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Physico-chemical Properties of Effluents Discharged from Different Industries of Gazipur, Bangladesh and its Suitability for Agricultural Land

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Abstract: The study was conducted to assess physical parameters, major ionic constituents and trace metals content at Gazipur area to know the quality of effluent during March in 2013 for irrigation usage. The pH of collected effluent samples were almost neutral but in case of TDS values all the samples were suitable for irrigation where considering EC values almost harmful for irrigation. The anion i.e. in case of CO_3, SO_4 and PO_4 all the collected effluent samples were suitable for irrigation but in case of almost Cl values and all HCO_3 values unsuitable for irrigation. Similarly, the cation i.e. in case of Na, Mg, Ca and K all the collected effluent samples were suitable for irrigation. Among the studied trace metals (Fe, Zn, Cu, Pb, Cd and Mn) all of the collected effluent samples were suitable for irrigation except two samples for Mn and Cu. On the other hand, in case of SAR most of the samples were excellent category but in case of SSP most of the samples were graded as doubtful and in case of RSC and hardness most of the samples were unsuitable class for irrigation purposes. So to protect the agricultural land whole of the study area a pollution free technology such as Effluent Treatment Plants (ETP) to each industry should be established.

Key Words: Industrialization, Effluent, Trace metals and Water pollution

Introduction

Bangladesh lies in the northeastern part of South Asia between 20°34´ to 26°38´ North latitude and 88°01´to 92°41´East latitude. It is one of the least developed countries with a low resources base under high population pressure, a low land man ratio. More than 124 million people live in the country of 147570 sq. km area. Rapid population growth increasing poverty, unemployment and scarce of natural resources leading the country to least developed. The vast majority of the population depends on natural resources. However, most of the resources are over-exploited. This is causing environmental deprivation in the way of at present day's unplanned industrialization and urbanization, vehicular pollution, deforestation, unsustainable agriculture practices etc. They offer the alteration of physical, chemical and biological properties of air, water and soil counting change in temperature, odor, noise, turbidity, ray and to the original properties that is harmful to public health, livestock, wildlife, fish and other biodiversity (Huq *et al.,* 1993; Mohammad *et al.*, 2011).

The industrial areas in Bangladesh are situated in the middle part of densely populated regions and the growth of industries has generally been unplanned without keeping the issue of environmental protection in careful consideration. Gazipur District is one such industrial cluster where rapid, unplanned industrial expansion has led to serious local pollution. This area was historically important rice growing area but its close proximity to Dhaka has gradually led to more industries locating there over the past 15 years. There are now several types of industry in the area including tannery, poultry farms and pharmaceutical industries but it is dominated by textile manufacturers, including dyeing and printing units. There are so many industries in Gazipur, only a few of them have installed effluent treatment plant (ETP). Indiscriminate discharges of liquid waste by the industries in and around Gazipur industrial has ruined a large part of the Turag River and Baimail *jheel* causing immense sufferings to residents living on the banks as well as surrounding agricultural land (Rashid, 2012).

Local peoples say bricks kilns have left their fruit trees unproductive, while industrial waste exterminated fish in the river and nearby water bodies, increased mosquitoes and made cropland infertile. Bangladesh Small and Cottage Industrial Corporation (BSCIC) were established at Konabari in 1980 by the Bangladesh Government to promote and expand small and cottage industries. Since then the industries are polluting surrounding environment despite getting different facility packages from the government. Recently, the BSCIC authority have made a list of 152 polluting industries that include 56 dyeing and textile industries, 50 chemical and pharmaceuticals, 9 food processing industries and other 37 engineering industries. None of these industries has installed an effluent treatment plant (ETP). The BSCIC provided to the entrepreneur in a subsidized price along with many other facilities, but most of the industries are paying back by polluting the environment. The industry waste has spoiled everything (CNN Report, 2012).

Keeping all this views in mind an experiment was set up to assess the physico-chemical properties of the effluents such as pH, DO, TDS, EC, chloride, phosphate, sulphate, calcium, magnesium, carbonate, bicarbonate, sodium and pottasium discharged from different industries, to determine the status of trace metals (Fe, Cd, Pb, Cu, Zn, Mn) concentration of the effluent discharged from different industries and to assess the suitability of the effluents as irrigation water.

Materials and Methods

A total of 26 effluent samples were collected from Chandra to Baimail beside the Chandra-Gazipur Chourasta highway road at the outlet of different industries under the Gazipur districts during March in 2013 following the sampling techniques as outlined by APHA (1995) and Sincero and Sincero (2004) shown in Table 1. Each effluent samples were collected in 500 ml narrow-mouth high density polyethylene bottles. Each bottle were cleaned in the laboratory with dilute HCl (1:1) and then rinsed twice with distilled water. Before sampling, bottles were also rinsed with the sampled effluent. After sampling, the bottles containing samples were sealed immediately to avoid exposure to air and marked with necessary information. Then all the effluent samples were analysed for pH, EC, TDS and DO at the laboratory of Department of Environmental Science and Resource Management (ESRM), Mawlana Bhashani Science and Technology University (MBSTU), Tangail. The samples for the analysis of trace metals were carefully filtered through Whatman filter paper no. 42 to remove undesirable solid and suspended materials. After filtration 150 ml of each sample was taken and a few drops of concentrated HNO_3 (extra-pure) was added into the samples and then kept in the freeze for further analysis. Then the samples were taken to the Department of Agricultural Chemistry, Bangladesh Agricultural University (BAU), Mymensingh for analyzed major cations (Ca, Mg, Na and K), major anions (Cl, HCO_3, CO_3, SO_4 and PO_4) and trace metals (Fe, Mn, Zn, Pb, Cd and Mn) following standard analytical methods. Calcium and magnesium were determined titrimetrically using standard Na_2EDTA. Chloride was measured by titrimetrically using standard $AgNO_3$ solution. Carbonate and bicarbonate were also determined by titrimetrically using standard H_2SO_4 solution. Sodium and potassium were measured by flame photometrically whereas sulphate and phosphate were determined by spectrophotometrically. The concentrations of Fe, Mn, Zn, Pb, Cd and Cu in effluent samples were analyzed by atomic absorption spectrophotometer by using single hallow cathode lamp at the wavelengths of 248.3, 279.5, 213.9, 283.3, 228.8 and 324.7 nm, respectively following the procedure as described by APHA (1995). The parameters such as sodium adsorption ratio (SAR), soluble sodium percent (SSP), residual sodium carbonate (RSC), permeability index (PI) and hardness (H_T) were calculated to evaluate the suitability of the effluent quality for agricultural purposes. Further the results of the analyses were interpreted using graphical representations like SAR vs salinity hazard as described by Richards (1968) and Doneen plot (1964).

