water bodies. Also intrusion or infiltration of saline water contaminates groundwater. Extensive use of agrochemicals can lead to groundwater pollution. Leaking sewers/septic tanks/pit latrines also

cause groundwater pollution. Heavy metal contamination in water is an increasing worldwide environmental concern. The issue of arsenic is now the most important environmental concern of Bangladesh. In recent times arsenic in tube-well waters has upset the drinking water supply from groundwater.

Arsenic contamination of the groundwater in Bangladesh is a serious problem. The issue came to international attention in 1995. British geological survey found 900 villages with arsenic above the government limit [8]. This is a large health concern for people living in areas of Bangladesh where the only source of water they have is contaminated with arsenic that is either above or well above the WHO standard ($<0.01 \text{ mgL}^{-1}$), but also the limit set by the government of Bangladesh (0.05 mgL^{-1})[8]. It is a high-profile problem due to the use of *shallow-tube-wells* for water supply causing serious *arsenic poisoning* to large numbers of people. A chronic condition is a *human health condition or disease* that is persistent or otherwise long-lasting in its effects or a disease that comes with time.

Sampling Areas:

A total of more than 80 water quality monitoring stations were identified (Fig.-1) and water samples were collected in the middle month of four seasons namely pre monsoon (January-March), Summer (April-June), monsoon (July-September), and post monsoon (October-December) of the hydrological years 2016-2018 for continuous monitoring of water quality parameters.

Groundwater samples from different points or spots of Chittagong region were collected for this study. Sample collection points are shown in figure-1.

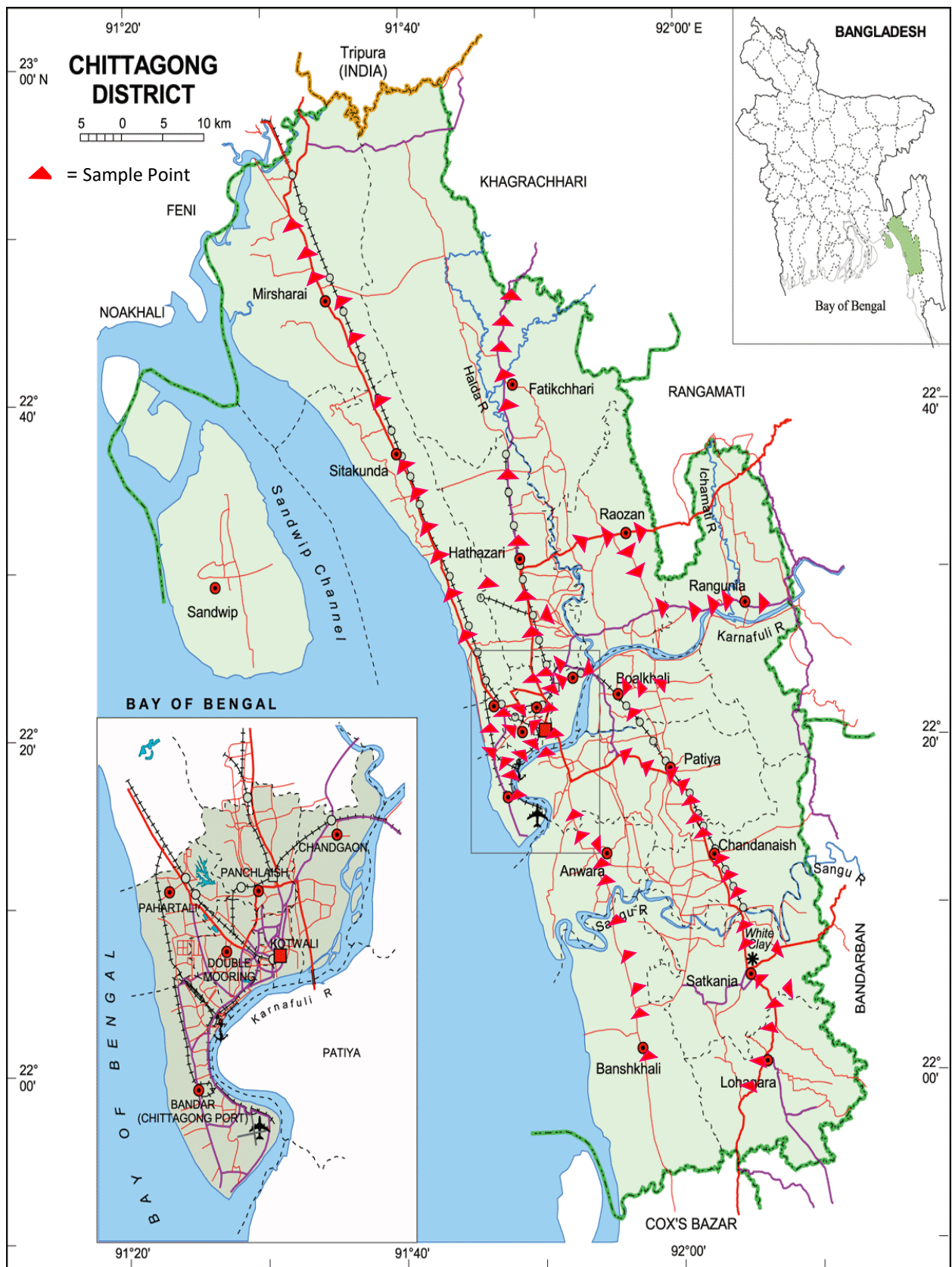


Fig. 1: Groundwater sample collection points of Chittagong Region.

Materials and Methods

Groundwater samples from different points of greater Chittagong district were collected for this study. Samples were collected in amber color polyethylene bottle cleaned by rinsing thoroughly with 8M HNO₃, followed by repeated washing with distilled water. The samples were mixed well and a sample of 1.0-1.5-L was transferred for analysis in the laboratory. It was fixed to collect the sample from different places during winter season, especially December to January, which was first analyzed for physicochemical analysis. There was followed the standard procedures prescribed by American Public Health Association (APHA)[9] for Physicochemical Analysis, such as Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), pH, Bicarbonate, Acidity, Carbon dioxide, Alkalinity, Arsenic, Chloride, Chromium, Copper, Cobalt, Dissolved Oxygen (DO), Iron, Lead, Manganese, Nickel, Nitrate, Oxygen demand (Chemical) COD, Oxygen demand (Biochemical) BOD, Phosphate, Sulfate, Zinc etc.[10, 11].The results of drinking water quality were compared with standard values, which were suggested by World Health Organization WHO in 2006 and 2008.

Results and Discussion

The demand for water in Bangladesh is gradually increasing with accelerating development, mainly for human consumption, agricultural and livestock, recreational and industrial requirements. This necessity is exerting considerable weight on the available groundwater resources. The present study focused on physicochemical assessment and monitoring of groundwater resources of the greater Chittagong region using simple and rapid methods is of paramount importance. An extensive study was carried out to elucidate the distribution and occurrence of different physicochemical parameters of groundwater quality of greater Chittagong region. To study of the different physicochemical parameters, groundwater samples from almost every Upazila, Thana, town and cities were collected and analyzed following by the standard methods recommended by APHA[9].

Results of groundwater resources of the Chittagong region are shown in Tables 1-8 and minimum, maximum and mean values are shown in Tables 9-15.

Pearson correlations among the different parameters of Chittagong region water are shown in Table1.

Table 1. Water quality parameters of Chittagong City of Chittagong district.

Parameter s	Units	Location: Chittagong City									
		Oxygen Moor	Laldegirpar	Pathorghata	Kotawali	Free port	Agrabad	Chowmuhani	Dewanhat	New Bridge	Alongkar Moor
pH		8.04	7.50	7.80	7.80	7.30	7.30	7.10	7.95	7.39	7.04
Temp.	(°C)	23.90	25.40	23.50	24.00	25.20	24.80	25.70	23.20	26.10	25.40
EC	µscm ⁻¹	125.3	308	291	283	788	1023	361	201	1818	185
TDS	mgL ⁻¹	62.6	154.1	145.5	141.5	394	511	180.6	100.3	909	87.3
Salinity	mgL ⁻¹	0.06	0.15	0.14	0.14	0.49	0.49	0.11	0.05	0.90	0.08
DO	mgL ⁻¹	8.50	7.50	8.40	8.5	7.60	7.10	6.10	8.80	6.68	6.91
Turbidity	NTU	0	4	0	3	0	20.	0	0	110	5
Phosphate	mgL ⁻¹	0.24	0.82	1.65	1.12	0.13	0.20	0.22	0.07	5.20	8.30
Sulphate	mgL ⁻¹	2	24	14	3	37	5	23	20	15	14
Nitrate	mgL ⁻¹	0.7	0.1	0.1	1.2	0.6	0.50	0.10	0.20	0.40	0.10
BOD	mgL ⁻¹	4.18	3.16	4.02	3.94	3.10	3.0	1.74	4.32	2.11	2.57
COD	mgL ⁻¹	56.00	8.40	18.82	23.20	15.40	23.20	39.42	17.20	2.80	23.20
Hardness	mgL ⁻¹	20	140	60	80	160	22	20	20	340	40
Alkalinity	mgL ⁻¹	105.07	199.27	163.04	202.88	215.25	298.77	277.12	121.24	606.20	121.24
Acidity	mgL ⁻¹	3.6	4	5.5	7.6	3.6	3.6	3.6	4.4	3.6	12.6
CO ₂	mgL ⁻¹	3.18	3.53	5.12	6.11	3.18	3.18	3.18	3.85	3.18	10.6
Chloride	mgL ⁻¹	3.268	3.373	3.808	3.482	4.324	15.56	1.088	1.523	8.486	49.61
Arsenic	mgL ⁻¹	0.01	0.1	0.02	0.05	0.03	0.02	0.1	0.01	0.03	0.04
Cadmium	mgL ⁻¹	0.0009	0.0002	0.0005	0.0011	0.0008	0.0008	0.0005	0.0003	0.0002	0.0009
Cobalt	mgL ⁻¹	BDL	0.001	BDL	BDL	0.005	BDL	BDL	0.0001	BDL	BDL
Chromium	mgL ⁻¹	0.0108	0.0032	0.0092	0.0012	0.0056	0.0065	0.0085	0.0035	0.0116	0.0023
Copper	mgL ⁻¹	0.009	0.01	0.008	BDL	BDL	0.003	BDL	0.005	0.002	BDL
Iron	mgL ⁻¹	0.554	0.621	0.125	BDL	0.3541	0.4531	0.315	0.0950	BDL	0.589
Manganese	mgL ⁻¹	0.048	0.045	0.0827	0.017	0.0524	0.8087	0.2987	0.1551	0.17	0.4180
Nickel	mgL ⁻¹	0.025	0.034	0.019	0.018	0.029	0.026	0.028	0.020	0.016	0.017
Lead	mgL ⁻¹	0.0027	0.0014	0.0019	0.0013	0.0018	0.0021	0.0015	0.018	0.0028	0.0013
Zinc	mgL ⁻¹	0.0175	0.0181	0.0141	0.020	0.0014	0.0015	0.0192	0.0185	0.014	0.0167

