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Comparative Study of Surface Water Quality in Coastal District Bagerhat, Bangladesh

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Abstract

The study area lies in the lower delta plain of southern Bangladesh adjoined to the Bay of Bengal where seawater intrusion is a normal phenomenon. In the pre-monsoon period when the normal flow of rivers or canals is usually stopped, the regular tidal saltwater can easily enter the canals and rivers. Occasionally, the tidal salt water is intruded into *Ghers* and ponds for human immoral purposes and logged into long time. The present study focuses the quality of surface (*Ghers*, Ponds and Canal) water in the study area. In addition twenty eight (28) surface water samples were collected from different location and analyzed for various parameters. To attempt this goal, samples were analyzed for various physicochemical parameters such as Temperature, pH, EC, TDS , Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, CO_3^{2-}, HCO_3^- , SO_4^{2-} and NO_3^-. The abundance of major cations in the surface water are $Na^+ > Ca^{2+} > K^+ > Mg^{2+}$ while that of anions are $Cl^- > SO_4^{2-} > HCO_3^- > NO_3^-$. The Piper diagram indicates that all samples are Na-Cl type. The Wilcox diagram notice that all the *Gher* samples are unsuitable in bath seasons except one, the pond samples are permissible to doubtful in pre-monsoon and excellent to good in post-monsoon and canal water samples are unsuitable in pre-monsoon and excellent to doubtful in post-monsoon. According to USSL diagram, most of the sample exhibits very high and high salinity hazard (C4S4 and C3S4) in *Gher* and canal water during both seasons while high salinity hazard found (C3S4) during the pre-monsoon period and medium salinity hazard in pond water during the pre-monsoon period. Due to the high levels of sodium and chloride concentration and high SAR, ESP, %Na, PI values proved that the most of the surface water are unsuitable for drinking and irrigation purposes. The results of the study show the surface water quality very alarming and management strategies are very necessary.

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1.1 Introduction

Bangladesh is a place that is always threatened by sea level rise and seawater intrusion (Dasgupta et al., 2014). The Bangladesh offshore zone is the smallest lying zone in the world where 36 million people are living within 1 meter elevation from high drift position. The clean coastal regional drinking water reservoir is now a vital problem in the near shore Bangladesh (Islam et al., 2017). The recently saline area is adding day by day and districts like Jessore, Khulna, Magura, and Gopalganj are considered potentially threatened area. (Islam et al., 2017). The coastal belt of Bangladesh is at fatal risk of seawater intrusion because of climate change, sea level rise, unfavorable environment and its geographical location. Roughly 20 million people living along the seacoast are affected by varying degrees of salinity in drinking water captured from varied natural sources (Rasheed et al., 2016). The coastal region of Bangladesh covering over 30% of the arable land of the country where about 53% of the coastal zones are affected by different types of salinity (Haque, 2006) and about 20% of net cultivable land of coastal region is affected by varied degrees of salinity (Karim et al., 1990). A vast plain with 21 out of 64 districts is called as coastal area in which Bagerhat is directly connected with the Bay of Bengal. Direct seawater intrusion by tidal surges, super cyclone and tsunami are normal phenomenon in coastal area. The surface reservoirs (*Ghers*, Ponds and Canals) of the coastal areas are contaminated by the saline water cause of direct seawater intrusion and the water quality is deteriorating day by day. Scarcity of drinking water is an acute problem in southwest coastal Bangladesh. Seawater intrusion in the exposed coastland is basically responsible for the drinking water breaking point in this region (Khan et al., 2011; Rahman et al., 2016). The offshore population relies mostly on tube-wells (groundwater) and rain-fed ponds for drinking water (Islam et al., 2013). Still, brackish aquifers are heavily affected by saline water intrusion (Sultana et al., 2013; Islam et al., 2015). Fresh water ponds are also progressively salinized by saline water from rivers, soil runoff, and shallow groundwater (Khan et al., 2016). Consequently, both the fresh water and groundwater sources are unsuitable for human consumption generally because of high saltiness (Benney worth, 2016). Surface and ground water are the main water resources for drinking, bathing, irrigation and household purposes for the coastal population of Bangladesh. Water quality in the coastal region is basically influenced by saltiness due to seawater intrusion which reduces agriculture product and causes health hazards. Insufficient quantity of safe water is a serious hazard to human (Miah et al., 2015). Geographical location, drought, regular tides and natural disasters at different times are increasing this salinity. Water in the coastal area is comparatively vulnerable to the pollution by the intrusion of seawater (Rani and Babu, 2007). At present, there are about 76730 *Ghers*, 41306 Ponds and 139 canals in Bagerhat district (DFO, Bagerhat). When super cyclone Sidr (2007), Aila (2009) and Amphan (2020) hit the coastal districts, the Bagerhat district was flooded with seawater. As a result, the *Ghers*, ponds and canals water were polluted by seawater and the phenomena is occurring continuously with tidal flooding.

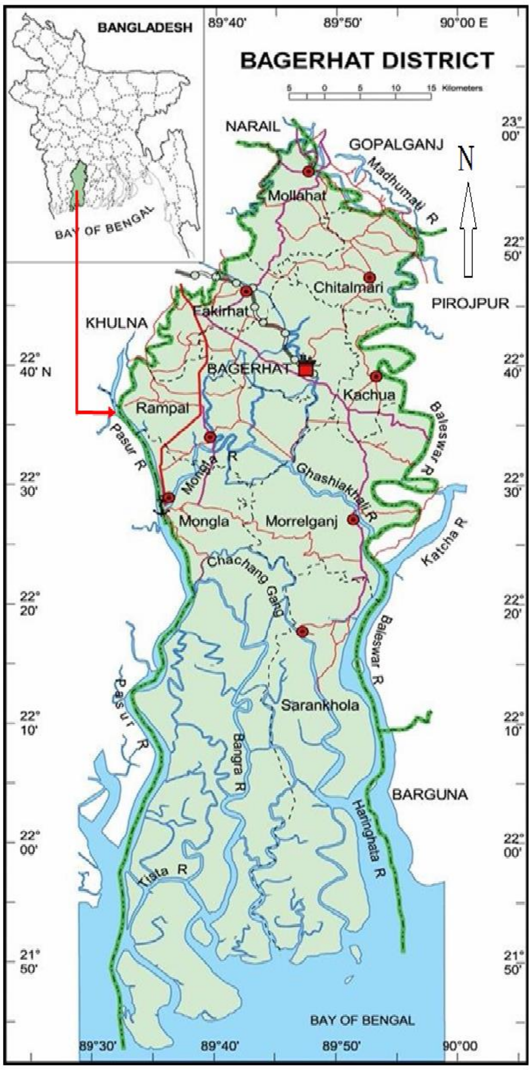
Rivers are vital and important ecosystems that are critical for the nourishment of all life (Zeb et al., 2011). Rivers are most accessible to population and they're also most studied (Tereza et al., 2014). Pangunchi river passes through Morrelgonj upazila, contributing much to the water demand of people living here (Bangladesh National Portal, 2021). Various studies have been done in coastal area of Bangladesh based on shrimp culture, seawater intrusion, food security, impacts of salinity, salinity problems and crop production, salinity hazard, salinity associated health crisis etc but very few works have been done on comparative study of surface water in Bagerhat district. That is why there are many opportunities for research on surface water in the study area. The objective of the study is to find out the comparative surface water quality for drinking and irrigation purposes in the research area.