Results and Discussions

The results of the analysis of effluents samples collected from different industrial outlet are given in Table 2 & 3. Figure 1 shows the percent contribution of individual ions towards the total cationic and anionic mass balance.

a) Physicochemical properties of effluent

The pH of collected effluent samples were fluctuated between 6.05 to 7.28 with a mean value of 6.64 (SD±0.35) indicating little acidity to alkaline of water (Table 2). These might be due to the presence of ions such as Ca, Mg and Na in water (Rao *et al.*, 1982). According to Ayers and Westcot (1985), the acceptable range of pH for irrigation water is 6.5 to 8.4. On the basis of measured pH of all collected effluent samples were not problematic for long-term irrigation. The EC of all collected effluent samples were within the range of 181 to 1995 $\mu S\ cm^{-1}$ with an average value of 1337.35 $\mu S\ cm^{-1}$ (SD±494.50) (Table 2). According to Richards (1968), samples under test were rated in the category C1 (EC < 250 μScm^{-1}), C2 (EC = 250-750 μScm^{-1}) and C3 (EC = 751-2250 $\mu S\ cm^{-1}$) indicating low to high salinity. Medium salinity class water might be applied with moderate leaching. High salinity class of water was treated as unsuitable for irrigation purpose (Agarwal *et al.*, 1982). On the basis of measured EC most of the collected effluent samples were problematic for long-term irrigation. A similar observation was reported by Singh *et al*. (2010) for waste water of Raniganj industrial area in India.

Table 1: Detailed information regarding effluents sampling sites at the major polluting industrial areas of Gazipur, Bangladesh

Sample ID.	Name of the industry	Sampling area
01	Moizuddin Knitwaer Limited	Bimail (Konabari)
02	Delta Composite Textile Limited	Sofipur
03	General Pharmaceuticals Ltd.	Mouchak
04	Beximco Pharmaceuticals	Mouchak
05	Zaber and Zubuaer Fabrics limited	Bimail (Konabari)
06	Hydroxide Knitwear Limited	Mouchak
07	Amco Drugs Industries	BSCIC (Konabari)
08	Cotton Club Limited	Zurun (Konabari)
09	Purbani Yarn Dyeing Ltd.	Mouchak
10	N.T.K.C Apparels Ltd.	Bimail (Konabari)
11	Pasha Yarn Dyeing	Sofipur (pollybiddyut)
12	Islam Group	Zurun (Konabari)
13	BSCIC-1	Konabari
14	Jalal Yarn Dyeing	Sofipur (pollybiddyut)
15	Mondol Group of Company	Zurun (Konabari)
16	R.L Yarn Dyeing	Sofipur (pollybiddyut)
17	Purbani Fabrics Dyeing Limited	Mouchak
18	A.T.S Apparels Limited	Mouchak
19	IBN-SINA Pharmaceuticals	Sofipur (Gazipur)
20	Standard Group	Zurun (Konabari)
21	BSCIC-2	Konabari
22	New way Clothings	Mouchak
23	Karooni Kniting Limited	Mouchak
24	Shadin Group	Zurun (Konabari)
25	Apex Dyeing Industries	Sofipur (pollybiddyut)
26	Moazzem Kniting and Dyeing Industries	Zurun (Konabari)

The DO of all collected effluents samples were within the range of 0.3 to 1.5 mg L^{-1} with an average value of 0.59 mg L^{-1} (SD±0.25) (Table 2). Adequate dissolved oxygen is necessary for good water quality as well as to all forms of life. As dissolved oxygen levels in water drop below 5.0 mg L^{-1}, aquatic life is put under stress. The acceptable range of DO for fish culture is 5 mg L^{-1} to saturation (Meade, 1998). On the basis of measured DO of all effluent samples collected from the Gazipur industrial area was problematic for aquatic life but DO is not essential for irrigation purposes. TDS values of collected effluent samples were within the range of 465 to 1587 mg L^{-1} with an average value of 957.57 mg L^{-1} (SD±293.07) (Table 2). Most of effluent samples containing TDS < 1000 mg L^{-1} were rated as fresh water (Freeze and Cherry, 1979). High TDS values indicated the presence of an appreciable quantities of bicarbonates, sulphates and chlorides of Ca, Mg and Na (Karanth, 1994). On the basis of measured TDS most of the collected effluent samples were rated as fresh water that is not problematic for irrigation purposes. A similar observation was reported by Singh *et al*. (2010) for waste water of Raniganj industrial area in India.