Table 2. Water quality parameters of Chittagong City and Anwara Upazila of Chittagong district

Parameter s	Units	Chittagong City					Anwara				
		New Market	Ghatfarhadbag	Matarbari	Dewanbazar	GEC	Bottoli	Chapatoli	Mohalkhan Bazar	Chaturi	Tailar Dwip
pH		7.68	7.70	7.50	6.04	6.55	7.72	7.45	7.32	7.00	6.91
Temp.	(°C)	23.90	26.20	25.50	24.80	24.40	28.80	27.50	26.90	28.80	27.40
EC	µscm ⁻¹	160	233	245	239	309	260	48.2	64.5	179.6	172.7
TDS	mgL ⁻¹	80.1	116.6	123.7	119.7	154.5	130.1	24.1	32.3	89.9	86.3
Salinity	mgL ⁻¹	0.10	0.12	0.12	0.12	0.08	0.1	0.03	0.02	0.5	0.7
DO	mgL ⁻¹	7.02	6.62	7.11	7.31	6.75	7.50	7.26	7.42	7.32	7.15
Turbidity	NTU	1	13	93	1	23	16	3	2	35	128
Phosphate	mgL ⁻¹	5.60	4.40	4.80	5.80	9.30	3.1	3.5	3.3	5.0	5.4
Sulphate	mgL ⁻¹	13	15	24	21	49	15	6	8	9	9
Nitrate	mgL ⁻¹	0.10	0.90	0.30	0.40	0.30	0.6	0.6	0.5	1.7	0.8
BOD	mgL ⁻¹	2.72	2.18	2.99	2.85	2.50	2.73	2.78	3.08	3.27	2.67
COD	mgL ⁻¹	5.60	16.80	13.80	11.20	68.99	2.80	5.60	11.20	156.8	145.6
Hardness	mgL ⁻¹	40	120	80	40	80	40	40	5	20	40
Alkalinity	mgL ⁻¹	106.08	155.88	93.09	119.07	0	74.48	34.58	18.62	117.04	0
Acidity	mgL ⁻¹	3.6	4.5	7.5	3.6	12	3	3.6	4	3.6	10
CO ₂	mgL ⁻¹	3.18	3.88	6.1	3.18	10.6	2.65	3.18	3.53	3.18	8.8
Chloride	mgL ⁻¹	33.51	2.670	2.502	3.264	1.958	6.093	0.653	1.088	1.741	0.544
Arsenic	mgL ⁻¹	0.01	0.01	0.01	0.05	0.06	0.3	0.08	0.1	0.05	0.02
Cadmium	mgL ⁻¹	0.0008	0.0007	0.0008	0.0009	0.0006	BDL	BDL	BDL	0.0004	0.0002
Cobalt	mgL ⁻¹	0.001	BDL	0.0005	BDL	BDL	0.003	BDL	BDL	0.001	BDL
Chromium	mgL ⁻¹	0.0055	0.0013	0.0015	0.0023	0.0015	0.0084	BDL	0.0055	0.0094	0.0034
Copper	mgL ⁻¹	BDL	0.006	BDL	BDL	0.004	0.007	0.012	0.005	0.016	BDL
Iron	mgL ⁻¹	0.381	0.4371	0.6001	0.2381	0.1116	BDL	0.352	0.871	2.40	0.632
Manganese	mgL ⁻¹	0.0853	0.1187	0.6360	0.1035	0.4396	0.1654	0.0419	0.0406	0.1860	1.5093
Nickel	mgL ⁻¹	0.018	0.017	0.019	0.020	0.021	BDL	BDL	0.017	0.018	0.013
Lead	mgL ⁻¹	0.0025	0.0027	0.0023	0.0024	0.0027	BDL	0.0115	0.0007	0.0143	0.0009
Zinc	mgL ⁻¹	0.0195	0.0143	0.0143	0.0149	0.0141	BDL	0.167	0.1289	0.3055	0.2013

Table 3. Water quality parameters of Mirsharai and Sitakundu Upazilas of Chittagong district

Parameters	Units	Mirsharai					Sitakundu				
		Methachhar a	City corporation	Barotakia	Nizampur	Kamoldhah o Bazar	Bhatiari	Bashbaria	Kumira	Baro aoulia	City corporation
pH		6.95	7.77	7.01	7.77	7.75	8.21	7.18	7.76	8.03	7.10
Temp.	(°C)	30.00	29.00	24.30	27.00	29.00	24.30	24.10	24.20	24.40	24.00
EC	µscm ⁻¹	651	393	577	375	444	1712	1662	856	309	429
TDS	mgL ⁻¹	326	785	1153	750	889	831	428	154.5	215	62.6
Salinity	mgL ⁻¹	0.33	0.40	0.59	0.38	0.44	0.85	0.53	0.46	0.62	0.21
DO	mgL ⁻¹	7.5	6.2	7.6	8.1	8.7	7.4	8.4	8.5	7.5	7.5
Turbidity	NTU	10	19	11	15	26	11	203	10	20	4
Phosphate	mgL ⁻¹	3.21	5	9.3	6.4	6.0	8.7	5.4	9.3	7.3	4.3
Sulphate	mgL ⁻¹	9	22	5	4	30	7	5	22	24	8
Nitrate	mgL ⁻¹	0.2	0.4	0.6	0.5	0.5	1.8	0.4	0.3	0.3	0.3
BOD	mgL ⁻¹	3.32	1.78	3.10	4.19	4.94	3.04	3.89	4.10	3.40	3.07
COD	mgL ⁻¹	16.80	23.20	16.80	5.60	5.60	94.08	44.80	37.63	23.20	5.60
Hardness	mgL ⁻¹	240	300	140	120	320	60	56	24	460	40
Alkalinity	mgL ⁻¹	0	60.62	80.10	489.29	412.20	1097.7	496.35	409.34	0	373.17
Acidity	mgL ⁻¹	126	6.6	7	6	6.1	12.6	13.2	60.6	180	40
CO ₂	mgL ⁻¹	106	5.88	6.11	5.3	5.4	10.6	11.41	53.5	148.4	31.8
Chloride	mgL ⁻¹	3.699	5.875	18.06	6.746	2.503	22.195	13.71	12.078	9.683	3.808
Arsenic	mgL ⁻¹	0.5	0.02	0.1	0.1	0.01	0.5	0.1	0.01	0.03	0.05
Cadmium	mgL ⁻¹	0.0009	0.0014	0.0013	0.0007	0.0002	0.0031	0.0023	0.0011	0.0009	0.0004
Cobalt	mgL ⁻¹	0.007	BDL	BDL	0.0001	BDL	BDL	0.006	BDL	0.001	BDL
Chromium	mgL ⁻¹	0.0073	0.0069	0.0081	0.0071	0.0084	0.0052	0.0046	0.0043	0.0049	0.0035
Copper	mgL ⁻¹	0.011	0.009	0.017	0.0010	0.028	0.021	BDL	0.019	0.017	0.021
Iron	mgL ⁻¹	5.651	4.72	4.812	4.731	6.258	0.201	0.104	BDL	0.051	0.359
Manganese	mgL ⁻¹	0.2615	0.6690	0.1079	0.1388	0.6480	0.0180	0.032	0.031	0.032	0.031
Nickel	mgL ⁻¹	0.024	0.022	0.023	0.022	0.025	0.034	0.032	0.031	0.032	0.031
Lead	mgL ⁻¹	0.0921	0.1105	0.0435	0.0629	0.0105	0.0143	0.0157	BDL	BDL	0.0150
Zinc	mgL ⁻¹	0.1589	0.0311	0.1163	0.1083	0.1904	0.0909	0.0731	BDL	0.0479	0.0931

Table4.Water quality parameters of Hathazari and Faticchhari Upazilas of Chittagong district