1.2 Study area

Bagerhat district included the Ganges-Delta and is composed of sandy alluvial sediments. The depth of the Holocene sediment layer here is about a few thousand meters (Jamal, 1999). The study area, Bagerhat district is located in the southern part of Bangladesh lies between Latitudes 21°49' to 22°59' N to Longitudes 89°32' to 89°98' E (BDS, 2011). It is about 3959.11 sq. km. includes 9 Upazilas, 77 Unions and 1031 Villages. The Upazilas are Mollahat, Fakirhat, Chitalmari, Kachua, Rampal, Mongla, Morrelganj and Sarankhola. The area is bounded by Gopalganj district and Norail district on the north, the Bay of Bengal on the south, Perojpur and Barguna district on the east and Khulna district on the west which is shown in Figure 1.

1.3 Materials and methods

Twenty eight (28) surface water samples were collected from 9 upazillas of Bagerhat, including 9 *Ghers*, 9 Ponds and 10 Canals during pre-monsoon (May) and post-monsoon (November), 2016 which is in Figure 2. Samples were collected in 500 ml high-density polypropylene (HDPP) bottles (washed with 1% HNO_3 for 3 times with distilled water) following the procedure outlined by Bhattachary et al., (1999). Physical parameters such as pH was measured by pH meter (HANNA pH-209 & EZ-DO-6011, SN-000367, Model-IP57, Made in Taiwan), EC was measured by EC meter (HANNA EC & TDS, S-349456, and Model-98312). TDS and chemical parameters, such as Na^+, Ca^{2+}, Mg^{2+} and K^+ were analyzed by AAS method (Atomic Absorption-Spectrophotometer, Model: Simadzu AA-6800). Cl^- and HCO_3^- were analyzed by Titration Method, and SO_4^{2-} was analyzed by Sulfaver-4 Sulphate Method (HACH Model: DR-3900) and Cadmium Reduction Method (HACH Model: DR-3900). Most of the parameters were analyzed in the Institute of Environmental Science Lab, RU; Environmental Science and Technology Lab, Jashore University of Science and Technology (JUST), Chemical Engineering Lab, Jashore University of Science and Technology (JUST) and Soil Resource and Development Institute (SRDI), Rajshahi. SAR, ESP, %Na, PI values is measured by following equations.



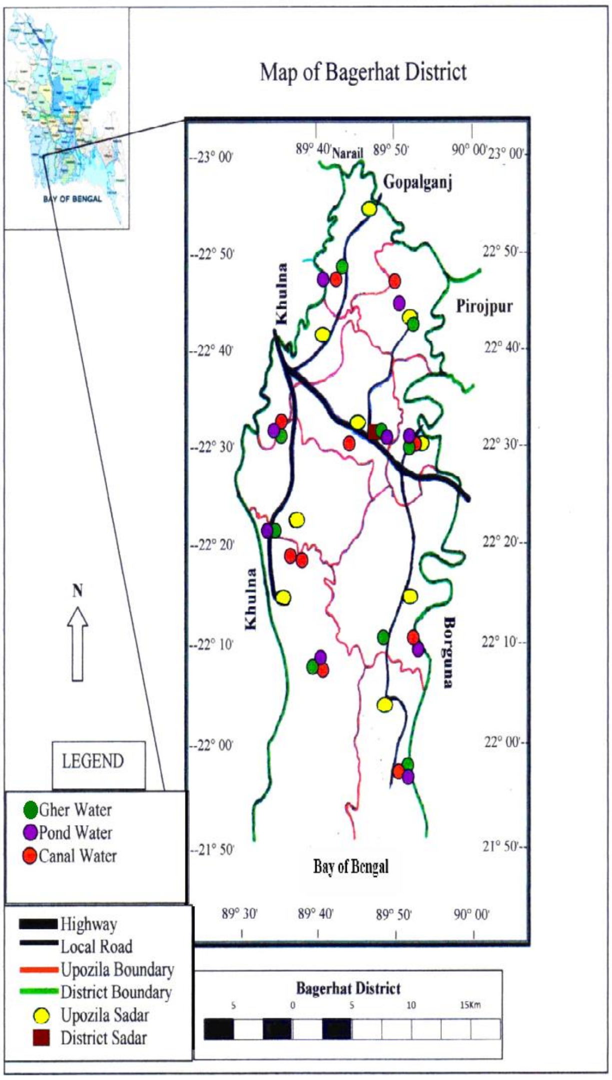


Figure 1: Study area. **Figure 2:** Sampling stations of surface water.

Sodium Adsorption Ratio (SAR)

Sodium Adsorption Ratio (SAR) is a calculated parameter which is used to determine water quality for irrigation purposes. SAR is calculated by using formula proposed by Ayers and Wescot (1985).

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

Exchangeable Sodium Percentage (ESP)

Exchangeable Sodium Percentage is a parameter which used to identify the classification of plants in the salinity porn area. The formula is given below.

$$ESP= \frac{(Na^{+})}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \text{ X } 100$$

$\%Na^{+}$ (Percentage Sodium)

The sodium in irrigation waters is also expressed as percentage sodium ($\%Na^{+}$) and percentage sodium is calculated by using formula proposed by Wilcox (1955).

$$\%Na^{+} = \frac{(Na^{+} + K^{+})}{(Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})} \text{ X } 100.$$

Permeable Index (PI) Permeable Index is one of the indicators of sodium hazard is calculated by using formula proposed by Richard (1954). The proposed formula is given below.

$$PI = \frac{(Na^{+} + HCO_3^{-})}{(Ca^{2+} + Mg^{2+} + Na^{+})} X 10$$

1.4 Result and Discussion

The outcome of surface water samples as a physicochemical parameter including Temperature, Electrical Conductivity (EC), pH (concentration of hydrogen ion), Total Dissolved Solids (TDS), Cations (Na^{+}, Ca^{2+}, Mg^{2+}, K^{+}) and Anions (Cl^{-}, HCO_3^{2-}, SO_4^{2-}, NO_3^{-}) and calculated such as Percentage Sodium (%Na), Sodium Adsorption Ratio (SAR), Exchangeable Sodium Percentage (ESP) and Permeability Index (PI).