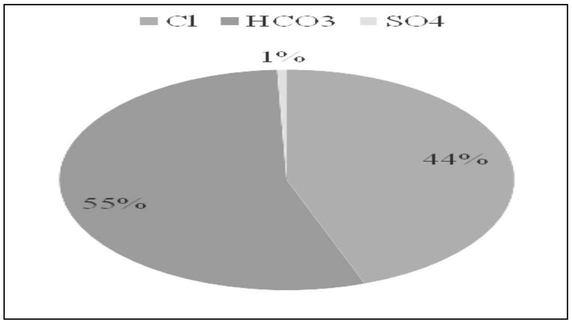
b) Major anionic constituents in water

Chloride concentration in collected effluent samples were ranging from 1.40 to 25.77 me L^{-1} with an average value of 5.92 me L^{-1} (SD±5.42) (Table 2) and contributed 44 % of the total anionic balance (Fig. 1). Maximum permissible limit of Cl in irrigation water is 4.00 me L^{-1} (141.80 mg L^{-1}) as reported by Ayers and Westcot (1985). On the basis of this report, only 9 effluent samples were within the permissible limit and suitable for irrigation and the rest 18 effluent samples were exceed the permissible limit and not suitable for irrigation. Excess chloride in the study area may result from anthropogenic sources including domestic and industrial wastes water (Appelo and Postma, 1993). The concentration of HCO_3 in effluent samples were within the range of 4.0 to 14.0 me L^{-1} with the mean value of 7.31 me L^{-1} (SD±2.51) (Table 2) and contributed 55 % of the total anionic balance (Fig. 1). In respect of HCO_3 content, all of the studied effluent samples were found unsuitable for irrigation, which exceed the recommended limit (1.50 me L^{-1}) as reported by Ayers and Westcot (1985).

Table 2: Physicochemical properties and major anionic constituents of effluent collected from the major polluting industrial areas of Gazipur in Bangladesh

Sample ID	pH	EC µS cm^{-1}	DO mg L^{-1}	TDS mg L^{-1}	Cl me L^{-1}	CO_3 me L^{-1}	HCO_3 me L^{-1}	PO_4 mg L^{-1}	SO_4 mg L^{-1}
1	6.89	1995	0.80	1366	25.77	Trace	9.00	0.061	0.136
2	6.65	1560	0.40	1052	1.93	Trace	6.00	0.053	0.072
3	6.90	1880	0.40	1150	5.49	Trace	10.00	0.139	0.205
4	6.89	1890	0.40	1130	9.00	Trace	14.00	0.102	0.057
5	6.18	1370	0.60	950	4.78	Trace	9.00	0.077	0.274
6	7.28	1890	0.40	1233	16.89	Trace	8.00	0.075	0.954
7	7.01	1130	0.70	720	2.81	Trace	6.00	0.135	0.249
8	6.67	195	0.30	1587	14.36	Trace	6.00	0.081	0.282
9	6.05	1720	0.90	1071	1.40	Trace	8.00	0.044	0.465
10	7.09	1380	0.50	921	4.78	Trace	8.00	0.084	0.143
11	6.52	1780	0.70	1088	6.47	Trace	9.00	0.285	0.283
12	6.69	181	0.30	1450	2.53	Trace	11.00	0.032	0.541
13	6.28	1380	0.60	720	5.34	Trace	4.00	0.015	0.204
14	6.75	1900	0.70	1322	7.60	Trace	9.00	0.051	0.030
15	6.19	1160	0.50	739	2.81	Trace	5.00	0.041	0.193
16	6.35	1760	0.60	1125	4.78	Trace	8.00	0.053	0.235
17	6.15	780	1.50	486	4.93	Trace	10.00	0.258	0.370
18	6.39	1010	0.60	641	4.22	Trace	7.00	0.146	0.057
19	7.08	990	0.90	629	2.53	Trace	6.00	0.175	0.045
20	6.57	1520	0.30	955	1.55	Trace	4.00	0.077	0.407
21	6.26	1360	0.50	887	5.49	Trace	5.00	0.047	0.102
22	7.15	1010	0.80	627	4.08	Trace	9.00	0.047	0.069
23	6.61	1660	0.50	930	2.53	Trace	4.00	0.123	0.662
24	6.91	1140	0.60	740	4.50	Trace	4.00	0.010	0.180
25	6.43	750	0.50	465	2.11	Trace	5.00	0.038	0.067
26	6.75	1380	0.40	913	5.34	Trace	6.00	0.103	0.121
Max.	**7.28**	**1995**	**1.50**	**1587**	**25.77**	**Trace**	**14.00**	**0.29**	**0.95**
Min.	**6.05**	**181**	**0.30**	**465**	**1.40**	**Trace**	**4.00**	**0.01**	**0.03**
Mean	**6.64**	**1337.35**	**0.59**	**957.57**	**5.92**	**Trace**	**7.31**	**0.09**	**0.25**
SD	**0.35**	**494.50**	**0.25**	**293.07**	**5.42**	**Trace**	**2.51**	**0.07**	**0.22**

The phosphate content of collected effluent samples were varied from 0.01 to 0.29 mg L^{-1} with a mean value of 0.09 mg L^{-1} (SD±0.07) (Table 2). Maximum permissible limit of PO_4 in irrigation water is 2.00 mg L^{-1} (Ayers and Westcot, 1985). Considering this value as standard out of the 26 effluent samples, all the samples were within the permissible limit and suitable for irrigation. The SO_4 content of all collected effluent samples were ranged between 0.03 to 0.95 mg L^{-1} with a mean value of 0.25 mg L^{-1} (SD±0.22) (Table 2) and contributed 1% of the total anionic balance (Fig. 1). Maximum permissible limit of SO_4 in irrigation water is 20.00 mg L^{-1} (Ayers and Westcot, 1985). Out of the 26 effluent samples, all the samples were within the permissible value and suitable for irrigation.