Parameters	Units	Hathazari					Faticchhari				
		CU Campus	Nandirhat	Chawdhari Hat	Anayat Bazar	Fatepur	Bebirhat	South dhurang	Najerhat	Zangkar mor	Farhadabad
pH		7.80	7.18	7.47	7.60	6.20	7.30	7.90	7.90	7.60	7.55
Temp.	(°C)	28.10	29.50	25.20	27.00	29.10	27.20	27.10	27.20	27.60	27.10
EC	µscm ⁻¹	82.1	81.8	3020	189	59.2	99	275	436	319	1074
TDS	mgL ⁻¹	41	40.9	1510	94.6	29.5	49.5	138	218	159.7	537
Salinity	mgL ⁻¹	0.04	0.03	1.60	0.09	0.03	0.03	0.03	0.22	0.15	0.48
DO	mgL ⁻¹	6.71	6.91	4.71	3.73	4.75	4.20	4.30	5.6	4.8	3.4
Turbidity	NTU	10	0	5	5	1	36	1	4	6	4
Phosphate	mgL ⁻¹	4.2	5.8	8.7	2.3	0.9	0.7	0.5	1.3	0.9	1.4
Sulphate	mgL ⁻¹	8	9	7	3	0.1	12	1	6	3	18
Nitrate	mgL ⁻¹	0.4	0.4	0.6	0.7	0	3.2	0.4	0.9	0.5	1.0
BOD	mgL ⁻¹	2.50	2.45	0.11	0.05	0.54	0.10	0.09	1.12	0.50	0.05
COD	mgL ⁻¹	235.2	2.80	5.60	2.80	22.40	18.82	2.80	5.60	2.80	2.80
Hardness	mgL ⁻¹	60	60	480	40	80	60	80	80	180	120
Alkalinity	mgL ⁻¹	155.79	54.345	811.55	239.12	0	108.69	86.952	278.97	376.79	297.09
Acidity	mgL ⁻¹	2.2	2.2	2.0	2.2	60	6.0	1.2	1.2	3.6	0.6
CO ₂	mgL ⁻¹	1.96	1.96	1.8	1.96	52	5.3	1.06	1.06	3.18	0.53
Chloride	mgL ⁻¹	0.641	0.712	4.35	0.762	1.088	1.447	1.44	3.155	2.937	18.06
Arsenic	mgL ⁻¹	0.01	0.03	0.1	0.04	0.08	0.07	0.01	0.06	0.04	0.02
Cadmium	mgL ⁻¹	0.0002	BDL	BDL	0.0004	BDL	0.008	0.0031	0.0004	0.0016	0.0094
Cobalt	mgL ⁻¹	BDL	0.0002	BDL	0.001	BDL	BDL	0.0003	0.0001	BDL	BDL
Chromium	mgL ⁻¹	0.0002	BDL	BDL	0.0002	BDL	0.0023	0.0016	0.0012	0.0015	0.0024
Copper	mgL ⁻¹	BDL	BDL	BDL	0.30	BDL	BD;L	0.025	BDL	0.019	0.031
Iron	mgL ⁻¹	1.831	BDL	BDL	1.847	1.251	3.331	2.995	1.645	2.461	3.626
Manganese	mgL ⁻¹	0.098	0.0725	0.2845	0.2050	0.1427	0.2271	0.1073	0.0660	0.1685	0.1360
Nickel	mgL ⁻¹	0.001	BDL	0.001	0.002	0.002	0.007	0.011	BDL	0.010	0.017
Lead	mgL ⁻¹	0.0020	BDL	0.0013	0.0021	0.0017	0.0027	0.0018	0.0029	0.0018	0.0014
Zinc	mgL ⁻¹	0.0117	BDL	0.0089	0.0118	0.0115	0.0109	0.0099	0.0202	0.0098	0.0098

Table 5. Water quality parameters of Raozan and Rangunia Upazilas of Chittagong district.

Parameters	Units	Raozan					Rangunia				
		Munshighata	Berulia	Janalihat	Kundayshary	Gahera	Zia Nagor	Uttar Pomra	Pomra	Shanterhat	Burcer Dokan
pH		7.40	7.60	8.10	7.80	7.50	7.56	8.13	8.80	8.25	8.96
Temp.	(°C)	30.7	31.3	31.4	31.5	30.5	30.5	29.7	29.9	30.3	30.00
EC	µscm ⁻¹	170	262	851	178	172	46.9	337	359	373	366
TDS	mgL ⁻¹	85	131	425	89	86.4	93.7	168.8	179.4	186.7	182.8
Salinity	mgL ⁻¹	0.07	0.13	0.22	0.09	0.08	0.08	0.04	0.16	0.18	0.09
DO	mgL ⁻¹	5.52	6.82	5.95	6.93	6.01	7.99	6.6	6.65	5.8	6.40
Turbidity	NTU	30	4	3	6	31	1	2	0	0	0
Phosphate	mgL ⁻¹	2.00	0.28	0.60	1.00	0.18	0.8	0.7	0.24	0.26	0.88
Sulphate	mgL ⁻¹	8	1	5	4	10	5	11	133	9	24
Nitrate	mgL ⁻¹	1.7	0.3	1.2	0	0.4	0.8	0.4	1.0	0.8	1.2
BOD	mgL ⁻¹	1.31	2.43	1.58	2.58	1.69	3.56	2.18	2.35	1.32	1.99
COD	mgL ⁻¹	60.30	94.08	11.20	2.80	5.60	28.22	28.22	135.2	112.0	5.60
Hardness	mgL ⁻¹	60	40	80	60	80	40	200	20	20	20
Alkalinity	mgL ⁻¹	110.16	194.85	482.79	138.39	136.39	112.58	240.32	423.91	329.69	329.69
Acidity	mgL ⁻¹	6.0	1.2	1.2	3.6	0.6	6.0	3.6	1.2	1.2	0.6
CO ₂	mgL ⁻¹	5.3	1.06	1.06	3.18	0.53	5.3	3.18	1.06	1.06	0.53
Chloride	mgL ⁻¹	2.316	1.282	10.47	0.534	1.068	0.854	1.175	1.175	1.709	1.069
Arsenic	mgL ⁻¹	0.02	0.1	0.06	0.1	0.04	0.02	0.03	0.1	0.1	0.3
Cadmium	mgL ⁻¹	0.0016	BDL	0.0023	0.0277	BDL	0.0006	BDL	0.001	0.0009	BDL
Cobalt	mgL ⁻¹	0.0011	BDL	BDL	0.0052	BDL	BDL	0.006	BDL	BDL	0.0003
Chromium	mgL ⁻¹	0.0032	0.0041	0.0012	0.0013	0.0016	0.0037	0.0028	0.0044	0.0039	0.0027
Copper	mgL ⁻¹	0.0064	BDL	0.162	0.0194	BDL	BDL	0.0184	0.0131	0.0161	BDL
Iron	mgL ⁻¹	0.8115	0.3578	0.2330	0.5838	0.9848	0.0689	0.1259	0.0264	0.0283	0.0239
Manganese	mgL ⁻¹	0.0602	0.005	0.0069	0.0509	0.0648	0.0069	0.0338	0.0069	0.0110	0.0050
Nickel	mgL ⁻¹	0.016	0.005	0.010	0.011	0.013	0.004	0.001	0.002	0.001	BDL
Lead	mgL ⁻¹	0.0382	BDL	0.0235	0.0291	0.0153	0.0168	0.0184	0.0586	0.0437	BDL
Zinc	mgL ⁻¹	0.0198	BDL	0.0156	0.012	0.0008	BDL	0.0166	0.0276	0.0256	0.0277

Table 6. Water quality parameters of Potiya and Boalkhali Upazilas of Chittagong district.

Parameters	Units	Potiya					Boalkhali				
		Munshirghata	Bus station	Thanarnor	Mollopara	Sabjarpara	Kanongopara	Jotpukurpar	Akubdandi	Thana sador	Fultal
pH		7.30	7.11	7.55	7.95	7.48	7.92	7.65	8.07	7.51	7.82
Temp.	(°C)	23.90	24.10	27.20	28.10	29.50	20.94	21.22	21.06	21.59	20.89
EC	µscm ⁻¹	320	110.2	855	1811	127.9	398	738	369	914	398
TDS	mgL ⁻¹	160.2	55.1	427	906	64	199.1	369	184.7	457	198.8
Salinity	mgL ⁻¹	0.16	0.03	0.33	0.90	0.06	0.2	0.3	0.1	0.4	0.1
DO	mgL ⁻¹	8.4	7.90	6.90	7.10	7.05	7.15	7.10	7.25	7.81	7.75
Turbidity	NTU	7	32	13	10	13	4	9	6	16	7
Phosphate	mgL ⁻¹	0.6	0.4	1.12	1.80	1.21	2.4	2.5	0.61	0.81	2.1
Sulphate	mgL ⁻¹	4	4	5	7	8	21	2	4	3	2
Nitrate	mgL ⁻¹	0.9	1.2	0.6	0.5	1.4	0.3	1.0	2.7	0.8	1.3
BOD	mgL ⁻¹	3.04	3.89	4.10	3.40	3.07	2.36	3.23	3.35	3.93	3.63
COD	mgL ⁻¹	94.08	44.80	37.63	23.20	5.6	33.60	28.22	5.63	5.80	138.2
Hardness	mgL ⁻¹	80	120	240	300	20	40	20	10	60	60
Alkalinity	mgL ⁻¹	220.83	80.10	106.09	84.435	97.43	284.62	399	335.16	404.32	263.34
Acidity	mgL ⁻¹	1.2	2.6	3.6	12	1.20	6.0	3.6	1.2	1.2	0.6
CO ₂	mgL ⁻¹	1.06	2.34	3.18	1.06	1.06	5.3	3.18	1.06	1.06	0.53
Chloride	mgL ⁻¹	1.741	5.44	17.08	6.854	1.088	3.046	10.336	1.8496	12.076	8.269
Arsenic	mgL ⁻¹	0.01	0.1	0.08	0.02	0.011	0.09	0.03	0.04	0.07	0.01
Cadmium	mgL ⁻¹	0.0009	0.0003	0.0001	0.0013	0.0019	0.0005	0.0004	0.0004	0.0009	0.0006
Cobalt	mgL ⁻¹	BDL	0.0005	0.0003	BDL	BDL	0.0001	BDL	0.0004	0.0006	BDL
Chromium	mgL ⁻¹	0.0042	0.0039	0.0043	0.0043	0.0038	0.0009	0.0006	0.0007	0.0008	0.0010
Copper	mgL ⁻¹	0.015	BDL	BDL	0.006	BDL	0.0015	0.009	BDL	BDL	BDL
Iron	mgL ⁻¹	3.241	0.398	5.958	1.556	1.422	0.598	3.020	0.352	0.624	0.531
Manganese	mgL ⁻¹	0.0468	0.3325	0.3980	0.4560	0.3340	0.0915	0.079	0.2387	0.2924	0.2703
Nickel	mgL ⁻¹	0.014	0.009	0.016	0.010	0.005	0.001	0.008	BDL	BDL	0.002
Lead	mgL ⁻¹	0.0011	0.0004	0.015	0.0009	0.0006	0.0017	0.0031	BDL	0.0018	0.0029
Zinc	mgL ⁻¹	0.021	0.0173	0.0272	0.0211	0.0120	0.125	0.0281	BDL	0.0278	0.0016

Table 7. Water quality parameters of Chadanaish and Satkania Upazilas of Chittagong district