1.4.1 Physical parameters of surface water

Monitoring water quality of surface water supply important documents that help to take decision making on health problems and environmental impacts (Myers, 2018). Temperature controls some characteristics of organisms, solubility of gases and salts in water, No other factor has so much influence as temperature (Welch, 1952). The average highest temperature 31.78°C found in *Gher* water and the lowest temperature 31.28°C found in canal water during the pre-monsoon period while in the post-monsoon period, the average highest temperature 22.64°C found in pond water and the lowest temperature 22.31°C found in canal water. The temperature mentioned that the surface water is not thermal polluted. pH is one of the most important operational water quality parameters (WHO, 2004). In the study, the average highest pH 8.19 found in *Gher* water and the lowest temperature 6.17 found in pond water during the pre-monsoon period while in the post-monsoon period, the average highest pH 7.52 found in *Gher* water and the lowest pH 5.56 found in pond water. In general, increasing pH in coastal region is related to the chloride in seawater or from marine clay (Kuttimani et al, 2017). Electrical conductivity (EC) is a dimension of the dissolved material in an aqueous solution, which pertains to the capacity of the material to conduct electric current through it. The high level of electrical conductivity in water is related to the input of sewage water, agricultural activities and seawater intrusion in the coastal aquifers. In the pre-monsoon period, the average highest EC 9427.78 µS/cm found in *Gher* water and the lowest EC 1244.44 µS/cm found in pond water and in the post-monsoon period, the average highest EC 4862.22 µS/cm found in canal water and the lowest EC 610.56 found in pond water. Total dissolved solids are a significant parameter for evaluating groundwater quality; the term is used to explain the inorganic salts and small quantities of organic materials present in solution of water. The foremost factors ingredients are typically calcium, magnesium, sodium, and potassium cations and carbonate, bicarbonate, chloride, sulphate, and nitrate anions. The dissolved solid of groundwater samples vary significantly and it fluctuates with the season. The average highest TDS 6316.61 mg/l found in *Gher* water and the lowest TDS 833.78 mg/l found in pond water during the pre-monsoon period while in the post-monsoon period, the average highest TDS 3479.91 mg/l found in canal water and the lowest TDS 409.07 mg/l found in pond water. The physical parameters are always more in the pre-monsoon period than the post-monsoon period because due to the dilution of the rainfall and rising of the water level. The average values of physical parameters are shown in table 1 and graphically presented in Figure 3.

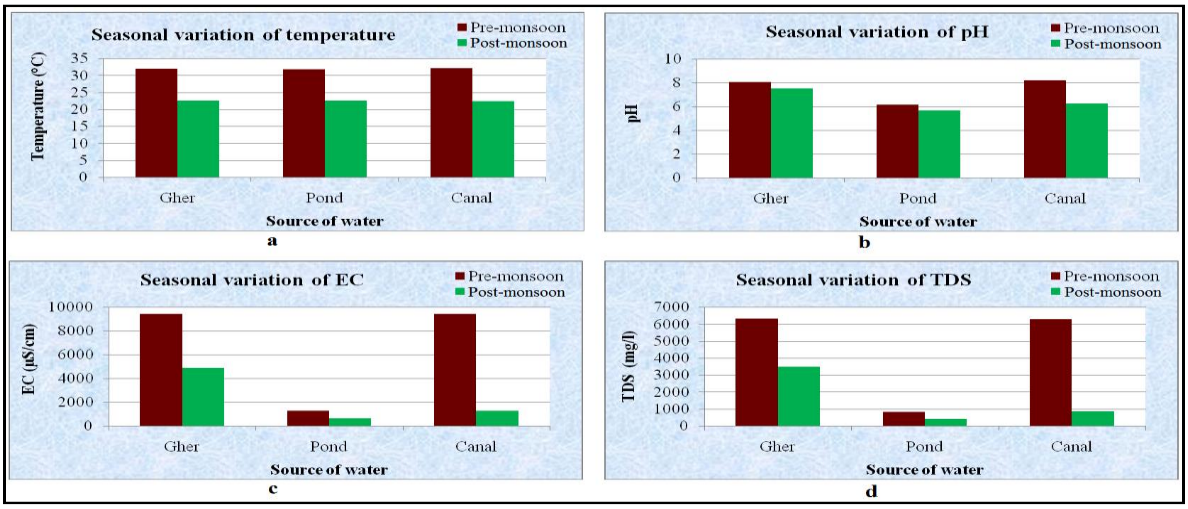


Figure 3a-d: Seasonal variation of physical parameters.

1.4.2 Chemical parameters of surface water

The sodium and chloride are the two important parameters in the coastal areas. The Na–Cl relationships have often used to identify the mechanisms for acquiring salinity and saline intrusions in semi-arid regions (Jalali, 2006). The analytical result showed that the average highest concentration of Sodium (Na^+) 6937.79 mg/l found in *Gher* water and the lowest Sodium (Na^+) 1060.64 mg/l found in pond water during the pre-monsoon period while in the post-monsoon period, the average highest Sodium (Na^+) 3410.81 mg/l found in canal water and the lowest Sodium (Na^+) 573.12 mg/l found in pond water. Calcium and magnesium are known to occur naturally in water due to its passage through mineral deposits and rock strata and contribute to its total hardness. Calcium is a very ductile silvery metal. It is normally present in water. It can also additionally dissolve from rock which includes limestone, marble, calcite, dolomite etc. The chemistry of calcium is that of a typical heavy alkaline earth metal and it is also active as a pH stabilizer because of its buffering qualities. from the data result, the average highest concentration of Calcium (Ca^{2+}) 38.52 mg/l found in *Gher* water and the lowest Calcium (Ca^{2+}) 28.05 mg/l found in pond water during the pre-monsoon period while in the post-monsoon period, the average highest Calcium (Ca^{2+}) 20.94 mg/l found in *Gher* water and the lowest Calcium (Ca^{2+}) 19.94 mg/l found in canal water. In the pre-monsoon period, the average highest concentration of Magnesium (Mg^{2+}) 8.37 mg/l found in canal water and the lowest Magnesium (Mg^{2+}) 7.16 mg/l found in pond water and in the post-monsoon period, the average highest Magnesium (Mg^{2+}) 5.13 mg/l found in pond water and the lowest Magnesium (Mg^{2+}) 4.79 mg/l found in canal water. In the pre-monsoon period, the average highest concentration of Potassium (K^+) 42.38 mg/l found in *Gher* water and the lowest Potassium (K^+) 26.50 mg/l found in pond water and in the post-monsoon period, the average highest Potassium (K^+) 20.82 mg/l found in *Gher* water and the lowest Potassium (K^+) 9.99 mg/l found in pond water. The average results showed in table 1 and graphically presented figure 4.

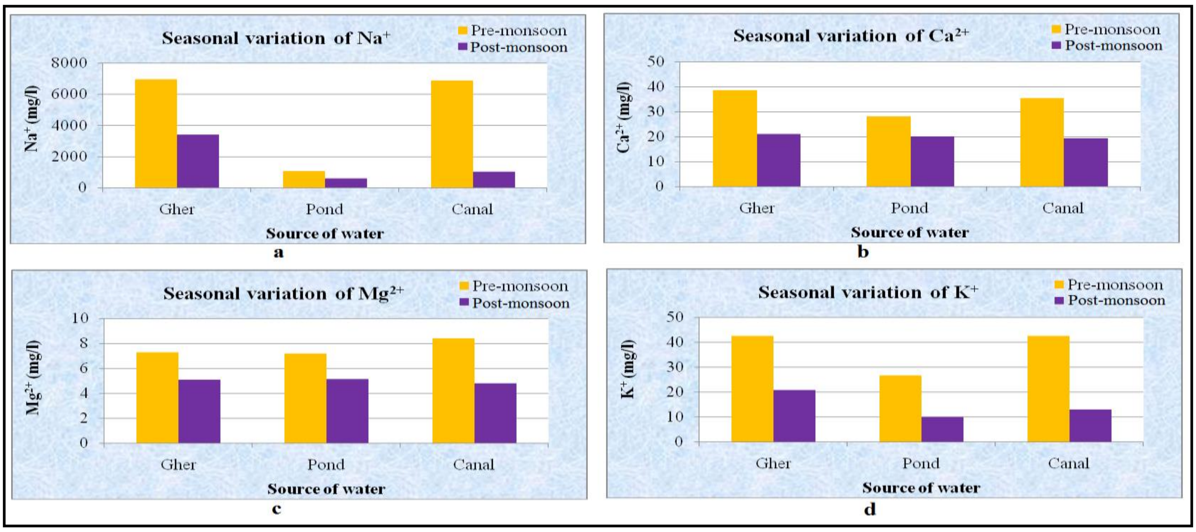


Figure 4a-d: Seasonal variation of major cations.