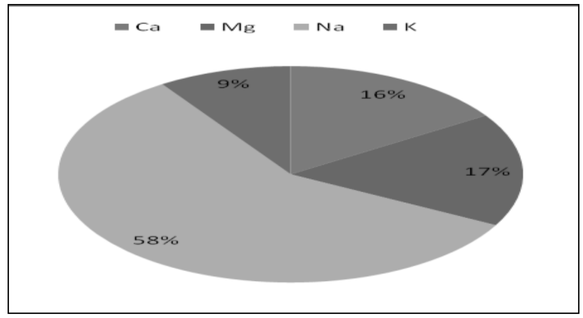


Fig. 1: Contribution of individual major ions towards the total anionic (a) and cationic (b) mass balance in effluent of major polluting areas of Gazipur, Bangladesh

c) Major cationic constituents in water

The content of Ca in collected effluent samples were varied between Trace to 80.16 mg L^{-1} with an average value of 43.16 mg L^{-1} (SD±14.01) (Table 3) and contributed 16 % of the total cationic mass balance (Fig. 1). The contribution of Ca in effluent was largely dependent on the solubility of $CaCO_3$, $CaSO_4$ and rarely on $CaCl_2$ (Karanth, 1994). Irrigation water containing less than 20 me L^{-1} (800 mg L^{-1}) Ca that is suitable for irrigating crops (Ayers and Westcot, 1985). On the basis of Ca content, all effluent samples could safely be used for irrigation and soils of the study area would not be affected.

The concentration of Mg in collected effluent samples were detected within the range of 21.87 to 92.32 mg L^{-1} with an average value of 46.06 mg L^{-1} (SD±13.96) (Table 3) which contributed 17% of the total cationic balance (Fig. 1). According to Ayers and Westcot (1985), irrigation water containing below 5.0 me L^{-1} (121.5 mg L^{-1}) Mg that is suitable for crops and soils. Considering this as standard, all effluent samples were within this recommended limit and could safely be used for irrigation and would not affect soils of the study area. The content of Na in collected effluent samples were varied from 36.58 to 379.29 mg L^{-1} with the mean value of 157.54 mg L^{-1}(SD±118.7) (Table 3) and contributed 58 % of the total cationic mass balance (Fig. 1). Na in the aquatic system is mainly derived from atmospheric deposition; evaporate dissolution and silicate weathering (Berner and Berner, 1987). According to Ayers and Westcot (1985), irrigation water generally containing less than 40 me L^{-1} Na that is suitable for crops and soils. The detected Na content in all the effluent samples under test were far below this specified limit and could safely be applied for long-term irrigation without any harmful effect on soils and crops. The concentration of K present in collected effluent samples were varied from 11.71 to 64.75 mg L^{-1} with the mean value of 25.43 mg L^{-1} (SD±11.62) (Table 3) and contributed 9 % of the total cationic mass balance (Fig. 1). According to Ayers and Westcot (1985), the recommended limit of K in irrigation water is 2.0 mg L^{-1}. In the investigated area, all of the effluent samples exceeded the permissible limit for irrigation purposes.

d) Heavy metal concentration in water

Table 3 showed the concentration of trace metals found in collected effluent samples. The Fe content of collected effluent samples ranging from trace to 0.27 mg L^{-1} with an average value of 0.02 mg L^{-1} (SD±0.09) (Table 3). According to Ayers and Westcot (1985), maximum recommended concentration of Fe in water used for irrigation is 5.0 mg L^{-1}. Considering this limit as standard, amount of Fe in all effluent samples of the study area were below the recommended value and suitable for irrigation. The concentration of Mn in collected effluent samples were ranging from Trace to 0.29 mg L^{-1} with an average value of 0.04 mg L^{-1} (SD ±0.08) (Table 3). According to Ayers and Westcot (1985), maximum recommended limit of Mn in water used for irrigation is 0.20 mg L^{-1}. Considering this limit as standard, amount of Mn in all effluent samples except one (Sample No. 6) of the study area were below the recommended value that is suitable for irrigation. The collected effluent samples contained Cu were varied from Trace to 4.91 mg L^{-1} with an average value of 0.19 mg L^{-1} (Table 3). Among the 26 effluent samples except one sample (Samples no. 17), all samples were found within the recommended limit as described by Ayers and Westcot (1985) for irrigation where its acceptable limit is 0.20 mg L^{-1}. The National Academy of Science has recommended that for continuous use irrigation effluent water should contain no more than 0.2 mg L^{-1} Cu (Gibeault and Cockerham, 1985). Zn concentration in collected effluent samples from the Gazipur industrial areas varied from Trace to 0.01 mg L^{-1} with an average value of 0.001 mg L^{-1} (SD±0.005) (Table 3). The

National Academy of Science has recommended that for continuous use of irrigation for effluent should contain Zn no more than 5.0 mg L^{-1} (Gibeault and Cockerham, 1985). On the other hand, according to Ayers and Westcot (1985) the maximum permissible limit of Zn in irrigation water is 2.00 mg L^{-1}. Considering this limit as standard, all effluent samples were found within the maximum permissible limits which were suitable for irrigation in respect of Zn. The collected effluent samples contained Pb were fluctuated from Trace to 0.24 mg L^{-1} with an average value of 0.05 mg L^{-1} (SD±0.06) (Table 3). According to Ayers and Westcot (1985), the standard limit of lead is 5.00 mg L^{-1} for irrigation purposes, which indicates that all of these effluent can safely be used for irrigation as well as other purposes in respect of lead. The concentration of Cd in collected effluent samples were Trace in amount of Cd. Considering these amount of Cd in industrial effluent, all the effluents samples were suitable for irrigation in respect of cadmium**.**

e) Suitability of water for irrigation usage

The important characteristics or properties of water to be considered for irrigation use are electrical conductivity, salinity, percent sodium, sodium adsorption ratio, residual sodium carbonate and permeability index.