Parameters	Units	Chandnaish					Satkania				
		Dohazari	Boropara	Dhewanhat	Gachbaria	Badurpara	Hasmot shop	Rastarnor	Keranihat	Mouloveer 's shop	CNB Office
pH		7.45	7.64	7.05	7.60	7.95	8.25	8.30	7.60	7.50	7.73
Temp.	(°C)	27.60	24.50	23.90	23.30	2350	24.40	24.90	24.80	24.00	25.90
EC	µscm ⁻¹	292	884	2208	43.5	87.6	387	679	243	1184	306
TDS	mgL ⁻¹	146.2	442	1104	21.7	43.8	193.5	339	121.5	592	152.9
Salinity	mgL ⁻¹	0.11	0.49	1.10	0.06	0.05	0.10	0.27	0.06	0.65	0.15
DO	mgL ⁻¹	6.95	8.05	8.10	8.7	8.20	7.30	7.99	7.51	7.20	7.10
Turbidity	NTU	2	9	95	0	1	56	9	7	34	0
Phosphate	mgL ⁻¹	1.12	2.09	3.09	0.48	0.46	0.72	0.9	1.18	2.12	1.36
Sulphate	mgL ⁻¹	4	7	2	0.1	0.1	8	8	5	7	3
Nitrate	mgL ⁻¹	1.0	1.6	1.4	0.2	0.3	1.2	1.12	1.7	0.9	0.6
BOD	mgL ⁻¹	2.36	3.23	3.35	3.93	3.63	2.66	3.29	2.85	2.89	280
COD	mgL ⁻¹	33.60	28.22	5.63	5.80	138.2	5.60	11.20	33.60	5.6	2.8
Hardness	mgL ⁻¹	100	480	260	40	40	120	20	40	180	20
Alkalinity	mgL ⁻¹	95.25	134.23	220.83	73.61	49.795	0	318.25	197.08	32.48	235.99
Acidity	mgL ⁻¹	6.0	3.6	1.2	1.2	0.6	10	1.4	2.2	1.2	1.2
CO ₂	mgL ⁻¹	5.3	3.18	1.06	1.06	0.53	8.8	1.22	2.06	1.06	1.06
Chloride	mgL ⁻¹	1.197	16.650	18.496	16.320	1.197	1.523	11.53	0.653	16.43	0.979
Arsenic	mgL ⁻¹	0.01	0.02	0.08	0.06	0.05	0.01	0.1	0.03	0.08	0.05
Cadmium	mgL ⁻¹	0.0045	0.0060	0.0049	0.0053	0.0064	0.0009	0.0003	0.0084	0.0042	0.0087
Cobalt	mgL ⁻¹	0.0006	0.003	0.0007	0.002	BDL	0.0071	BDL	0.0001	BDL	0.0005
Chromium	mgL ⁻¹	0.0109	0.0085	0.0039	0.0053	0.0024	0.0053	0.0051	0.0055	0.0057	0.0068
Copper	mgL ⁻¹	0.002	0.0133	0.0121	0.0113	BDL	0.0073	BDL	0.137	BDL	0.014
Iron	mgL ⁻¹	0.339	0.689	0.452	0.827	0.953	0.754	1.935	0.989	0.732	0.556
Manganese	mgL ⁻¹	0.111	0.1471	0.3795	0.0281	0.0120	0.1132	0.070	0.2432	0.2512	0.043
Nickel	mgL ⁻¹	0.012	0.013	0.014	0.012	0.014	0.013	0.020	0.012	0.014	0.018
Lead	mgL ⁻¹	0.0027	0.0026	0.0025	0.0026	0.0021	0.0011	0.0021	0.0017	0.0013	0.002
Zinc	mgL ⁻¹	0.0170	0.0173	0.0175	0.0179	0.0180	0.0128	0.0134	0.0127	0.0131	0.0126

Table 8. Water quality parameters of Lohagra and Banshkhali Upazilas of Chittagong district

Parameters	Units	Lohagra					Banshkhali				
		Amerabad	Rajghata	Podua	Thakurdeghi	Shibbari	Chadpur Bazar	Banigram	Gunagori	Kaipur college	Jaldi thana
pH		7.81	7.92	7.55	6.30	6.90	7.21	7.63	7.18	7.38	6.90
Temp.	(°C)	23.40	25.80	26.10	27.20	24.80	29.80	25.60	27.80	27.20	29.90
EC	µscm ⁻¹	499	223	269	187	313	54.7	29.7	89.1	101	116
TDS	mgL ⁻¹	249	111	134.6	93.3	156.3	27.3	14.9	44.5	50.5	58.1
Salinity	mgL ⁻¹	0.26	0.05	0.06	0.05	0.08	0.03	0.03	0.03	0.04	0.06
DO	mgL ⁻¹	8.5	7.25	7.60	6.92	7.90	7.20	7.05	7.19	7.45	7.95
Turbidity	NTU	12	31	22	34	76	13	1	27	8	30
Phosphate	mgL ⁻¹	0.32	0.29	0.25	0.33	0.62	4.60	2.70	1.50	2.30	4.30
Sulphate	mgL ⁻¹	6	6	5	8	8	11	1	9	9	7
Nitrate	mgL ⁻¹	0.20	1.20	0.50	1.00	0.60	1.20	0.40	0.60	1.20	1.20
BOD	mgL ⁻¹	3.70	2.84	2.86	2.15	3.28	2.90	2.71	2.86	3.00	3.40
COD	mgL ⁻¹	5.60	13.80	47.04	5.60	13.80	22.40	22.40	16.80	78.40	16.80
Hardness	mgL ⁻¹	140	60	100	100	80	10	40	30	20	40
Alkalinity	mgL ⁻¹	0	166.71	199.18	0	0	34.580	26.60	47.88	63.84	0
Acidity	mgL ⁻¹	50	6.6	6.80	12.0	11.0	20	1.5	0.6	0.6	2.0
CO ₂	mgL ⁻¹	44	5.88	6.10	10.6	9.2	16.7	1.3	0.53	0.53	1.7
Chloride	mgL ⁻¹	5.33	0.7616	0.653	0.544	2.062	0.762	0.762	0.762	0.979	0.871
Arsenic	mgL ⁻¹	0.02	0.01	0.1	0.08	0.01	0.03	0.1	0.07	0.012	0.023
Cadmium	mgL ⁻¹	0.0005	0.0004	0.0002	0.0003	0.0002	BDL	0.0001	BDL	0.0009	BDL
Cobalt	mgL ⁻¹	BDL	0.0001	BDL	0.0003	BDL	BDL	0.0002	BDL	BDL	0.0001
Chromium	mgL ⁻¹	0.0021	0.0027	0.002	0.0028	0.0042	0.0079	0.0081	BDL	0.31	0.0014
Copper	mgL ⁻¹	0.002	0.002	0.0005	BDL	BDL	0.015	0.012	0.016	0.018	0.014
Iron	mgL ⁻¹	BDL	3.0125	11.20	1.901	BDL	0.785	0.0293	0.543	1.293	0.557
Manganese	mgL ⁻¹	0.183	0.8677	0.5869	0.6120	0.834	0.1222	0.0200	0.1689	0.1726	0.2050
Nickel	mgL ⁻¹	0.027	0.018	0.022	0.014	0.012	BDL	0.016	0.015	0.005	0.004
Lead	mgL ⁻¹	0.0018	0.0017	0.0018	0.0018	0.0017	0.0336	0.008	0.0082	0.0492	0.0395
Zinc	mgL ⁻¹	0.0210	0.0201	0.0192	0.0189	0.0182	0.0191	0.0145	BDL	0.0295	0.0225

Comparative Study of Groundwater Quality Parameters

Table 9. Water quality of Chittagong City and Anwar Upazilas of Chittagong district.

Parameters	Units	Chittagong City			Anwara			BSTI	WHO
		Min	Max	Mean	Min	Max	Mean		
pH		6.04	8.04	7.37±0.53*	6.96	7.79	7.29±0.32*	6.5-8.6	6.5-8.5
Temp.	°C	23.20	26.10	24.81±0.94	26.9	28.8	27.88±0.87	20-30	20-30
EC	µscm ⁻¹	125	1818	437.27±3.0	48.2	260	145.1±8.15	500	500
TDS	mgL ⁻¹	62.6	909	218.7±6.4	24.1	130	72.50±4.03	500	500
Salinity	mgL ⁻¹	0.05	0.49	0.21±0.03	0.02	0.12	0.06±0.001	-	-
Chloride	mgL ⁻¹	1.08	49.61	10.88±0.76	0.54	6.093	2.02±2.32	600	250
DO	mgL ⁻¹	6.10	8.80	7.39±0.81	7.15	7.50	7.33±0.13	6	6
Turbidity	NTU	0	110	18.2±1.77	2	128	36.8±6.80	20	25
Phosphate	mgL ⁻¹	0.07	9.30	3.189±0.18	3.10	5.40	4.06±0.059	6	-
Sulphate	mgL ⁻¹	2	49	18.6±1.39	6	15	9.4±0.03	400	10
Nitrate	mgL ⁻¹	0.10	1.10	0.36±0.03	0.50	1.70	0.96±0.02	<1	50
Hardness	mgL ⁻¹	20	340	84.13±0.79	20	40	29±1.96	500	500
Alkalinity	mgL ⁻¹	0	606.2	185.6±1.17	0	117.04	48.94±3.93	400	600
Acidity	mgL ⁻¹	3.6	12.6	5.3±0.02	3	10	4.44±0.09	-	-
CO ₂	mgL ⁻¹	3.18	10.6	5.0±0.001	2.65	8.88	3.88±0.01	-	-
BOD	mgL ⁻¹	1.72	4.32	3.03±0.78	2.67	3.27	2.906±0.05	-	6.0
COD	mgL ⁻¹	2.8	68.99	22.93±1.45	2.8	156.8	64.3±0.39	6	10
Arsenic	mgL ⁻¹	0.05	0.1	0.037±0.01	0.01	0.3	0.06±0.004	0.05	0.01
Cadmium	mgL ⁻¹	0.0002	0.001	0.001±0.000	BDL	0.0004	0.0002±0.00	0.005	0.003
Cobalt	mgL ⁻¹	BDL	0.005	0.001±0.000	BDL	0.003	0.0005±0.00	0.01	0.01
Chromium	mgL ⁻¹	0.0012	0.012	0.006±0.001	BDL	0.0094	0.004±0.001	0.05	0.05
Copper	mgL ⁻¹	BDL	0.010	0.003±0.001	BDL	0.016	0.008±0.001	1	2
Iron	mgL ⁻¹	BDL	0.621	0.325±0.01	BDL	2.40	0.851±0.015	0.3	0.3
Manganese	mgL ⁻¹	0.017	0.809	0.232±0.04	BDL	1.5093	0.344±0.03	0.5	0.1
Nickel	mgL ⁻¹	0.016	0.034	0.022±0.002	BDL	0.018	0.009±0.001	0.1	0.02
Lead	mgL ⁻¹	0.0013	0.003	0.002±0.001	BDL	0.0143	0.008±0.001	0.05	0.03
Zinc	mgL ⁻¹	0.014	0.020	0.016±0.001	BDL	0.3055	0.016±0.005	5	3

*= The measure of precision is the standard deviation(s).

