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REVIEW ARTICLE

Coastal surface water suitability analysis for irrigation in Bangladesh

Mohammad Hossain Mahtab[1] · Anwar Zahid[2]

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Abstract
Water with adequate quality and quantity is very important for irrigation to ensure the crop yields. Salinity is common problem in the coastal waters in Bangladesh. The intensity of salinity in the coastal zone in Bangladesh is not same. It fluctuates over the year. Sodium is another hazard which may hamper permeability and ultimately affects the fertility. It can reduce the crop yields. Although surface water is available in the coastal zone of Bangladesh, but its quality for irrigation needs to be monitored over the year. This paper will investigate the overall quality of coastal surface waters. Thirty-three water samples from different rivers were collected both in wet period (October–December) and in dry period (February–April). Different physical and chemical parameters are considered for investigation of the adequacy of water with respect to international irrigation water quality standards and Bangladesh standards. A comparison between the dry and wet period coastal surface water quality in Bangladesh will also be drawn here. The analysis shows that coastal surface water in Bangladesh is overall suitable for irrigation during wet period, while it needs treatment (which will increase the irrigation cost) for using for irrigation during dry period. Adaptation to this situation can improve the scenario. An integrated plan should be taken to increase the water storing capacity in the coastal area to harvest water during wet period.

Keywords Coastal zone · Crop yields · Permeability · Salinity · Sodium

Introduction

Water and soil salinity are normal hazards in many parts of the coastal area in Bangladesh, affecting different uses of water including irrigation, drinking, household, fisheries, and functioning of the ecosystem (Khanom and Salehin 2012).

Characteristics of irrigation water that define its quality vary with the source of the water. The quality of water also depends on whether the source is from surface water bodies (rivers and ponds) or from groundwater aquifers with varying geology, and whether the water has been chemically treated. If there is any harmful chemical component, it can affect plant growth directly through toxicity or deficiency, or indirectly by altering plant availability of nutrients (Ayers and Westcot 1985; Rowe and Abdel Magid 1995; Islam and Shamsad 2009).

Irrigation water quality is related to its effects on soils and cultivated crops and its management. High-quality crops need high-quality irrigation water keeping other inputs optimal. Salinity in the coastal area degrades soil quality which in turn reduces rice production. Due to this salinity problem in the coastal area, many rice fields are converted into shrimp ponds, and total rice production decreases accordingly. In the financial year 1997–1998, the area of rice production decreased by 1% compared to that in the 1993–1994, while the total rice production declined by 26% during the same period (Islam 2004).

Haque (2006) analyzed that the severity of salinity problem in the coastal area increases with the desiccation of the soil. It affects crops depending on degree of salinity at the critical stages of growth, which reduces yield and in severe cases; total yield is lost. About 53% of the coastal areas are affected by salinity. He focused on the soil characteristics related to the rice production in the coastal area in Bangladesh.

Salinity intrusion due to sea-level rise will decrease agricultural production through the unavailability of fresh water

✉ Mohammad Hossain Mahtab
mahtabce82@gmail.com

[1] Bangladesh Water Development Board (BWDB), Dhaka 1000, Bangladesh

[2] Ground Water Hydrology, BWDB, 72 Green Road, Dhaka, Bangladesh

and soil degradation (Sarwar and Khan 2007). A World Bank (2000) study reported that increased salinity from a 0.3 m sea-level rise will alone reduce the net production of rice by 0.5 million metric tons in coastal area in Bangladesh. During winter, the saline front starts to penetrate into inland, and the affected areas rise sharply from 10% in the monsoon to over 40% in the dry season. It is observed that sea flow (saline water) is moving far inside the country causing in contamination both in surface and ground waters (DMB 2010). It is measured that saline water intrusion has increased which will be intensified with the sea-level rise. It is highly seasonal and affects crop productivity (SDC 2010). Bangladesh Rice Research Institute (BRRI) invented saline tolerant variety. This new rice variety can tolerate the salinity up to 8 ds/m.

Bangladesh Water Development Board (BWDB) carried a study under Ganges study project to investigate the effects of Farraka barrage in the coastal area in Bangladesh. This study clearly identifies the adverse effects of the Farraka barrage on the surface and ground water in the coastal area. Salinity in the surface water has increased in the last few years. Upstream flow towards sea is significantly reduced during dry period (SWHC 2013).