Chlorides occur in all natural waters in widely varying concentrations. The chloride content normally increases as the mineral content increases (Sawyer and Mccarty, 1978). The chloride ion is the most dominant natural form of the element chlorine and is extremely stable in the water. It is formed when the element chlorine gains an electron or when a compound such as Hydrogen chloride or sodium chloride is dissolved in water. It likes to make compounds with others such as sodium chloride (NaCl). The average highest concentration of Chloride (Cl^-) 10153.69 mg/l found in *Gher* water and the lowest Chloride (Cl^-) 1525.29 mg/l found in canal water during the pre-monsoon period while in the post-monsoon period, the average highest Chloride (Cl^-) 5355.39 mg/l found in *Gher* water and the lowest Chloride (Cl^-) 810.91 mg/l found in pond water. The bicarbonate ion (Hydrogen carbonate ion) is an anion with the empirical formulation of HCO_3^-. Bicarbonate is the dominant form of dissolved inorganic carbon in seawater and in most fresh water. In the result, the average highest concentration of Bi-carbonate (HCO_3^-) 250 mg/l found in *Gher* water and the lowest HCO_3^- 241.67 mg/l found in pond water during the pre-monsoon period while in the post-monsoon period, the average highest HCO_3^- 172.22 mg/l found in *Gher* water and the lowest HCO_3^- 150 mg/l found in canal water. In the pre-monsoon period, the average highest concentration of Sulphate (SO_4^{2-}) 385.48 mg/l found in *Gher* water and the lowest SO_4^{2-} 111.74 mg/l found in pond water and in the post-monsoon period, the average highest SO_4^{2-} 242.61 mg/l found in *Gher* water and the lowest SO_4^{2-} 90.23 mg/l found in pond water. In the pre-monsoon period, the average highest concentration of Nitrate (NO_3^-) 3.91 mg/l found in canal water and the lowest NO_3^- 0.79 mg/l found in pond water and in the post-monsoon period, the average highest NO_3^- 3.01 mg/l found in canal water and the lowest NO_3^- 0.86 mg/l found in *Gher* water. The anions and cations concentration were always more in the pre-monsoon period than the post-monsoon period because due to the dilution of the rainfall and rising of the water level. The average results showed in table 1 and graphically presented Figure 5.

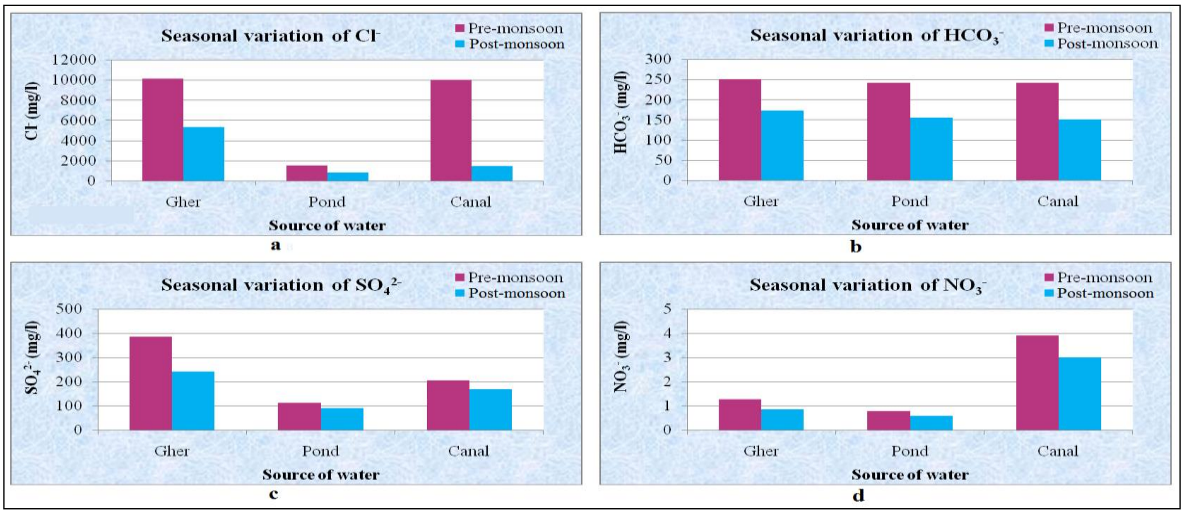
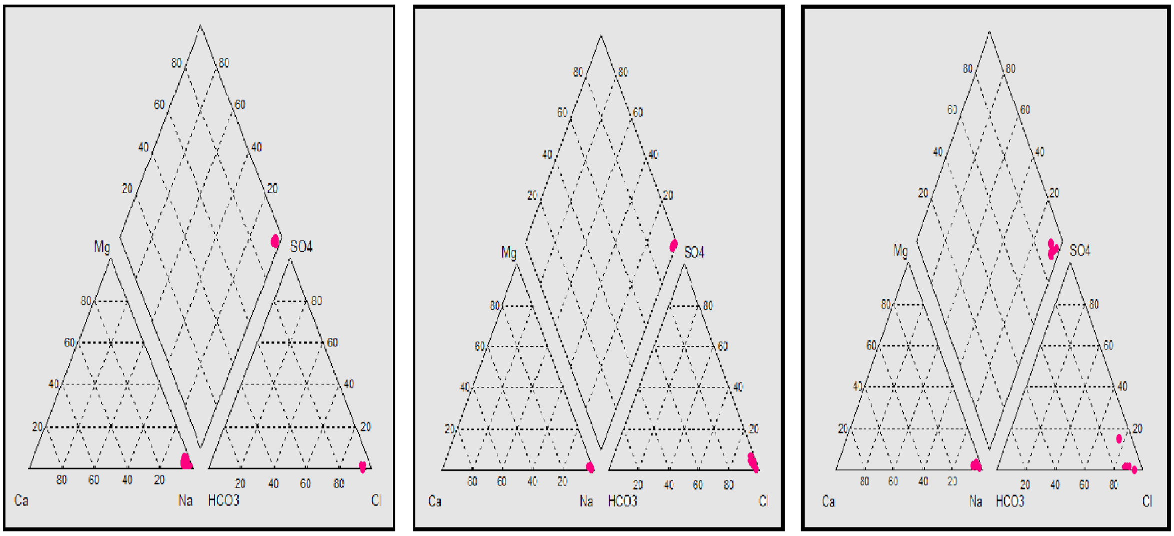


Figure 5a-d: Seasonal variation of major anions.

1.5 Surface water type determination

The type of water was determined based on the various properties present in surface water. The type of water is determined by piper diagram using the most significant chemical parameters of surface water. The parameters are Na^+, Ca^{2+}, Mg^{2+}, Cl^-, HCO_3^-, SO_4^{2-} and the water type is remarked as Na^+-Cl^- type which is graphically presented in figure 6.



(a) *Gher* water (b) Pond water (c) Canal water

Figure 6a-d: Piper diagrams of surface water.