Table 3: Heavy metals and major cationic constituents of effluent collected from Gazipur industrial area in Bangladesh

Sample ID	Ca mg L^{-1}	Mg mg L^{-1}	Na mg L^{-1}	K mg L^{-1}	Mn mg L^{-1}	Cu mg L^{-1}	Zn mg L^{-1}	Pb mg L^{-1}	Fe mg L^{-1}	Cd mg L^{-1}
1	60.12	38.88	290.65	11.71	Trace	Trace	Trace	Trace	Trace	Trace
2	36.07	46.17	251.97	12.92	0.156	Trace	Trace	Trace	0.113	Trace
3	56.11	55.89	62.71	48.95	Trace	Trace	Trace	Trace	Trace	Trace
4	Trace	60.75	67.23	17.38	0.179	Trace	Trace	Trace	Trace	Trace
5	48.09	43.74	36.58	27.10	Trace	Trace	0.004	0.082	Trace	Trace
6	40.08	51.03	67.46	64.75	0.286	Trace	Trace	0.106	Trace	Trace
7	52.14	48.60	85.33	23.04	Trace	Trace	Trace	0.094	Trace	Trace
8	32.06	31.59	355.17	24.25	Trace	Trace	Trace	0.175	Trace	Trace
9	60.12	43.74	273.77	44.04	Trace	Trace	Trace	0.235	Trace	Trace
10	Trace	43.74	92.36	26.28	Trace	Trace	Trace	0.036	Trace	Trace
11	Trace	48.60	322.01	23.04	0.102	Trace	Trace	0.036	0.075	Trace
12	Trace	21.87	249.14	23.44	Trace	Trace	Trace	0.129	Trace	Trace
13	60.12	36.45	92.86	23.45	0.009	Trace	Trace	0.153	Trace	Trace
14	44.08	48.60	352.16	25.47	Trace	Trace	Trace	Trace	Trace	Trace
15	32.06	31.59	89.35	20.62	0.019	Trace	Trace	Trace	Trace	Trace
16	44.08	40.74	337.08	23.04	0.020	Trace	Trace	Trace	Trace	Trace
17	60.12	29.16	73.77	16.97	Trace	4.91	0.011	Trace	0.272	Trace
18	72.14	60.75	62.71	22.23	Trace	Trace	Trace	Trace	Trace	Trace
19	64.13	58.32	58.19	31.55	0.083	Trace	Trace	Trace	Trace	Trace
20	44.08	36.45	98.89	12.92	Trace	Trace	Trace	Trace	Trace	Trace
21	40.08	41.41	93.87	23.04	Trace	Trace	Trace	Trace	Trace	Trace
22	44.13	55.89	63.22	21.83	0.090	Trace	0.001	Trace	Trace	Trace
23	80.16	63.18	379.29	31.54	0.107	Trace	0.011	0.059	0.143	Trace
24	64.12	53.46	80.80	21.02	0.040	Trace	Trace	0.008	Trace	Trace
25	48.09	51.03	66.73	14.54	0.006	Trace	Trace	0.094	Trace	Trace
26	40.08	92.32	92.86	26.28	0.022	Trace	Trace	0.153	0.019	Trace
Max.	**80.16**	**92.32**	**379.29**	**64.75**	**0.29**	**4.91**	**0.01**	**0.24**	**0.27**	**Trace**
Min.	**Trace**	**21.87**	**36.58**	**11.71**	**Trace**	**Trace**	**Trace**	**Trace**	**Trace**	**Trace**
Mean	**43.16**	**46.06**	**157.54**	**25.43**	**0.04**	**0.19**	**0.001**	**0.05**	**0.02**	**Trace**
SD	**14.01**	**13.96**	**118.70**	**11.62**	**0.08**	**-**	**0.005**	**0.06**	**0.09**	**-**

(i) Sodium adsorption ratio (SAR)

A high Na concentration changes soil properties and reduces soil permeability, which leads to development of an alkaline soil (Singh *et al.*, 2010). The Na or alkali hazard is determined by the absolute and relative concentration of cations and is expressed in terms of the SAR, which is determined by the following formula:

$$SAR = Na^{+}/ \sqrt{(Ca^{2+} + Mg^{2+})/2}$$

[all concentrations in meq L^{-1}]

The computed SAR of effluent samples were ranged from 2.66 to 45.9 with a mean value of 12.6 (SD±11.13) (Table 4). According to Todd (1980) categorized irrigation water into 4 groups. Considering this classification, 17 effluent samples were graded as excellent category for irrigation purpose, 6 were graded as fair and the rest 3 effluent samples were graded as poor for irrigation purposes. The present investigation revealed that a good proportion of Ca and Mg existed in all effluent. These were suitable for good structure and tilth condition of soil and also the improvement of soil permeability. The plot of data on the US salinity diagram as described by Richards (1968), in which the EC is taken as salinity hazard and SAR as alkalinity hazard shows that effluents samples were in the category of C3S4, C3S1, C1S4, C3S2 and C2S1 indicating low alkalinity to high salinity and low alkali hazard (Fig. 2). Low sodium water (S1) can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium.

Table 4: Quality rating and suitability of water for irrigation collected from the major polluting areas of Gazipur industrial area in Bangladesh