Max= Maximum.

Min= Minimum.

BSTI= Bangladesh Standards and Testing Institute.

WHO= World Health Organization

Table 10. Water quality of Mirsharai and Sitakundu Upazilas of Chittagong district.

Parameters	Units	Mirsharai			Sitakundu			BSTI	WHO
		Min	Max	Mean	Min	Max	Mean		
pH		6.95	7.77	7.45±0.42*	7.10	8.21	7.65±0.49*	6.5-8.6	6.5-8.5
Temp.	°C	24.3	30	27.86±0.26	24.00	24.4	24.2±0.15	20-30	20-30
EC	µscm ⁻¹	651	1153	845.6±11.7	309	1712	993.6±5.17	500	500
TDS	mgL ⁻¹	326	577	423±5.87	154.5	856	496.9±2.41	500	500
Salinity	mgL ⁻¹	0.33	0.59	0.428±0.09	0.15	0.85	0.492±0.02	-	-
Chloride	mgL ⁻¹	3.699	18.06	7.377±0.21	3.808	22.19	12.29±0.68	600	250
DO	mgL ⁻¹	6.2	8.7	7.62±0.92	7.4	8.5	7.86±0.54	6	6
Turbidity	NTU	10	26	16.2±0.53	4	203	49.6±2.94	20	25
Phosphate	mgL ⁻¹	3.21	9.30	5.982±0.22	4.30	8.70	7±2.12	6	-
Sulphate	mgL ⁻¹	5	30	14±1.46	5	24	13.2±0.03	400	10
Nitrate	mgL ⁻¹	0.02	0.60	0.52±0.051	0.30	1.8	0.4±0.06	<1	50
Hardness	mgL ⁻¹	120	320	224±10.99	24	460	128±2.1	500	500
Alkalinity	mgL ⁻¹	0	489.29	210.2±6.8	0	1097.8	475.3±3.41	400	600
Acidity	mgL ⁻¹	6.0	126	30±0.09	12.6	180	60±0.057	-	-
CO ₂	mgL ⁻¹	5.3	106	26±0.06	10.6.	148.4	51.4±0.078	-	-
BOD	mgL ⁻¹	1.78	4.94	3.466±0.19	3.04	4.10	3.50±0.47	-	6.0
COD	mgL ⁻¹	5.60	23.20	13.04±0.75	5.60	94.08	41.06±3.21	6	10
Arsenic	mgL ⁻¹	0.02	0.5	0.24±0.014	0.01	0.5	0.244±0.02	0.05	0.01
Cadmium	mgL ⁻¹	0.0002	0.0014	0.001±0.00	0.001	0.009	0.002±0.00	0.005	0.003
Cobalt	mgL ⁻¹	BDL	0.007	0.001±0.00	BDL	0.006	0.001±0.00	0.01	0.01
Chromium	mgL ⁻¹	0.0069	0.0084	0.008±0.00	0.004	0.005	0.01±0.001	0.05	0.05
Copper	mgL ⁻¹	0.009	0.028	0.02±0.001	BDL	0.021	0.02±0.001	1	2
Iron	mgL ⁻¹	4.72	6.258	5.12±0.69	0.054	0.359	0.156±0.01	0.3	0.3
Manganese	mgL ⁻¹	0.139	0.669	0.37±0.07	0.018	0.032	0.03±0.02	0.5	0.1
Nickel	mgL ⁻¹	0.022	0.025	0.02±0.001	0.031	0.034	0.03±0.001	0.1	0.02
Lead	mgL ⁻¹	0.0105	0.1105	0.062±0.01	BDL	0.015	0.02±0.001	0.05	0.03
Zinc	mgL ⁻¹	0.0311	0.1904	0.121±0.01	BDL	0.093	0.06±0.01	5	3

*= The measure of precision is the standard deviation(s).

Max= Maximum.

Min= Minimum.

BSTI= Bangladesh Standards and Testing Institute.

WHO= World Health Organization.

Table 11. Water quality of Hathazari and Faticchhari Upazilas of Chittagong district.

Parameters	Units	Hathazari			Faticchhari			BSTI	WHO
		Min	Max	Mean	Min	Max	Mean		
pH		6.20	7.80	7.26±0.56*	7.30	7.90	7.65±0.25*	6.5-8.6	6.5-8.5
Temp.	°C	25.2	29.50	27.91±1.58	27.10	27.60	27.24±0.20	20-30	20-30
EC	µscm ⁻¹	59.2	3020	597.3±7.8	99	1074	440.6±4.25	500	500
TDS	mgL ⁻¹	29.5	1510	298.72±3.9	49.5	5337	220.4±7.24	500	500
Salinity	mgL ⁻¹	0.03	1.60	0.31±0.06	0.03	0.48	0.49±0.08	-	-
Chloride	mgL ⁻¹	0.64	4.35	1.55±0.43	1.447	18.06	5.41±2.11	600	250
DO	mgL ⁻¹	3.73	6.92	5.63±0.39	3.4	5.6	7.87±0.81	6	6
Turbidity	NTU	0	10	3.28±0.77	1	36	49.6±1.53	20	25
Phosphate	mgL ⁻¹	0.90	8.70	3.95±0.92	0.50	1.40	0.96±0.08	6	-
Sulphate	mgL ⁻¹	0.10	9	5.58±0.35	1	18	8±0.964	400	10
Nitrate	mgL ⁻¹	0	0.70	0.35±0.09	0.40	3.20	1.2±0.14	<1	50
Hardness	mgL ⁻¹	40	480	126.6±3.70	60	180	104±4.74	500	500
Alkalinity	mgL ⁻¹	0	811.55	230.6±6.5	108.69	376.79	229.6±1.10	400	600
Acidity	mgL ⁻¹	2.0	60	13.1±0.03	0.6	6	2.8±0.03	-	-
CO ₂	mgL ⁻¹	1.8	53	11.6±0.03	0.53	5.3	2.2±0.02	-	-
BOD	mgL ⁻¹	0.05	2.50	1.35±0.21	0.05	1.12	0.372±0.05	-	6.0
COD	mgL ⁻¹	2.80	135	62.87±0.70	2.80	18.81	6.564±0.95	6	10
Arsenic	mgL ⁻¹	0.01	0.1	0.035±0.01	0.01	0.08	0.03±0.001	0.05	0.01
Cadmium	mgL ⁻¹	BDL	0.0004	0.0002±0.00	0.0004	0.0094	0.01±0.001	0.005	0.003
Cobalt	mgL ⁻¹	BDL	0.001	0.0005±0.00	BDL	0.0003	0.0002±0.0	0.01	0.01
Chromium	mgL ⁻¹	BDL	0.0002	0.0001±0.00	0.0012	0.0024	0.002±0.00	0.05	0.05
Copper	mgL ⁻¹	BDL	0.030	0.007±0.001	BDL	0.031	0.02±0.001	1	2
Iron	mgL ⁻¹	BDL	1.847	1.024±0.07	1.645	3.626	2.34±0.78	0.3	0.3
Manganese	mgL ⁻¹	BDL	0.205	0.164±.061	0.0606	0.136	0.14±0.06	0.5	0.1
Nickel	mgL ⁻¹	BDL	0.002	0.001±.0001	BDL	0.017	0.01±0.001	0.1	0.02
Lead	mgL ⁻¹	BDL	0.0021	0.002±0.00	0.0014	0.0029	0.002±0.00	0.05	0.03
Zinc	mgL ⁻¹	BDL	0.0118	0.01±.004	0.0098	0.0202	0.01±0.001	5	3

*= The measure of precision is the standard deviation(s).

Max= Maximum.

Min= Minimum.

BSTI= Bangladesh Standards and Testing Institute.

WHO= World Health Organization.

Table 12.Water quality of Raozan and Rangunia Upazilas of Chittagong district.

Parameters	Units	Raozan			Rangunia			BSTI	WHO
		Min	Max	Mean	Min	Max	Mean		
pH		7.40	8.10	7.68±0.27*	7.56	8.96	8.34±0.56*	6.5-8.6	6.5-8.5
Temp.	°C	30.5	31.5	31.08±0.44	29.7	30.5	30.08±0.31	20-30	20-30
EC	µscm ⁻¹	170	851	326.6±5.66	93.7	373	305.7±1.28	500	500
TDS	mgL ⁻¹	85.1	425	163.3±4.54	46.9	187	152.9±5.67	500	500
Salinity	mgL ⁻¹	0.07	0.22	0.12±0.06	0.04	0.18	0.116±0.05	-	-
Chloride	mgL ⁻¹	2.32	10.47	3.13±0.15	0.85	1.175	1.196±0.31	600	250
DO	mgL ⁻¹	5.52	7.93	6.24±0.60	5.80	7.99	6.69±0.80	6	6
Turbidity	NTU	3	31	14.8±1.37	0	2	0.60±0.09	20	25
Phosphate	mgL ⁻¹	0.18	2	0.81±0.03	0.24	2.26	0.98±0.05	6	-
Sulphate	mgL ⁻¹	1	10	5.6±0.50	5	24	12.4±1.12	400	10
Nitrate	mgL ⁻¹	0	1.70	0.72±0.07	0.4	1.20	0.84±0.09	<1	50
Hardness	mgL ⁻¹	40	80	64±1.73	20	200	60±2.74	500	500
Alkalinity	mgL ⁻¹	110.2	482.8	212.5±1.25	112.6	423.9	287.2±7.25	400	600
Acidity	mgL ⁻¹	0.6	6	2.8±0.03	0.6	6	2.8±0.03	-	-
CO ₂	mgL ⁻¹	0.53	5.3	2.2±0.02	0.53	5.3	2.2±0.02	-	-
BOD	mgL ⁻¹	1.31	2.43	1.92±0.05	1.32	3.56	2.28±0.015	-	6.0
COD	mgL ⁻¹	2.80	94.08	34.79±0.61	5.6	112	81.85±4.85	6	10
Arsenic	mgL ⁻¹	0.01	0.1	0.05±0.001	0.02	0.3	0.07±0.002	0.05	0.01
Cadmium	mgL ⁻¹	BDL	0.028	0.01±0.004	BDL	0.001	0.0005±0.0	0.005	0.003
Cobalt	mgL ⁻¹	BDL	0.005	0.003±0.00	BDL	0.006	0.0021±0.0	0.01	0.01
Chromium	mgL ⁻¹	0.001	0.004	0.003±0.001	0.003	0.005	0.0035±0.0	0.05	0.05
Copper	mgL ⁻¹	BDL	0.019	0.009±0.008	BDL	0.019	0.009±0.0	1	2
Iron	mgL ⁻¹	0.233	0.985	0.59±0.010	0.024	0.126	0.05±0.003	0.3	0.3
Manganese	mgL ⁻¹	0.005	0.065	0.04±0.009	0.007	0.034	0.01±0.002	0.5	0.1
Nickel	mgL ⁻¹	0.005	0.016	0.01±0.001	BDL	0.004	0.002±0.001	0.1	0.02
Lead	mgL ⁻¹	BDL	0.038	0.02±0.004	BDL	0.059	0.03±0.001	0.05	0.03
Zinc	mgL ⁻¹	BDL	0.020	0.012±0.003	BDL	0.028	0.02±0.005	5	3

*= The measure of precision is the standard deviation(s).