1.6 Water quality for drinking and domestic purposes

The safety and accessibility of drinking water are major concerns throughout the world (WHO, 2006). Central and south-central Bangladesh is facing deterioration of groundwater quality basically due to low river flow, lack of supervision, climatic factors, and anthropogenic exercise. Both surface water and groundwater are facing increased demand and pollution (Islam et al., 2017). Nonstop storage of saltwater in shrimp ponds alters the chemical properties of the soil which is unsuitable for farming yield (Chowdhury et al., 2011). The water of the Rupsha river in this area is largely contaminated and needs monitoring of water quality as well as defensive measure to reduce pollution. The present physicochemical study revealed that water of the study areas is alkaline and the values of chloride, TDS, total hardness and total alkalinity of this region exceeded the acceptable limit (Islam et al., 2018). World Health Origination (WHO), DoE and DPHE of Bangladesh have given individual guideline of different parameters of water for drinking purposes. High levels of physicochemical parameters appear to be responsible for the poor quality of surface water in an area (Quist, 1976; Amuzu, 1978; Akiti, 1986). So, the present study has emphasized the quality of drinking water on the basis of some physical parameters especially Temperature, pH, EC, TDS and chemical parameters including major cations, anions which are described below in respect of the recommendation of World Health Origination (WHO, 2006) and Bangladesh standard guideline of DoE (1997) to evaluate the suitability of surface water for drinking purpose in the study.

1.6.1 Water quality based on some physical parameters

There are 28 surface water samples show normal temperature during the pre-monsoon and post-monsoon period. So, the result concluded that 100% surface water samples are normal for drinking and domestic purposes. The acceptable values of pH in drinking water given by WHO (2006) is 6.5 to 9.6 and by Department of Environment (DoE, 1997) Bangladesh is 6.5 to 8.5. According guideline, all the samples of surface water are within the recommended permissible limit. The guideline range of EC of water prescribed for drinking purpose by WHO (2006) is 400 to 1500 μS /cm whereas 100% *Gher* water samples in both periods exceeded the prescribed guideline of WHO. 100% pond water samples in both periods are within prescribed guideline of WHO and 100% canal water samples in pre-monsoon periods exceeded the prescribed guideline but in the post-monsoon periods, 100% canal water samples are within prescribed guideline of WHO. The WHO (2006) permissible limit of TDS is 500 to 1500 mg/l and DoE (1997) of Bangladesh has given a guideline of TDS 1000 mg/l for drinking purpose. 100% *Gher* water samples in both periods exceeded the prescribed guideline of WHO. 100% pond water samples in both periods are within prescribed guideline of WHO and 100% canal water samples in pre-monsoon periods exceeded the prescribed guideline but in the post-monsoon periods, 100% canal water samples are within prescribed guideline of WHO. The average values of physical parameters of surface water showed in table 1.

1.6.2 Water quality based on chemical parameters

The World Health Organization (WHO, 2006) and Department of Environment (DoE, 1997) recommended permissible limit of sodium for drinking water is 10 to <20 mg/l and 200 mg/l respectively. The result concluded that the surface water quality based on sodium concentration is unsuitable as WHO and DoE guideline in the pre-monsoon and post-monsoon period. The WHO (2006) has been recommended the permissible limit of Calcium for drinking water is 75 to 200 mg/l and 75 mg/l of calcium in water has been recommended by DoE (1997) of Bangladesh. The result shows that all the surface water values are below the lower limits of WHO and DoE guideline in both seasons. The WHO (2006) guideline limit for magnesium in drinking water is 40 to 150 mg/l and the DoE (1997) of Bangladesh has also given a guideline limit 30 to 35 mg/l of magnesium concentration for drinking water. The result shows that all the surface water samples in study area are within the acceptable level of WHO and DoE in both periods. WHO (2006) guideline limit for potassium in potable water is 10 to 15 mg/l and DoE (1997), Bangladesh also has given a guideline limit 12 mg/l. The result shows that all the samples of *Gher* and canal water samples during both periods are exceeded the WHO and DoE guideline but pre-monsoon values of pond water are exceeded the guideline and post-monsoon values are within the guideline. The WHO (2006) and DoE (1997) permissible limit of chloride for drinking water is 200 to 400 mg/l and 150 to 600 mg/l respectively. The study result observed that about 100% surface water samples exceed the WHO (2006) and DoE (1997) permissible limit in both seasons except one sample of pond water are within the limit of DoE guideline during the post-monsoon but not within the WHO limit. The pre-monsoon values are higher than post-monsoon values and it is noticed that the surface water in the area contain high concentration of chloride (Cl^-) and the area is highly chloride contaminated at the stations near the coastal areas than the others. So, it is concluded that the surface water quality based on chloride is unsuitable for drinking and other purposes in the area. The World Health Organization (WHO, 2006) and Department of Environment in Bangladesh (DoE, 1997) have given a guideline of bi-carbonate concentration for drinking water is 200 to 600 mg/l and 600 mg/l, respectively. The result shows that 100% sample of surface water (*Gher*, Pond, Canal) values of Bi-Carbonate during pre-monsoon and post-monsoon are below the guideline of WHO and within the guideline of DoE limit. The WHO (2006) and DoE (1997) have given a guideline of sulphate concentration in drinking water is 150 to 250 mg/l and 400 mg/l respectively. Only pre-monsoon values of *Gher* water samples are exceeded the limit but all the samples of *Gher*, pond and canal water samples are within the limit of WHO and DoE guideline. The WHO (2006) permissible limit of Nitrate (NO_3^-) is 20 to 45 mg/l and DoE (1997) limit is 45 mg/l. The Nitrate (NO_3^-) values of surface water shows that 100% result in the pre-monsoon and post-monsoon period are so much below the guideline of WHO and DoE limit exceptional one sample of canal water that exceeded the guideline of WHO but not DoE. It is observed that most of the nitrate values in surface water of study area decreased in post-monsoon period. The average values of chemical parameters of surface water showed in table 1.

Table-1: Water quality of surface water in respect of WHO (2006) and DoE (1997) standard for drinking purpose