Sample ID	**SAR**	**SSP%**	**RSC meL^{-1}**	**Hard-ness mgL^{-1}**	**Water class based on**				**Alkalinity & salinity hazard classes[5]**
					SAR[1]	**SSP[2]**	**RSC[3]**	**Hardness[4]**	
1	20.4	89.25	-0.59	309.7	Fair	Doubt.	Suit.	VH	C3S4
2	18.7	88.95	2.70	279.4	Fair	Doubt.	Unsuit.	Hard	C3S4
3	4.06	64.68	0.20	379.5	Ex.	Doubt.	Suit.	VH	C3S1
4	5.21	71.51	11.50	249.0	Ex.	Doubt.	Unsuit.	Hard	C3S1
5	2.66	56.87	4.50	489.4	Ex.	Perm.	Unsuit.	VH	C3S1
6	4.75	70.95	3.20	309.7	Ex.	Doubt.	Unsuit.	VH	C3S1
7	5.82	70.98	3.90	329.5	Ex.	Doubt.	Unsuit.	VH	C3S1
8	30.5	93.83	1.40	209.6	Poor	Doubt.	Mar.	Hard	C1S4
9	18.8	88.51	4.70	329.6	Fair	Doubt.	Unsuit.	VH	C3S4
10	5.57	82.96	1.00	299.7	Ex.	Doubt.	Suit.	Hard	C3S1
11	28.4	93.55	9.00	199.2	Poor	Doubt.	Unsuit.	Hard	C3S4
12	45.9	97.21	6.10	89.66	Poor	Doubt.	Unsuit.	MH	C1S4
13	8.52	74.43	1.70	329.4	Ex.	Doubt.	Mar.	VH	C3S2
14	24.9	91.09	16.0	348.8	Fair	Doubt.	Unsuit.	VH	C3S4
15	7.64	79.92	4.90	209.6	Ex.	Doubt.	Unsuit.	Hard	C3S2
16	24.7	91.27	11.1	389.4	Fair	Doubt.	Unsuit.	Hard	C3S4
17	5.57	71.77	7.20	179.3	Ex.	Doubt.	Unsuit.	Hard	C3S1
18	4.57	58.63	2.00	399.4	Ex.	Perm.	Mar.	VH	C3S1
19	3.76	59.76	5.90	749.9	Ex.	Perm.	Unsuit.	VH	C3S1
20	7.59	77.56	6.30	369.4	Ex.	Doubt.	Unsuit.	VH	C3S2
21	7.08	76.54	2.30	269.7	Ex.	Doubt.	Mar.	Hard	C3S2
22	3.98	61.10	9.30	269.8	Ex.	Doubt.	Unsuit.	Hard	C3S1
23	22.2	88.15	2.90	459.4	Fair	Doubt.	Unsuit.	VH	C3S4
24	5.14	66.75	5.10	289.5	Ex.	Doubt.	Unsuit.	Hard	C3S2
25	6.64	65.42	2.70	429.4	Ex.	Doubt.	Unsuit.	VH	C2S1
26	5.25	64.72	1.20	478.7	Ex.	Doubt.	Suit.	VH	C3S1
Max.	**45.9**	**97.55**	**16.00**	**749.9**					
Min.	**2.66**	**56.87**	**-0.59**	**89.66**					
Mean	**12.6**	**67.75**	**4.84**	**331.7**					
SD	**11.13**	**4.19**	**3.93**	**127.9**					

Legend: Ex. = Excellent, Perm. = Permissible, Doubt = Doubtful, MH = Moderately hard, VH = Very hard, Suit. = Suitable, Unsuit.= Unsuitable, Mar. = Marginal, C2 = Medium Salinity, C3 = High Salinity and S1 = Low alkalinity. [1, 2, 3 & 4] = According to Appendix 1, 2, 3 & 4, respectively. [5] = According to Fig. 2.

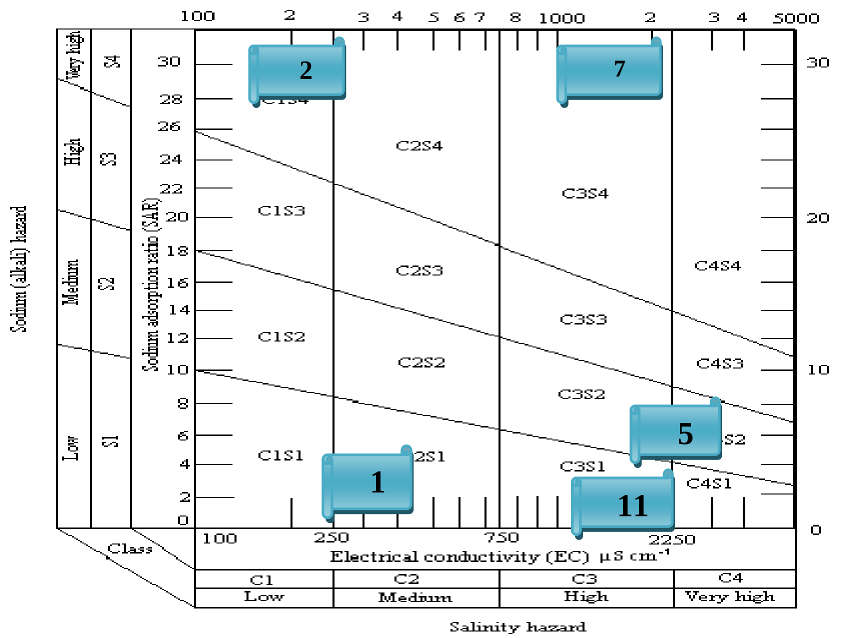


Fig. 2: Diagram for classifying irrigation water on the basis of SAR and EC as described by Richards (1968)

(ii) Soluble sodium percentage (SSP)

Percent Na is widely used for evaluating the suitability of water for irrigation (Wilcox, 1955). High Na irrigation water causes exchange of Na in water for Ca and Mg in soil, reduces permeability, and eventually results in soil with poor internal drainage. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry (Collins and Jenkins, 1996; Saleh *et al*., 1999). The Indian Standard (BIS, 1991) recommends a maximum SSP of 60% for irrigation water, where SSP is calculated by:

$$SSP = [(Na^{+}+K^{+})\times100] / (Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})$$ [all concentrations in meq L^{-1}]

The calculated soluble sodium percentage (SSP) values of all collected effluent samples were varied from 56.87 to 97.55% with the mean value of 67.75% (SD±4.19) (Table 4). According to water classification proposed by Wilcox (1955), out of 26 effluent samples, 3 samples were classified as permissible limit (SSP = 40-60%), 23 samples were classified as doubtful. In the study area, the effluent having permissible limit classes might safely be applied for irrigating agricultural crops but the effluent samples exceed the permissible limit considered as toxic for irrigation.