Max= Maximum.

Min= Minimum.

BSTI= Bangladesh Standards and Testing Institute.

WHO= World Health Organization.

Table 13.Water quality of Potiya and Boalkhali Upazilas of Chittagong district.

Parameters	Units	Potiya			Boalkhali			BSTI	WHO
		Min	Max	Mean	Min	Max	Mean		
pH		7.11	7.95	7.47±0.31*	7.51	8.07	7.70±0.22*	6.5-8.6	6.5-8.5
Temp.	°C	23.90	29.50	26.56±0.47	20.89	21.59	21.12±0.28	20-30	20-30
EC	µscm ⁻¹	110	1811	644.8±1.1	369	914	563.4±2.91	500	500
TDS	mgL ⁻¹	55.1	906	322.4±5.1	184.7	457	281.7±1.91	500	500
Salinity	mgL ⁻¹	0.03	0.90	0.296±0.05	0.1	0.4	0.22±0.03	-	-
Chloride	mgL ⁻¹	1.09	17.08	6.441±0.42	1.85	22.08	7.12±0.49	600	250
DO	mgL ⁻¹	6.9	8.4	7.47±0.64	7.10	781	7.41±0.34	6	6
Turbidity	NTU	7	32	15±0.82	4	16	8.4±0.61	20	25
Phosphate	mgL ⁻¹	0.4	1.8	1.026±0.15	0.61	2.90	1.76±0.01	6	-
Sulphate	mgL ⁻¹	4	8	5.6±0.81	2	21	6.4±0.20	400	10
Nitrate	mgL ⁻¹	0.5	1.4	0.78±0.08	0.3	2.7	1.4±0.90	<1	50
Hardness	mgL ⁻¹	20	300	152±1.42	10	60	38±2.80	500	500
Alkalinity	mgL ⁻¹	80.15	220.83	117.7±1.52	263.34	404.32	337.3±4.31	400	600
Acidity	mgL ⁻¹	1.2	12	3.6±0.001	0.6	6	2.8±0.03	-	-
CO ₂	mgL ⁻¹	1.06	10.6	3.2±0.005	0.53	5.3	2.2±0.02	-	-
BOD	mgL ⁻¹	2.23	3.89	2.91±0.89	2.75	3.50	3.08±0.35	-	6.0
COD	mgL ⁻¹	2.80	13.80	7.24±0.51	5.0	34.80	13.82±1.96	6	10
Arsenic	mgL ⁻¹	0.01	0.1	0.05±0.001	0.01	0.09	0.03±0.001	0.05	0.01
Cadmium	mgL ⁻¹	0.0001	0.0019	0.001±0.00	0.0004	0.0009	0.001±0.00	0.05	0.05
Cobalt	mgL ⁻¹	BDL	0.0005	0.0003±0.0	BDL	0.0006	0.0001±0.0	0.01	0.01
Chromium	mgL ⁻¹	0.0038	0.0043	0.01±0.001	0.0006	0.0010	0.001±0.00	0.5	0.1
Copper	mgL ⁻¹	BDL	0.0150	0.01±0.001	0.0015	0.0090	0.01±0.003	0.1	0.02
Iron	mgL ⁻¹	1.422	5.958	2.515±0.01	0.352	3.020	1.03±0.01	0.3	0.3
Manganese	mgL ⁻¹	0.334	0.398	0.314±0.07	0.079	0.452	0.19±0.02	1	2
Nickel	mgL ⁻¹	0.005	0.016	0.01±0.001	BDL	0.016	0.01±0.001	0.005	0.003
Lead	mgL ⁻¹	0.0006	0.0015	0.001±0.00	BDL	0.0031	0.01±0.001	0.05	0.03
Zinc	mgL ⁻¹	0.012	0.0272	0.02±0.001	BDL	0.0281	0.02±0.002	5	3

*= The measure of precision is the standard deviation(s).

Max= Maximum.

Min= Minimum.

BSTI= Bangladesh Standards and Testing Institute.

WHO= World Health Organization.

Table 14. Water quality of Chadanaish and Satkania Upazilas of Chittagong district.

Parameters	Units	Chadanaish			Satkania			BSTI	WHO
		Min	Max	Mean	Min	Max	Mean		
pH		7.06	7.95	7.53±0.32*	7.45	8.30	7.87±0.37*	6.5-8.6	6.5-8.5
Temp.	⁰ C	24.50	27.60	24.56±1.76	24.00	27.60	24.80±0.71	20-30	20-30
EC	µscm ⁻¹	43.5	2208	703.02±5.5	243	1184	559.8±3.81	500	500
TDS	mgL ⁻¹	21.7	1104	351.5±4.72	121.5	592	279.7±3.3	500	500
Salinity	mgL ⁻¹	0.05	1.10	0.36±0.05	0.06	0.65	0.246±0.23	-	-
Chloride	mgL ⁻¹	1.197	18.49	10.77±0.77	0.654	16.43	6.223±0.29	600	250
DO	mgL ⁻¹	6.95	8.70	8±0.64	6.95	7.99	7.42±0.35	6	6
Turbidity	NTU	0	95	21.4±0.29	0	34	21.2±2.31	20	25
Phosphate	mgL ⁻¹	0.46	3.09	1.45±0.13	0.72	2.12	1.256±0.04	6	-
Sulphate	mgL ⁻¹	0.10	7	2.64±0.22	3	8	6±0.08	400	10
Nitrate	mgL ⁻¹	0.20	1.60	0.88±0.03	0.60	1.70	1.064±0.40	<1	50
Hardness	mgL ⁻¹	40	480	184±1.32	20	180	76±1.27	500	500
Alkalinity	mgL ⁻¹	49.795	220.83	114.7±2.94	0	235.98	156.76±3.1	400	600
Acidity	mgL ⁻¹	0.6	6	2.8±0.03	1.2	10	3.2±0.01	-	-
CO ₂	mgL ⁻¹	0.53	5.3	2.2±0.02	1.06	8.8	3.1±0.01	-	-
BOD	mgL ⁻¹	2.36	3.93	3.3±0.59	2.66	3.29	2.898±0.23	-	6.0
COD	mgL ⁻¹	5.60	138.2	5.60±55.10	2.8	33.80	11.76±1.58	6	10
Arsenic	mgL ⁻¹	0.01	0.08	0.04±0.001	0.01	0.1	0.03±0.02	0.05	0.01
Cadmium	mgL ⁻¹	0.0045	0.0064	0.01±0.001	0.0003	0.0087	0.01±0.003	0.005	0.003
Cobalt	mgL ⁻¹	BDL	0.003	0.0007±0.0	BDL	0.007	0.002±0.00	0.01	0.01
Chromium	mgL ⁻¹	0.0024	0.0109	0.01±0.003	0.0051	0.0068	0.01±0.001	0.05	0.05
Copper	mgL ⁻¹	BDL	0.0173	0.01±.005	BDL	0.014	0.01±0.001	1	2
Iron	mgL ⁻¹	0.339	0.953	0.65±0.05	0.556	1.935	1.01±0.04	0.3	0.3
Manganese	mgL ⁻¹	0.012	0.3795	0.14±0.04	0.070	0.2512	0.15±0.001	0.5	0.1
Nickel	mgL ⁻¹	0.012	0.014	0.02±0.001	0.012	0.020	0.02±0.003	0.1	0.02
Lead	mgL ⁻¹	0.0021	0.0027	0.01±0.001	0.0011	0.0021	0.01±0.001	0.05	0.03
Zinc	mgL ⁻¹	0.017	0.018	0.02±0.001	0.0126	0.0134	0.02±0.001	5	3

*= The measure of precision is the standard deviation(s).

Max= Maximum.

Min= Minimum.

BSTI= Bangladesh Standards and Testing Institute.

WHO= World Health Organization.

Table 15. Water quality of Lohagra and Banshkhali Upazilas of Chittagong district.