Dewan et al. (2015) identifies three major shifts in the participatory water management system in the coastal area of Bangladesh. These are indigenous local systems managed by landlords, top–down engineering solutions, and depoliticized community-based water management. He also identifies the increasing demand for involvement of elected local government. Roy et al. (2017) investigate the change process of social and hydro-ecological systems. He identifies multiple physical and socio-economic drivers such as climatic change, upstream development, geologic process, land use change, etc. These drivers impact on ecology and society. He proposed drivers–pressure–state–impact–response (DPSIR) framework as an effective solution. Mutahara et al. (2017) analyze the tidal river management (TRM) from social perspective. He concludes that the coordination among the stakeholders makes the TRM process sustainable in the coastal area. Gain et al. (2017) identify the coastal area problems such as waterlogging, salinity, and loss of biodiversity. He suggested TRM approach with the trans-disciplinary framework to make it sustainable.

Water quality concerns have often been neglected if good quality water supplies have been plentiful and readily available. This situation is now changing in many areas especially in coastal and urban areas (Islam and Shamsad 2009). Water quality is deteriorated day by day due to numerous biological, physical, and chemical variables. Therefore, research work has been carried out to determine some vital water quality parameters those abate the water quality with its economical remedy (Razzak and Siddik 2013). Recently, delta plan was taken in Bangladesh. It is a long-term integrated strategy to address the water management, climate change, and environmental challenges in Bangladesh. Delta plan identifies the reduction in freshwater inflows from the Ganges river. It causes the siltation of the tributaries of the Ganges and siltation of other rivers. Salinity in the coastal zone increases steadily from December to February, reaching a maximum in late March and early April (GoB 2017).

Water logging and salinity are identified as the serious problem in the coastal area in Bangladesh. It causes a threat to the agricultural activities and a great damage of the overall environment (MoA 1999). Surface water was prioritized among other sources of water in Bangladesh. Use of water for agriculture is also prioritized to abstract water from any water stress area after using for household (IELRC 2013). Surface water in the coastal area should be used for agriculture as surface water was prioritized rather than the ground water. In this context, it needs to know the current state of the surface water in the coastal area. This information will help to know whether it needs any treatment for using the river water for irrigation or not. This research will only focus on the river water quality over the coastal area. The objectives of this study are (1) to provide an overall idea about the recent coastal river water quality in Bangladesh, (2) to present an analysis of the suitability of coastal waters of Bangladesh for irrigation, and (3) to provide scientific recommendations for policy makers for using the surface water for irrigation.

Study area

The coastal region in Bangladesh covers almost 29,000 km^2 or about 20% of the country land area, while it covers more than 30% of the cultivable lands of the country (Haque 2006). In terms of administrative consideration, 19 districts out of 64 are considered as coastal districts (BBS 2011; MoEF 2007). Ten out of 19 coastal districts of Bangladesh (Fig. 1) are considered in this study; these are Laksmipur, Barisal, Noakhali, Patuakhali, Khulna, Barguna, Barisal, Chittagong, Cox's bazaar, and Feni. Water samples have been collected directly from the concern Rivers and tested at laboratory located in Hydrology campus at Green road, Dhaka. The sampling sites are depicted in Fig. 1.

Methodology and data

Irrigation waters whether collected from rivers or pumped from wells contain appreciable amount of chemical substances. It may reduce crop yield and deteriorate soil fertility. Normally, irrigation water always carries substances which may come from its natural environment or from the waste products of man's activities (FAO 2007). The methodology