(iii) Residual sodium carbonate (RSC)

The quantity of bicarbonate and carbonate in excess of alkaline earths (Ca^{2+} + Mg^{2+}) also influence the suitability of water for irrigation purposes. When the sum of carbonates and bicarbonates is in excess of calcium and magnesium, precipitation Ca and Mg may occur (Raghunath, 1987). The effects of carbonate and bicarbonate, and suitability of water for irrigation can be assessed by computing residual sodium carbonate (RSC) values as follows:

$$RSC = (CO_3^{2-} + HCO_3^{-}) – (Ca^{2+} + Mg^{2+})$$ [all concentrations in meq L^{-1}]

A high RSC value in water leads to an increase in the adsorption of Na on soil. Irrigation water having RSC values greater than 5 me L^{-1} are considered harmful to the growth of plants, while water with RSC value above 2.5 me L^{-1} are not considered suitable for irrigation. Hence, continued usage of high RSC water will affect the yields of crop. The computed RSC varied from -0.59 to 16 me L^{-1} with mean value of 4.84 me L^{-1} (SD±3.93) (Table 4). Among the effluent samples under test, 1 sample exhibited negative value. According to Ghosh *et al.* (1983), out of 26 effluent samples, 4 samples were found in suitable class (RSC < 1.25 me L^{-1}), 4 samples were in marginal class (RSC = 1.25-2.50 me L^{-1}) and the rest 18 sample were found in unsuitable class (RSC > 2.50 me L^{-1}).

(iv)Hardness (H_T)

Water hardness has no known adverse effects on human; however, some evidence indicates its role in heart disease (WHO, 2008). Hardness of water resulted due to the abundant presence of divalent cations like Ca^{2+} and Mg^{2+} (Todd, 1980). Hard water is unsuitable for domestic usage, as well as hardness of water limits its use for industrial purposes; causing scaling of pots, boilers and irrigation pipes may cause health problems to humans, such as kidney failure (WHO, 2008). Hardness of water was computed by the following formula:

$$H_T = 2.5 \times Ca^{2+} + 4.1 \times Mg^{2+}$$

The calculated hardness of all effluent samples varied from 89.66 to 749.9 mg L^{-1} with a mean value of 331.7 mg L^{-1} (SD±127.9) (Table 4). On the basis of total hardness, water was classified as soft (< 75 mg L^{-1}), moderately hard (75-150 mg L^{-1}), hard (150-300 mg L^{-1}) and very hard (> 300 mg L^{-1}) (Sawyer and McCarty, 1967). According to the criteria described above, among the 26 effluent samples collected from the Gazipur industrial area, 1 sample were graded as moderately hard, 11 samples were graded as hard and the rest 14 effluent samples were graded as very hard.

(v) Permeability index (PI)

Soil permeability is affected by long term use of water rich in Na^+, Ca^{2+}, Mg^{2+} and HCO_3. The PI is also used to assess suitability of water for irrigation and is defined as follows:

$$PI = [(Na^+ + \sqrt{HCO_3^-}) \times 100] / (Ca^{2+} + Mg^{2+} + Na^+)$$
[all concentrations in meq L^{-1}]

Doneen (1964) classified irrigation water in three permeability index classes. Class-I and Class-II water types are suitable for irrigation with 75% or more of maximum permeability, while Class-III types of water with 25% of maximum permeability are unsuitable for irrigation. Plotting data on Doneen's chart indicates that no water samples fall in Class-I and 19 in Class-II, implying that the water is good for irrigation uses (Domenico and Schwartz, 1990). However, 7 water samples belong to Class-III, the unsuitable category (Fig. 3).

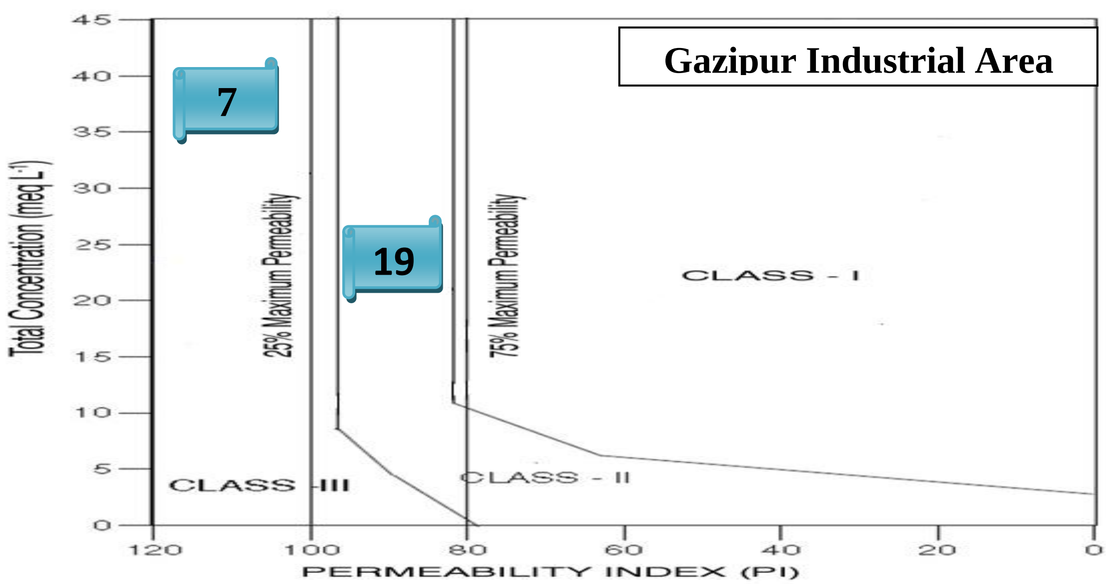


Fig. 3: Diagram for classifying irrigation waters on the basis of permeability index as escribed by Doneen (1964)

f) Relationship between water quality factors and ionic constituents

Correlation matrix for analyzed parameters of effluents were calculated to see if some of the parameters were interrelated with each other and the results are presented in Tables 5 (a & b). Examination of the matrix also provides clues about the carrier substances and the chemical association of ionic constituents in the study area (Jaquet *et al*., 1982). Considering the relationship between ionic constituents of water, the combinations of TDS vs SSP, TDS vs SAR, SAR vs SSP, Ca vs Zn ; Ca vs Fe ; Mg vs Fe ; Na vs Zn ; Fe vs HCO_3 ; K vs SO_4 ; K vs Mn ; Mn vs HCO_3 ; PO_4 vs Fe ; PO_4 vs Zn. ; SO_4 vs Fe ; SO_4 vs Fe ; SO_4 vs Mn ; Fe vs Mn showed positive significant correlation Table 5 (a, b) which indicates that the parameters were interrelated with each other and may be originated from the same source. On the contrary, the combinations of SSP vs $H_{T,}$ Fe vs Mg showed negative significant correlation with each other. Other relationships among the ionic constituents of water were insignificant Table 5 (a, b).