Para.	Period	Gher			Pond			Canal			Drinking water standards	
		Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	WHO Standard	DoE standard
pH	Pre-m.	7.61	7.91	8.5	5.99	3.38	3.17	7.8	8.6	8.23	6.5 to 9.6	6.5 to 8.5
	Post-m.	3.41	7.91	7.52	5.52	5.7	5.66	5.6	7	3.5		
EC (µS/cm)	Pre-m.	3460	13560	9427.78	950	1620	1244.4	2300	16940	10068	400 to1500	-----
	Post-m.	1860	7270	4862.22	350	760	610.56	360	2280	1351		
TDS (mg/l)	Pre-m.	2318.2	9085.2	6313.61	633.5	1085.4	833.78	1601.3	11349.8	6745.6	500 to1500	1000
	Post-m.	1243.2	4870.9	3257.69	234.5	509.2	409.07	201	527.6	905.17		
Na^+ (mg/l)	Pre-m.	2883.3	10600.	6937.79	834.49	1391.96	1060.6	1882.8	12169	7329.73	10 to 20	200
	Post-m.	1492.8	4735.7	3410.81	335.59	752.89	573.12	339.08	1722.99	1077.48		
Ca^{2+} (mg/l)	Pre-m.	22.04	58.11	38.52	14.03	42.08	28.05	43.09	14.03	34.87	75 to 200	75
	Post-m.	14.03	32.06	20.94	39.09	12.06	19.95	28.06	33.01	18.44		
Mg^{2+} (mg/l)	Pre-m.	3.94	10.94	7.27	3.65	9.72	7.16	4.86	10.94	8.63	40 to 150	10 to 15
	Post-m.	3.62	8.10	5.09	2.43	7.29	5.13	7.29	3.65	4.98		
K^+ (mg/l)	Pre-m.	17.82	70.38	42.38	8.82	63.47	23.50	93.84	11.73	43.92	10 to 15	12
	Post-m.	11.73	35.19	20.82	3.91	19.55	9.99	27.37	7.82	13.29		
Cl^- (mg/l)	Pre-m.	4043.2	13874	10153.7	1148.8	2098.73	1525.3	2748.8	17134.5	10653.6	200 to 400	150 to 600
	Post-m.	2079.9	7979.8	5355.4	489.84	1069.3	810.91	409.97	2549.89	1548.85		
HCO_3^{2-} (mg/l)	Pre-m.	150	350	250	150	350	241.67	150	350	245	200 to 600	600
	Post-m.	100	250	172.22	100	250	155.56	100	250	155		
SO_4^{2-} (mg/l)	Pre-m.	27.7	950.1	385.48	0.4	330.3	111.74	39.9	420.1	222.57	150 to 250	400
	Post-m.	17.1	552.9	242.61	0.3	290.2	90.23	32.7	340.26	181.93		
NO_3^- (mg/l)	Pre-m.	0.4	2.3	1.28	0.3	2.2	0.79	0.3	28.7	3.58	20 to 45	45
	Post-m.	0.2	1.3	0.86	0.1	1.8	0.59	0.1	21.3	2.77		

Note: Para=Parameters, Max=Maximum, Min= Minimum, Ave=Average.

1.7 Water quality for irrigation

The coastal areas of Bangladesh commonly the surface water are contaminated by seawater intrusion. Seawater intrusion in the coastal areas is the result of anthropogenic and natural causes as well as drastic change in climate. Water quality is in critical status in the studied regions, agriculturists are forced to use this water for farming practices (Islam et al., 2016). The desired yield of any crop depends on the quality of soil and soil quality depends on water. In this case, it is important to observe the water quality of the area for irrigation. The surface water is generally saline and unsuitable for any use as it has a sodium and chloride content about over 90%. Various quality controlling parameters of irrigation water such as %Na, EC, TDS, SAR, ESP, PI values and diagrams have been used to classify irrigation water. The values of %Na, EC, TDS, SAR, ESP, PI and diagrams show that the surface water quality is unsuitable for agricultural uses in the area.

1.7.1 Irrigation water classification based on Percent Sodium (%Na)

Todd (1980) has given a classification of water for irrigation based on %Na where water is classified into five classes; >20 is excellent, 20-40 is good, 40-60 is permissible, 60-80 is doubtful and more than 80 is unsuitable. According to the classification, 100% samples in pre-monsoon and post-monsoon of surface water (*Gher*, pond and canal water) of the area are unsuitable for agriculture purposes which in table 2 and details in table 8.

Table 2: Water classification for irrigation based on %Na (Todd, 1980)

%Na	Water Class	Frequency Percentage (Counts)					
		***Gher* water**		**Pond water**		**Canal water**	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
<20	Excellent	0	0	0	0	0	0
20-40	Good	0	0	0	0	0	0
40-60	Permissible	0	0	0	0	0	0
60-80	Doubtful	0	0	0	0	0	0
>80	Unsuitable	100% (9)	100% (9)	100% (9)	100% (9)	100% (10)	100% (10)

1.7.2 Irrigation water classification based on Electrical Conductivity (EC)

Based on EC values of water, Ayers and Wescot (1985) have made a classification of hazard for irrigation purposes, however >700 (µS/cm) is no hazard, 700-3000 (µS/cm) is slight to moderate hazard, and more than 3000 (µS/cm) is severe hazard. In the case, there are 9 samples of *Gher* water in pre-monsoon and 8 samples in post-monsoon shows severe hazard and the remaining one sample of post-monsoon show slight to moderate hazard which is in Mollahat Upazila. Pond samples, meanwhile, show 9 sample in pre-monsoon and 4 sample in post-monsoon included in this category of slight to moderate hazard and 5 samples in post-monsoon are considered normal that means no hazard. In canal water, 9 samples are severe hazard and 1 sample is slight to moderate hazard during pre-monsoon period where 3 samples are normal and 7 samples are slight to moderate hazard which is in table 3 and details in table 8.

Table 3: Water classification for irrigation based on EC (µS/cm) (Ayers and Wescot, 1985).

Hazard	Frequency Percentage (Counts)					
	***Gher* water**		**Pond water**		**Canal water**	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
None (<700)	0% (0)	0% (0)	0% (0)	55.6% (5)	0% (0)	30% (3)
Slight to Moderate (700-3000)	0% (0)	11.1% (1)	100% (9)	44.4% (4)	10% (1)	70% (7)
Severe(>3000)	100% (9)	87.5% (7)	0% (0)	0% (0)	90% (9)	0% (0)

1.7.3 Irrigation water classification based on Total Dissolved Solid (TDS).

Based on TDS values, Ayers and Wescot (1985) have done a classification of water hazard for irrigation purposes. Less than 450 is no hazard, 450-2000 is Slight to Moderate hazard, and more than 2000 is severe hazard. There are 9 samples of *Gher* water in the pre-monsoon and 8 samples are in the post-monsoon included severe hazard and the remaining one sample of post-monsoon showed slight to moderate hazard. Pond water samples, meanwhile, showed 9 samples in pre-monsoon and one sample in post-monsoon slight to moderate hazard and rest of the 8 samples are being considered as normal in post-monsoon. Water samples from the canal showed that in pre-monsoon included 1sample is slight to moderate hazard and 9 samples are severe hazard while in post-Monsoon 3 samples fall in normal category and 7 samples fall in slight to moderate category which is in table 4 and details in table 9.

Table 4: Water classification for irrigation based on TDS (mg/l) (Ayers and Wescot, 1985).

Hazard	Frequency Percentage (Counts)					
	Gher water		Pond water		Canal water	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
None (<450)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	30% (3)
Slight to Moderate (450-2000)	0% (0)	12.5% (1)	100% (9)	100% (9)	10% (1)	70% (7)
Severe (>2000)	100% (0)	87.5% (8)	0% (0)	0% (0)	90% (9)	0% (0)

1.7.4 Irrigation water classification based on Sodium Adsorption Ratio (SAR)

Ayers and Wescot (1985) classified the water for irrigation based on SAR values. According to the classification, 100% *Gher* water, pond water and canal water samples in pre-monsoon and post-monsoon included severe hazard which is in table 5 and details in table 9.

Table 5: Irrigation water quality classification based on SAR (Ayers and Wescot, 1985)

Hazard	Frequency Percentage (Counts)					
	Gher water		Pond water		Canal water	
	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
None (<3)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Slight to Moderate (3-9)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)	0% (0)
Severe(>9)	100% (9)	100% (9)	100% (9)	100% (9)	100% (10)	100% (10)

1.7.5 Classification of plants based on Exchangeable Sodium Percentage (ESP)

FAO-UNESCO (1973) and Pearson (1960) classified the selected plants based on ESP. It has shown what kind of crop can be cultivated according to the value of ESP. It can be seen that only tolerant plants can be grown according to the exchange sodium percentage value of surface water (*Ghers*, ponds and canal) which is in table 6 and details in table 10.