Parameters	Units	Lohagra			Banshkhali			BSTI	WHO
		Min	Max	Mean	Min	Max	Mean		
pH		6.30	7.82	7.29±0.68*	6.90	7.63	7.26±0.26*	6.5-8.6	6.5-8.5
Temp.	°C	23.40	27.20	25.46±1.43	25.60	29.90	28.06±1.82	20-30	20-30
EC	µscm ⁻¹	187	499	298.2±1.8	54.7	116	78.10±3.25	500	500
TDS	mgL ⁻¹	93.3	249	148.9±6.79	27.3	58.1	39.06±1.64	500	500
Salinity	mgL ⁻¹	0.05	0.26	0.10±0.09	0.03	0.06	0.04±0.01	-	-
Chloride	mgL ⁻¹	0.544	5.33	1.87±0.02	0.762	0.979	0.83±0.09	600	250
DO	mgL ⁻¹	6.92	8.5	7.63±0.60	7.05	7.95	7.37±0.35	6	6
Turbidity	NTU	12	76	35±2.47	1	30	15.8±1.39	20	25
Phosphate	mgL ⁻¹	0.25	0.62	0.36±0.04	1.50	4.60	3.08±0.327	6	-
Sulphate	mgL ⁻¹	5	8	6.6±0.34	1	11	7.4±0.847	400	10
Nitrate	mgL ⁻¹	0.20	1.20	0.9±0.03	0.40	1.20	1.06±0.38	<1	50
Hardness	mgL ⁻¹	60	140	96±2.66	10	40	28±1.03	500	500
Alkalinity	mgL ⁻¹	0	199.18	73.18±0.82	0	335.2	27.27±0.94	400	600
Acidity	mgL ⁻¹	6.6	50	16±0.02	1.2	20	9.4±0.01	-	-
CO ₂	mgL ⁻¹	5.83	44	13.8±0.01	1.06	17.0	8.1±0.02	-	-
BOD	mgL ⁻¹	2.15	3.70	2.96±0.51	2.34	3.4	2.97±0.25	-	6.0
COD	mgL ⁻¹	5.60	13.80	17.17±1.19	5.6	33.6	31.36±2.41	6	10
Arsenic	mgL ⁻¹	0.01	0.1	0.04±0.014	0.003	0.1	0.05±0.004	0.05	0.01
Cadmium	mgL ⁻¹	0.0002	0.0005	0.0003±0.0	BDL	0.0009	0.0002±0.0	0.005	0.003
Cobalt	mgL ⁻¹	BDL	0.0003	0.0001±0.0	BDL	0.0002	0.0001±0.0	0.01	0.01
Chromium	mgL ⁻¹	BDL	0.0042	0.01±0.001	BDL	0.0081	0.01±0.003	0.05	0.05
Copper	mgL ⁻¹	BDL	0.002	0.001±0.00	0.012	0.018	0.02±0.002	1	2
Iron	mgL ⁻¹	BDL	11.20	3.25±0.05	0.292	1.293	0.67±0.07	0.3	0.3
Manganese	mgL ⁻¹	0.183	0.834	0.62±0.07	0.020	0.75	0.14±0.07	0.5	0.1
Nickel	mgL ⁻¹	0.012	0.027	0.02±0.01	BDL	0.016	0.01±0.001	0.1	0.02
Lead	mgL ⁻¹	0.0017	0.0018	0.002±0.00	0.008	0.049	0.03±0.01	0.05	0.03
Zinc	mgL ⁻¹	0.0182	0.0210	0.02±0.001	0.014	0.0291	0.02±0.001	5	3

*= The measure of precision is the standard deviation(s).

Max= Maximum.

Min= Minimum.

BSTI= Bangladesh Standards and Testing Institute.

WHO= World Health Organization.

Pearson Correlations [24] of different parameters of greater Chittagong Area

Table 16. Pearson Correlations among the different parameters of groundwater of Chittagong area.

	pH	Temp	EC	TDS	Sal.	Cl ⁻	DO	Tur.	PO ₄ ³⁻	SO ₄ ²⁻	NO ₃ ⁻	T.H	T.A	BOD	COD	As	Ni	Cd	Fe	Mn	Cr	Cu	Pb	Zn
pH	1	.002	.071	.071	.036	.024	.055	-.236*	-.26**	.021	.230*	.080	.322**	.055	.159	.30**	-.096	.069	-.069	-.27**	-.088	.147	.051	-.175
Temp	.002	1	-.079	-.079	-.084	-.023	-.28**	-.060	-.093	.061	.014	.043	-.094	-.29**	.158	-.007	-.260*	.210*	.039	-.030	.049	.151	.39**	.208*
EC	.071	-.079	1	1.00**	.98**	.66**	.078	.27**	.193*	.109	.091	.535**	.597**	.047	-.055	.224*	.202	.108	.104	.072	-.013	.026	.019	-.014
TDS	.071	-.079	1.0**	1	.98**	.66**	.078	.27**	.193*	.109	.091	.535**	.597**	.047	-.055	.224*	.202	.108	.104	.072	-.013	.026	.020	-.014
Sal.	.036	-.084	.98**	.982**	1	.63**	.084	.240*	.243*	.083	.050	.523**	.570**	.054	-.073	.221*	.210*	.126	.073	.061	.037	-.089	.042	-.016
Cl ⁻	.024	-.023	.66**	.657**	.63**	1	.163	.102	.055	.152	.064	.289**	.273**	.163	-.022	.011	.251*	.193	.025	-.010	-.102	.080	-.092	-.009
DO	.055	-.28**	.078	.078	.084	.163	1	.171	.106	.079	-.051	.059	-.036	.976**	.070	.069	.394**	-.119	-.034	.097	.103	-.38**	.003	.170
Tur.	-.24*	-.060	.27**	.271**	.240*	.102	.171	1	.138	-.056	.082	.062	.072	.168	.096	.075	.127	-.060	-.024	.45**	-.001	-.103	-.052	.098
PO ₄ ³⁻	-.26**	-.093	.193*	.193*	.243*	.055	.106	.138	1	.172	-.152	.065	.197*	.132	-.011	.238*	.282**	-.186	.068	.149	.088	-.173	.243*	.247*
SO ₄ ²⁻	.021	.061	.109	.109	.083	.152	.079	-.056	.172	1	-.084	.364**	.099	.098	.091	-.010	.287**	-.139	-.083	.026	.032	-.042	.023	.084
NO ₃ ⁻	.230*	.014	.091	.091	.050	.064	-.051	.082	-.152	-.084	1	-.018	.150	-.056	.020	.042	-.235*	.059	-.034	.019	.007	.187	-.042	-.054
TH	.080	.043	.54**	.535**	.53**	.29**	.059	.062	.065	.36**	-.018	1	.126	.029	.035	-.036	.131	-.002	.110	.032	.015	-.012	.036	-.034
TA	.32**	-.094	.59**	.597**	.57**	.27**	-.036	.072	.197*	.099	.150	.126	1	-.021	.060	.58**	.131	.011	.009	-.099	-.047	.164	-.005	-.005
BOD	.055	-.29**	.047	.047	.054	.163	.98**	.168	.132	.098	-.056	.029	-.021	1	.066	.077	.417**	-.117	-.028	.097	.137	-.33**	.021	.219*
COD	.159	.158	-.055	-.055	-.073	-.022	.070	.096	-.011	.091	.020	.035	.060	.066	1	.150	-.131	-.102	-.111	-.018	-.111	-.051	.136	.118
As	.31**	-.007	.224*	.224*	.221*	.011	.069	.075	.238*	-.010	.042	-.036	.582**	.077	.150	1	.217*	.033	.008	-.098	.019	-.060	.097	.058
Ni	-.096	-.260*	.202	.202	.210*	.251*	.39**	.127	.28**	.29**	-.24*	.131	.131	.417**	-.131	.217*	1	-.201	.131	.223*	.162	-.186	.062	.208
Cd	.069	.210*	.108	.108	.126	.193	-.119	-.060	-.186	-.139	.059	-.002	.011	-.117	-.102	.033	-.201	1	-.045	-.131	-.043	.093	.019	-.099
Fe	-.069	.039	.104	.104	.073	.025	-.034	-.024	.068	-.083	-.034	.110	.009	-.028	-.111	.008	.131	-.045	1	.153	-.076	-.095	.258*	.109
Mn	-.27**	-.030	.072	.072	.061	-.010	.097	.45**	.149	.026	.019	.032	-.099	.097	-.018	-.098	.223*	-.131	.153	1	-.040	-.115	-.006	.112
Cr	-.088	.049	-.013	-.013	.037	-.102	.103	-.001	.088	.032	.007	.015	-.047	.137	-.111	.019	.162	-.043	-.076	-.040	1	-.129	.092	.41**
Cu	.147	.151	.026	.026	-.089	.080	-.38**	-.103	-.173	-.042	.187	-.012	.164	-.32**	-.051	-.060	-.186	.093	-.095	-.115	-.129	1	-.046	-.002
Pb	.051	.39**	.019	.020	.042	-.092	.003	-.052	.243*	.023	-.042	.036	-.005	.021	.136	.097	.062	.019	.258*	-.006	.092	-.046	1	.242*
Zn	-.175	.208*	-.014	-.014	-.016	-.009	.170	.098	.247*	.084	-.054	-.034	-.01	.219*	.118	.058	.208	-.099	.109	.112	.41**	-.002	.242*	1

* Correlation is significant at the 0.05 level (2-tailed). ** Correlation is significant at the 0.01 level (2-tailed). TH= Total Hardness, TA= Total Alkalinity, Tur. =Turbidity, Sal. = Salinity

pH

pH of Chittagong region groundwater samples have found pH in the acidic to alkaline (6.04-8.96) range. The lower values of pH, below the WHO limit (6.5-8.5), were found for the samples of Chittagong city (6.04) and Hathazari (6.20) Upazila. pH was found positively correlated with nitrate, total alkalinity, and arsenic, and negatively correlated with turbidity, phosphate and manganese. According to Halim *et al.* [12] the groundwater samples had pH values in the range between 6.9 and 7.3 with a mean value of 7.05 in Sherajdi khan, Bangladesh.

Temperature

The temperature of Chittagong region groundwater samples observed that almost all of the samples temperature within the permissible limit shown in (**Tab.1-8**).

Electrical conductivity (EC)

Most of the samples EC values of groundwater found below the WHO limit (500.00-mgL⁻¹) for drinking water but few samples of EC value quite higher of Chittagong (Hathazari 3020.00- mgL⁻¹) districts are far beyond the permissible limit. EC was found positively correlated with TDS, salinity, chloride, turbidity, phosphate, total hardness, total alkalinity and arsenic. Kouras [13] reported that in groundwater in the area of Chalkidiki, Northern Greece EC was relatively high, ranging from 828 to 1970- μScm^{-1} , with mean value 1406- $\mu\text{S/cm}^{-1}$.

Total dissolved solids (TDS)

Total dissolved solids are terms generally associated with freshwater systems and consist of inorganic salts, small amounts of organic matter and dissolved materials. Salinity is an oceanographic term and although not precisely equivalent to the total dissolved salt content it is related to it. TDS of Chittagong region groundwater samples observed that most of the samples have TDS values well below the WHO limit (500.00-mg L⁻¹) for drinking water shown in (**Table 1-8**) but some sample points got the higher values such as Chittagong (Chowdhury Hat, Hathazari 1510.00-mgL⁻¹) district are far away from the permissible limit. Water containing more than 500-mgL⁻¹ of TDS is not considered desirable for drinking water supplies, though more highly mineralized water may be used where better quality water is not available[14]. TDS was found positively correlated with EC, salinity, chloride, turbidity, phosphate, total hardness, total alkalinity and arsenic. Excess dissolved solids are objectionable in drinking water because of possible physiological effects, unpalatable mineral tastes and higher costs because of corrosion or the necessity for additional treatment.