Table 5(a): Relationship between quality parameters of effluent (n=26) collected from the major polluting areas of Gazipur industrial area in Bangladesh

Parameters	EC	TDS	SAR	SSP	RSC	H_T
pH	0.103^{ns}	0.187^{ns}	-0.127^{ns}	-0.149^{ns}	-0.014^{ns}	0.124^{ns}
EC		0.197^{ns}	-0.170^{ns}	0.080^{ns}	0.157^{ns}	0.192^{ns}
TDS			0.689**	0.668**	0.066^{ns}	-0.326^{ns}
SAR				0.867 **	0.218^{ns}	-0.417^{ns}
SSP					0.174^{ns}	-0.508 **
RSC						-0.118^{ns}

Legend: **=Significant at 1% level; *=Significant at 5% level; ^{ns}=Not significant; Tabulated values of r with 24 df is 0.496 at 1% level of significance and 0.388 at 5% level of significance

Table 5(b): Relationship between ionic constituents of effluent (n = 26) collected from the major polluting areas Gazipur industrial area in Bangladesh

Para-meters	Mg	Na	K	PO_4	SO_4	Cu	Zn	Fe	Mn	Cl	HCO_3	Cd
Ca	0.224^{ns}	-0.209^{ns}	0.071^{ns}	0.372^{ns}	0.242^{ns}	ND^{ns}	0.856 **	0.480*	-0.112^{ns}	-0.110^{ns}	-0.033^{ns}	ND^{ns}
Mg		-0.209^{ns}	0.206^{ns}	0.162^{ns}	-0.212^{ns}	ND^{ns}	-0.218^{ns}	-0.801 **	0.076^{ns}	-0.082^{ns}	-0.062^{ns}	ND^{ns}
Na			-0.072^{ns}	-0.011^{ns}	0.191^{ns}	ND^{ns}	0.596 **	-0.206^{ns}	0.0003^{ns}	0.220^{ns}	0.029^{ns}	ND^{ns}
K				0.047^{ns}	0.598**	ND^{ns}	0.063^{ns}	-0.344^{ns}	0.617**	0.120^{ns}	0.116^{ns}	ND^{ns}
PO_4					0.057^{ns}	ND^{ns}	0.803**	0.388 *	0.233^{ns}	-0.031^{ns}	0.266^{ns}	ND^{ns}
SO_4						ND^{ns}	0.864**	0.443*	0.577**	0.134^{ns}	0.266^{ns}	ND^{ns}
Cu							ND^{ns}	ND^{ns}	ND^{ns}	ND^{ns}	ND^{ns}	ND^{ns}
Zn								ND^{ns}	1^{ns}	-0.294^{ns}	-0.413^{ns}	ND^{ns}
Fe									0.801**	-0.177^{ns}	0.436*	ND^{ns}
Mn										0.721	0.507**	ND^{ns}
Cl											0.272^{ns}	ND^{ns}
HCO_3												ND^{ns}

Legend: **=Significant at 1% level; *=Significant at 5% level; ^{ns}=Not significant; Tabulated values of r with 24 df is 0.496 at 1% level of significance and 0.388 at 5% level of significance.

Conclusions and Recommendations

The pH of effluent samples ranged from 6.05 to 7.28 indicating all the samples were almost neutral. The EC of all collected effluent samples were within the range of 181 to1995 μS cm^{-1} indicating low to high value which is harmful for irrigation. The DO value were within the range of 0.30 to 1.5 mg L^{-1} indicating that aquatic life is in under stress but in case of irrigation it is not essential. The TDS value ranged from 465 to 1587 mg L^{-1} indicating effluent as fresh to brackish in which 58% of effluent samples were rated as fresh water (<1000 mg L^{-1}). The anion chemistry in the Gazipur industrial area was dominated by HCO_3 and Cl which contributed 55 and 44% of the total anionic balance, respectively. Results obtained from the study reflects that effluent collected from Gazipur industrial area were dominated by Na, Mg, Ca, and K, which contributed 58, 17, 16 and 9 % of the total cationic balance, respectively. Among the studied trace metals (Fe, Zn, Cu, Pb, Cd and Mn), all of the effluent samples were less than the maximum recommended concentration indicating them not problematic for long term irrigation purposes except two samples one for Mn and another for Cu. The quality assessment showed high values of HCO_3 (14.00 me L^{-1}), Cl (25.77 me L^{-1}), Mn (0.286 mg L^{-1}) and Cu (4.19 mg L^{-1}) in a number of samples, which make them unsafe for irrigation purpose. The computed SAR of all effluent samples were ranged from 2.66 to 45.9 with a mean value of 12.60. Among the 26 effluent samples, 17 effluents samples categorized as excellent, 6 samples were graded as fair and the rest 3 samples were graded as poor category for irrigation purpose. Considering SSP for 26 effluent samples, 23 effluent samples were graded as doubtful and the rest 3 samples were graded as permissible for irrigating agricultural crops. The computed RSC varied from -0.59 to 16 me L^{-1} with a mean value of 4.84 me L^{-1} and among the 26 effluent samples, 19 samples were found in unsuitable class (> 2.50), 4 samples were found in suitable class (< 1.25) and the rest 3 sample were in marginal class (1.25-2.50). As regards to hardness, out of 26 effluent samples, 11effluent samples were graded as hard and the rest 15 samples were graded as very hard. High values of hardness of some samples collected from Gazipur industrial areas restricted the suitability of water in this area for agriculture and demands suitable water management as well as proper treatment.

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