Table 6: Selection of plants based on ESP (FAO-UNESCO 1973 and Pearson 1960).

ESP	Classification of Plants	Frequency Percentage (Counts)					
		Gher water		Pond water		Canal water	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
>15	Sensitive	0	0	0	0	0	0
15-40	Semi-tolerant	0	0	0	0	0	0
>40	Tolerant	9	9	9	9	10	10

1.7.10 Irrigation water classification based on Permeability Index (PI)

Richards (1954) classified the water for irrigation based on PI values. According to the classification, 100% *Gher* water, pond water and canal water are unsuitable for irrigation purposes in both periods in table 7 and details in table 10. From the table, it appears that the *Ghers*, ponds and canals water of Bagerhat district is totally unsuitable in pre-monsoon and post-monsoon for irrigation.

Table 7: Irrigation water classification based on PI (Richards, 1954).

Permeability Index (PI)	Water class	Frequency Percentage (Counts)					
		Gher water		Pond water		Canal water	
		Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
<25	Good	0	0	0	0	0	0
25-70	Permissible	0	0	0	0	0	0
>70	Unsuitable	9	9	9	9	10	10

Table 8: Calculated and physical parameters of surface water.

Parameters	Percent Sodium (%Na)						Electrical Conductivity (EC)					
Upazilla	*Gher* water		Pond water		Canal water		*Gher* water		Pond water		Canal water	
	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.
Mollahat	99.04	98.85	97.17	94.73	97.14	93.30	3460	1860	950	350	2390	360
Fakirhat	99.23	99.12	98.10	94.05	98.98	92.65	8260	4350	1160	480	4030	600
Chitalmari	99.32	99.04	96.99	92.52	97.70	89.51	6580	3500	1250	540	3010	300
Kachua	99.14	99.05	95.75	94.48	99.27	98.64	9250	4230	960	760	7090	1160
Bagerhat Sadar	98.82	99.03	94.53	96.34	99.27	98.34	7350	3740	1080	610	8920	1100
Rampal	99.51	99.38	96.37	93.70	99.62 99.66	99.43 96.54	13560	6280	1380	720	16940 15360	2070 1990
Mongla	99.51	99.27	96.34	96.16	99.56	99.37	13230	7270	1290	610	16430	2130
Morrelganj	99.34	99.57	97.29	93.03	99.48	97.83	10840	5710	1510	710	11700	1520
Sarankhola	99.65	99.45	98.48	94.80	99.82	99.33	12320	6820	1620	715	14810	2280

Table 9: Calculated and physical parameters of surface water.

Parameters	Total Dissolved Solid (TDS)						Sodium Adsorption Ratio (SAR)					
Upazilla	*Gher* water		Pond water		Canal water		*Gher* water		Pond water		Canal water	
	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.
Mollahat	2318.2	1246.2	636.5	234.5	1601.3	241.2	769.76	501.98	238.24	109.20	356.41	96.10
Fakirhat	5534.2	2914.5	777.2	321.6	2700.1	402	1199.16	899.03	303.56	114.04	846.04	92.82
Chitalmari	4408.6	4345	837.5	361.8	2016.7	201	1154.14	740.42	259.03	101.49	437.88	67.29
Kachua	6197.5	2834.1	643.2	509.2	4750.3	777.2	1228.83	837.40	195.22	146.88	1183.16	377.08
Bagerhat Sadar	4924.5	2505.8	723.6	408.7	5976.4	737	966.54	702.95	165.96	170.44	1322.35	330.98
Rampal	9085.2	4207.6	924.6	482.4	11349.8 10291.2	1386.9 1333.3	2058.71	1098.55	251.77	149.22	2510.09 2493.73	737.35 293.45
Mongla	8864.1	4870.9	864.3	408.7	11008.1	1427.1	1981.14	1127.19	230.46	175.33	2281.04	724.21
Morrelganj	7262.8	3825.7	1011.7	475.7	7839	1018.4	1505.32	1357.53	309.55	141.08	1794.46	344.83
Sarankhola	8254.4	4569.4	1085.4	479.05	9922.7	1527.6	2289.92	1289.65	422.77	150.57	3481.45	713.53

Table 10: Calculated parameters of surface water.

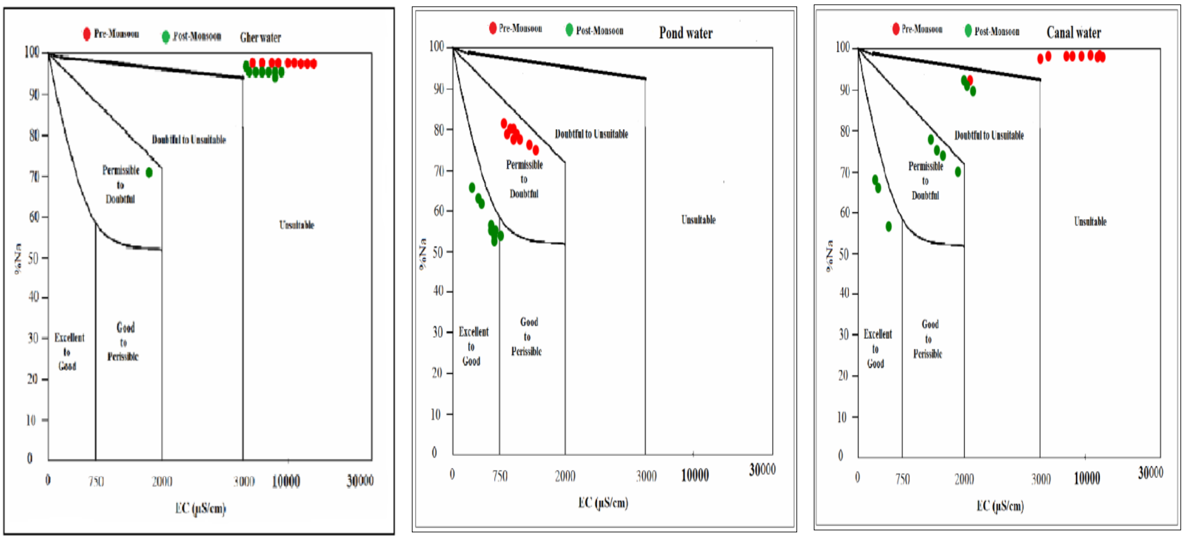
Parameters	Exchangeable Sodium Percentage (ESP)						Permeability Index (PI)					
Upazilla	***Gher* water**		**Pond water**		**Canal water**		***Gher* water**		**Pond water**		**Canal water**	
	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.	Pre-m.	Post-m.
Mollahat	98.11	97.48	96.27	93.64	96.34	91.20	101.96	103.45	106.85	113.84	100.19	106.51
Fakirhat	98.41	98.48	96.84	93.18	97.95	89.67	101.32	100.41	103.61	103.88	101.08	100.19
Chitalmari	98.94	98.61	94.90	89.28	97.20	87.02	100.73	100.83	104.32	104.69	102.68	104.76
Kachua	98.38	98.48	94.46	92.79	98.38	97.87	100.90	99.87	104.78	102.88	100.47	101.91
Bagerhat Sadar	98.14	98.40	89.17	93.75	98.38	96.73	99.85	100.99	102.99	101.28	100.49	107.39
Rampal	98.85	98.61	91.53	93.78	98.95	97.98	99.88	101.57	103.66	104.33	100.57	104.86
					98.79	95.82					100.23	99.22
Mongla	98.91	98.53	93.20	93.28	98.99	97.79	100.16	100.28	107.42	100.45	100.25	102.37
Morrelganj	98.73	99.09	95.91	95.58	98.98	96.98	100.94	101.82	101.25	105.16	100.45	101.44
Sarankhola	99.40	99.20	97.66	96.54	99.71	98.88	100.36	100.52	103.36	105.91	100.29	101.24