Salinity

Almost all of the samples salinity value got within the permissible limit. Salinity was found positively correlated with chloride, EC, TDS, total alkalinity, total hardness, turbidity, phosphate, arsenic and nickel.

Chloride

Chloride content of Chittagong region groundwater samples recorded shown in (**Table1-8**). Most of the samples have chloride below 200.0-mgL^{-1} which are also within the permissible limit (250.00-mgL^{-1}) of for drinking water). Chloride was found positively correlated with salinity, TDS, acidity, total alkalinity, total hardness, phosphate and arsenic.

Dissolved Oxygen (DO)

Dissolved oxygen is an important parameter in water quality assessment and biological processes prevailing in the water. The DO values indicate the degree of pollution in the water bodies. The presence of dissolved oxygen (DO) enhances the quality of water and also acceptability [15]. An ideal DO value of 5.0mgL^{-1} is the standard for drinking water. Dissolved oxygen (DO) of bore well water under the area determined in the present investigation ranged between from $3.4\text{--}8.5\text{-mgL}^{-1}$. Most of the DO value of Chittagong region groundwater samples was within the permissible limit as prescribed by WHO. Only a few samples have found under permissible limit. Kerketta *et al.* [15] found the value of DO (3.95 ± 0.05 to $8.95\pm 0.15\text{-mgL}^{-1}$) around Ranchi, Jharkhand, India. DO was found positively correlated with BOD and nickel and negatively correlated with temperature and copper.

Turbidity

Greater part of the samples of turbidity exceeds the permissible limit. Results observed the minimum and maximum value of turbidity is 0 to 203 NTU. Turbidity was found positively correlated with EC, TDS, salinity and manganese and negatively correlated with pH.

Phosphate

Phosphate of Chittagong region groundwater samples revealed that most of the samples have o-phosphate-P value below 5.00-mgL^{-1} . High value of phosphate was observed in Chittagong (Barotakia, Mirsharai 9.3-mgL^{-1}) district shown in (**Tab.-3**) are beyond the Bangladesh Standard Testing Institute (BSTI) limit for drinking water. Phosphate was found positively correlated with chloride. Phosphate was found positively correlated with EC, TDS, salinity, total alkalinity, arsenic, nickel, lead and zinc and negatively correlated with pH.

Sulphate and Nitrate

Sulphate and Nitrate of Chittagong region groundwater samples showed that maximum samples have sulfate-S value below 300.00-mgL^{-1} and nitrate-N value below 2.00-mgL^{-1} . Highest value of sulphate and nitrate was found 75-mgL^{-1} and 3.20-mgL^{-1} respectively for the sample of Chittagong district, which are also within the WHO limit for drinking water. Sulfate content of this region are within the acceptable limit of BSTI standard [16] (Max 400-mgL^{-1}). Sulfate was found positively correlated with total hardness and nickel. Nitrate was found positively correlated with pH and nickel.

Total hardness

Total hardness of Chittagong region groundwater samples have found below 300.0-mgL^{-1} . Total hardness was found positively correlated with EC, TDS, salinity, chloride and sulphate.

Total alkalinity

Chittagong region groundwater samples revealed that most of the samples have alkalinity below 500.0-mgL^{-1} . Highest value of alkalinity was found in Chittagong district 1097.77-mgL^{-1} . According to Gupta *et al.* [17] the city of Taz Mahal, India, total alkalinity of groundwater samples ranged from $200\text{-}600\text{-mgL}^{-1}$. Total alkalinity was found positively correlated with pH, EC, TDS, salinity, chloride and phosphate.

Biological oxygen demand (BOD)

Biochemical oxygen demand (BOD) is a chemical procedure for determining the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic

material present in a given water sample at certain temperature over a specific time period. It is not a precise quantitative test, although it is widely used as an indication of the organic quality of water. According to WHO (1993), the permissible limit of BOD in water is 5- mgL⁻¹. However, in all the stations samples showed that BOD value within permissible limits set by WHO and BSTI (Tab. 1-8).

Chemical oxygen demand (COD)

Chemical Oxygen Demand (COD) is a measure of pollution in aquatic system. High COD may cause oxygen depletion on account of decomposition by microbes to a level detrimental to aquatic life. In the present study COD values were found in the range of 2.8 to 156.8-mgL⁻¹ (Tab.1-8).

Acidity and Carbon dioxide (CO₂)

Acidity and CO₂ content of greater Chittagong district groundwater samples shows that all samples acidity and CO₂ values were in the permissible limits.

Arsenic (As)

A large number of sampling areas did not found Arsenic content of the greater Chittagong. About 1% of the samples contained arsenic ≥ 0.5 -mgL⁻¹ and 17% of the samples contained arsenic ≥ 0.1 -mgL⁻¹. Highest value was found of Chittagong district is 0.5-mgL⁻¹, which is far above the WHO limit (0.01-mgL⁻¹) for drinking water. Arsenic contamination of groundwater is a huge health problem and the largest environmental catastrophe now taking place in Bangladesh. Millions of people were suffering from chronic arsenic poisoning not only in Bangladesh but also in many countries of the world. Miah *et al.* [18] reported that irrigation with high arsenic water (>100 - μ gL⁻¹) is positively related to the high arsenic content in wetland rice. Proper investigation is urgently required to address the issue of food and medicine contamination with arsenic. Rahman *et al.* [19] also reported that $>94\%$ shallow tube wells of Mirsharai and 82.7% of Sitakunda Upazila contained arsenic above the permissible limit. Groundwater contamination by arsenic is a big threat to the lives of thousands of people in Bangladesh. Positively correlation was found for arsenic with pH, TDS, salinity, EC, PO₄³⁻, total alkalinity, and nickel. According to Halim *et al.*[12] groundwater samples had dissolved arsenic ranged from 0.006 to 0.461-mgL⁻¹, with 69% groundwater samples exceeded the Bangladesh limit for safe drinking water (0.05-mgL⁻¹)[20]. According to Hossain *et*

al. [21] an estimated 50 million people are at risk from drinking arsenic contaminated water in Bangladesh and West Bengal, India. Although Arsenic was found in many samples of this region, in comparison with other regions of this division, such as Comilla and Noakhali, this region is less prone to arsenic.

Iron (Fe)

Iron is an essential trace element required by both plants and animals. In some waters it may be a limiting factor for the growth of algae and other plants. Iron content of Chittagong region groundwater samples revealed that most of the samples contained iron above the WHO permissible limit of 0.30-mgL^{-1} . The highest values for Chittagong 11.20-mgL^{-1} which is far above the permissible limit for drinking water. Iron was found positively correlated with manganese and negatively correlated with pH. According to Rahman, *et al.* [22] the mean iron concentration in the groundwater samples from Cox's Bazaar district was 6.7-mgL^{-1} , which is above the standard (0.30-mgL^{-1}) set by WHO for iron content in potable water. According to Ray *et al.* [23] the distributed data for iron shows that 62.9% of the observations are equal to or less than the allowable limit of 0.3-mg L^{-1} , the maximum concentration being 60.8-mg L^{-1} in Rohtas district of Bihar. Higher values of iron content of all the districts is higher than the permissible limit of 0.3-mgL^{-1} for domestic water supplies [20]. Iron has positive correlation with arsenic.

Cadmium (Cd)

Cadmium content all the stations found in the range below detection limit (BDL) to 0.0094- mgL^{-1} . All the values were within the permissible limits. Important source of cadmium is the use of mineral phosphate fertilizer, which typically contains high cadmium concentrations in addition to other elements. Kerketta *et al.* [15] found the range for cadmium is (0.04 ± 0.01 to $0.11\pm 0.03\text{-mgL}^{-1}$) around Ranchi, Jharkhand, India.

Cobalt (Co) and Chromium (Cr)

Cobalt concentrations of greater Chittagong district were found very low and less than the permissible limits. Chromium content in the sampling areas was within the range BDL- 0.193-

mgL⁻¹. Most of the sample point's chromium (Cr) concentration was less than the permissible limits set by WHO and BSTI.

Copper (Cu)

All the stations showed the concentrations of Copper (Cu) between BDL to 0.18-mgL⁻¹. The low concentrations of copper might be due to non-utilization of copper compounds either as raw material or intermediates in the nearby industrial areas and agricultural practices.

Lead (Pb)

The concentrations of Lead in the present study were found in the range between BDL-0.1105-mgL⁻¹. Rasheed *et al.* [24] reported the lead metal ranged from 0.01 to 0.140-mgL⁻¹ in Uppal Industrial Area, Hyderabad, India, 2013.

Manganese (Mn)

Manganese content of Chittagong region groundwater samples revealed that most of the samples contained manganese above the WHO permissible limit of 0.1-mgL⁻¹. Manganese was found positively correlated with iron only.

Nickel (Ni)

Nickel content of Chittagong region groundwater samples found to BDL to 0.035-mgL⁻¹. The minimum and maximum concentrations of nickel were found Chittagong district. Rasheed *et al.* [24] reported the nickel metal ranged from 0.05 to 0.420-mgL⁻¹ in Uppal Industrial Area, Hyderabad, India 2013.

Zinc (Zn)

In the present study all the stations showed the values of zinc between BDL to 0.8052-mgL⁻¹. Zinc is a nutritionally essential element. It is necessary for growth and is involved in several physiological functions.

Conclusions

The present physicochemical study of groundwater resources of greater Chittagong region discloses the status of water quality of this region. It also identifies the sources and intensity of pollution load on groundwater resources of this region. Higher value of TDS and EC were found in some points of Hathazari Upzilla in Chittagong district. Iron content exceeds the WHO and BSTI limit in Chittagong City Corporation areas and some other points of Chittagong district. Some sampling point of Chittagong district have found high value of total alkalinity. Groundwater of Mirsharai and Anwara Upazilas are more prone to arsenic than other upazilas of this region. The vulnerable condition of Mirsharai area of ground water as described its high value of acidity, Carbon dioxide, Phosphate, Turbidity and arsenic.

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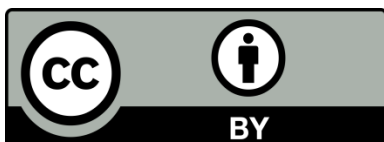
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