1.7.8 Water quality assessment for irrigation based on (Wilcox, 1955) diagram

There is a diagram for the classification of irrigation water based on %Na and EC (Wilcox, 1955). The diagram shows five classes of water for irrigation. Those are excellent to good, good to permissible, permissible to doubtful, doubtful to unsuitable and unsuitable. In the pre-monsoon, 9 samples of *Gher* water are unsuitable category but in post-monsoon, one out of 9 samples of *Gher* water is in permissible to doubtful category and 8 in unsuitable category. In pre-monsoon, 9 pond water samples are in permissible to doubtful category and in post-monsoon, 8 samples out of 9 samples pond water are in excellent to good and one sample is in good to permissible category. There is 1 sample out of 10 samples in canal water is in doubtful to unsuitable and 9 samples fall in unsuitable category in the pre-monsoon period where 3 samples out of 10 samples are in excellent to good, 8 samples out of 10 samples are in permissible to doubtful and 3 samples out of 10 samples are in doubtful to unsuitable category in the post-monsoon. So, it is concluded that the surface water of the study are unsuitable for irrigation purposes in pre-monsoon periods and most of the water are permissible to doubtful in the post-monsoon except pond water which are graphically presented in figure 7 (a,b,c).

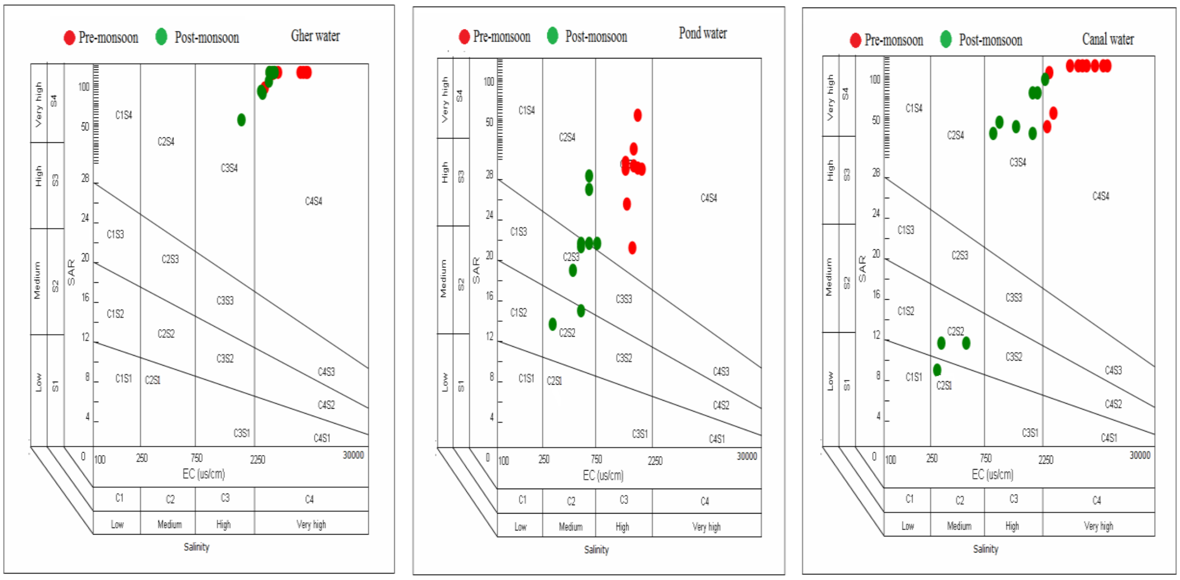
1.7.9 Irrigation water quality based on (USSL staff, 1954) diagram

A diagram has made by USSL staff (1954) for the classification of irrigation water based on SAR and EC due to find out for find salinity hazard where they showed four classes. Those are low class (C1S1), medium class (C2S2), high class (C3S3) and very high class (C4S4). The results show that all the samples of *Gher* water in pre-monsoon, salinity hazard are very high class (C4S4) while in the post-monsoon, 8 samples of *Gher* water, salinity hazard are very high (C4S4) but 1 sample's salinity hazard is high class (C3S3). There are 9 out of 9 samples of pond water in pre-monsoon, salinity hazard is high class while in the post-monsoon salinity hazard is medium class and but results are C2S2, C2S3 and C2S4. Salinity hazard of all 10 samples of canal water in pre-monsoon are very high (C4S4) while in the post-monsoon, salinity hazard are medium class (C2S1, C2S2), high class (C3S4) and one sample is very high class (C4S4). According to the results, surface water of the study are high class and very high class which means salinity hazard are predominant in the area during the pre-monsoon period and in the post-monsoon period, most of the water are medium class and high class exceptional few samples which are graphically presented in Figure 8 (a,b,c). So, it is concluded that pond and canal water of post-monsoon period are comparatively suitable for irrigation purposes.



(a) (b) (c)

Figure 7a-c: Water quality assessment for irrigation.



(a) (b) (c)

Figure 8a-c: Water quality assessment for Irrigation.

1.8 Conclusion

In the present study, surface water samples were collected due to find out water quality for drinking and irrigation purposes. The physiochemical analyzed results of the surface water samples was compared with the WHO (2006), DoE (1997) for drinking and %Na, EC, TDS, SAR, ESP, PI, Wilcox diagram and USSL staff diagram for irrigation water specification. WHO (2006), DoE (1997), calculated ratios and other diagrams offers a useful representation of overall quality of surface water for public or for any intended use as well as in water quality management. The evaluation of physicochemical parameters of surface water concluded that all parameters are seasonally fluctuated, while most of the parameters such as Temperature, pH, TDS, EC, Na^{+}, Ca^{2+}, Mg^{2+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{2-}, NO_3^{-} and some calculated parameters such as SAR,, ESP, %Na, and PI are remarkably decreased during post-monsoon period. The water quality controlling parameters especially EC, TDS, Na^{+} and Cl^{-} concentrations are objectionable because most of the surface water samples exceeded the WHO (2006) and DoE (1997) standards limit which means the surface water of the study area is unsuitable for drinking purposes. Other parameters especially pH, Ca^{2+}, K^{+}, Mg^{2+}, HCO_3^{2-}, NO_3^{2-} and SO_4^{2-} are not fully acceptable in most of the surface water of the study area. Find out the surface water quality for irrigation purposes is compared with the acceptable level of EC, TDS, SAR, ESP, %Na, PI and various diagrams which indicated that the surface water are unsuitable. So, it is concluded by the results of physicochemical parameters that the surface water quality is unsuitable for drinking and irrigation purposes. However, the pond water is comparatively good among the surface water and proper management and necessary steps such as Pattern change of crop lands, Reforming canal and Making Sluice gate on the canal, Rainwater harvesting reservoir, Protective river and canal embankment, Protective saltwater drainage system, Minimizing over pumping and less water extraction and Artificial recharge be utilize to restore the surface water quality

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