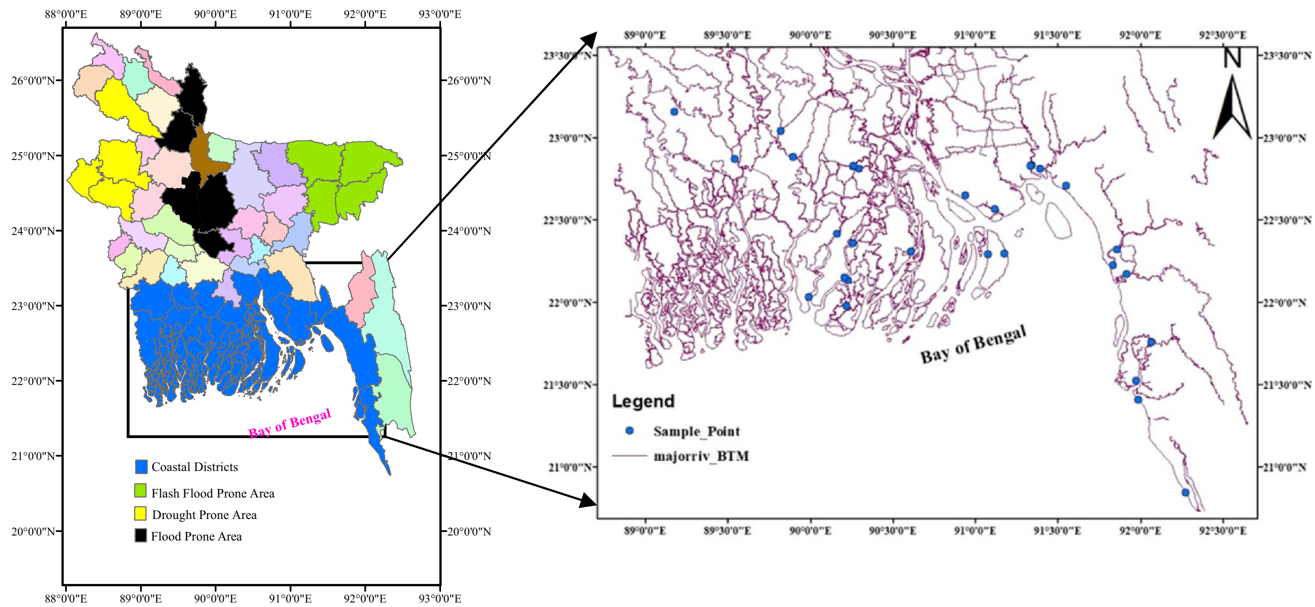

Fig. 1 Map of sampling sites and coastal area of Bangladesh

includes a field research to investigate the surface water suitability for irrigation in the coastal region in Bangladesh. A total of 66 surface water samples in the dry and wet periods were considered. To characterize the river water, samples were collected from different locations in the coastal districts during dry and wet periods, as listed in Appendix 1 and Appendix 2. Water samples were collected in plastic containers with stopper from beneath the surface from different sampling points. Water samples were collected about 1 ft below the river surface to ensure the quality of samples. Water samples were collected from the same location during dry and wet periods. Collected samples are carefully tested in the laboratory. The quality of the result is good. The particulars of the samples are presented in Appendix 1 and Appendix 2. These sampling includes the physical and chemical parameter, i.e., pH, EC, TDS, Ca^{2+}, Mg^{2+}, CO_3^{2-}, Na^+, and HCO_3^-. Tested sample results are analyzed to discuss the quality of the surface water for irrigation in the coastal districts. The samples were collected in the dry and wet periods in 2012 and 2013 (Appendix 1 and Appendix 2). Guidelines for irrigation water quality are collected by the desk literature reviews. A comparison between the dry and wet period water qualities in the coastal districts is drawn to show the seasonal variations of the water quality. Finally, recommendations for policy makers will be presented.

Water quality with respect to irrigated agriculture

Water quality analysis for irrigation mainly includes the determination of (1) the total concentration of soluble salts, (2) the relative proportion of sodium to the other cations, and (3) the carbonate and bicarbonate concentration with respect to the concentration of calcium and magnesium. To assess the suitability of coastal river's water of Bangladesh for irrigation and to find out the adequate management strategies, the following guidelines will be considered.

The limit of the water quality standard for irrigation in Bangladesh is relatively higher compare to the international standards. Ministry of environment and forest has sets this limit with respect to the socio-economic conditions in Bangladesh.

Results and discussion

In this section, the surface water quality in dry and wet seasons in the coastal part of Bangladesh with respect to irrigation will be illustrated. The calculated values of the water samples are presented in Appendix 1 and Appendix 2. The results are also graphically shown in Fig. 2. The extreme values are not considered for plotting the graphs (Appendix 1 and Appendix 2).

The pH value of the surface water at the study area ranges from 6.20 to 8.59 with an average value of 7.71 during October–December, while this value varies from 7.5 to

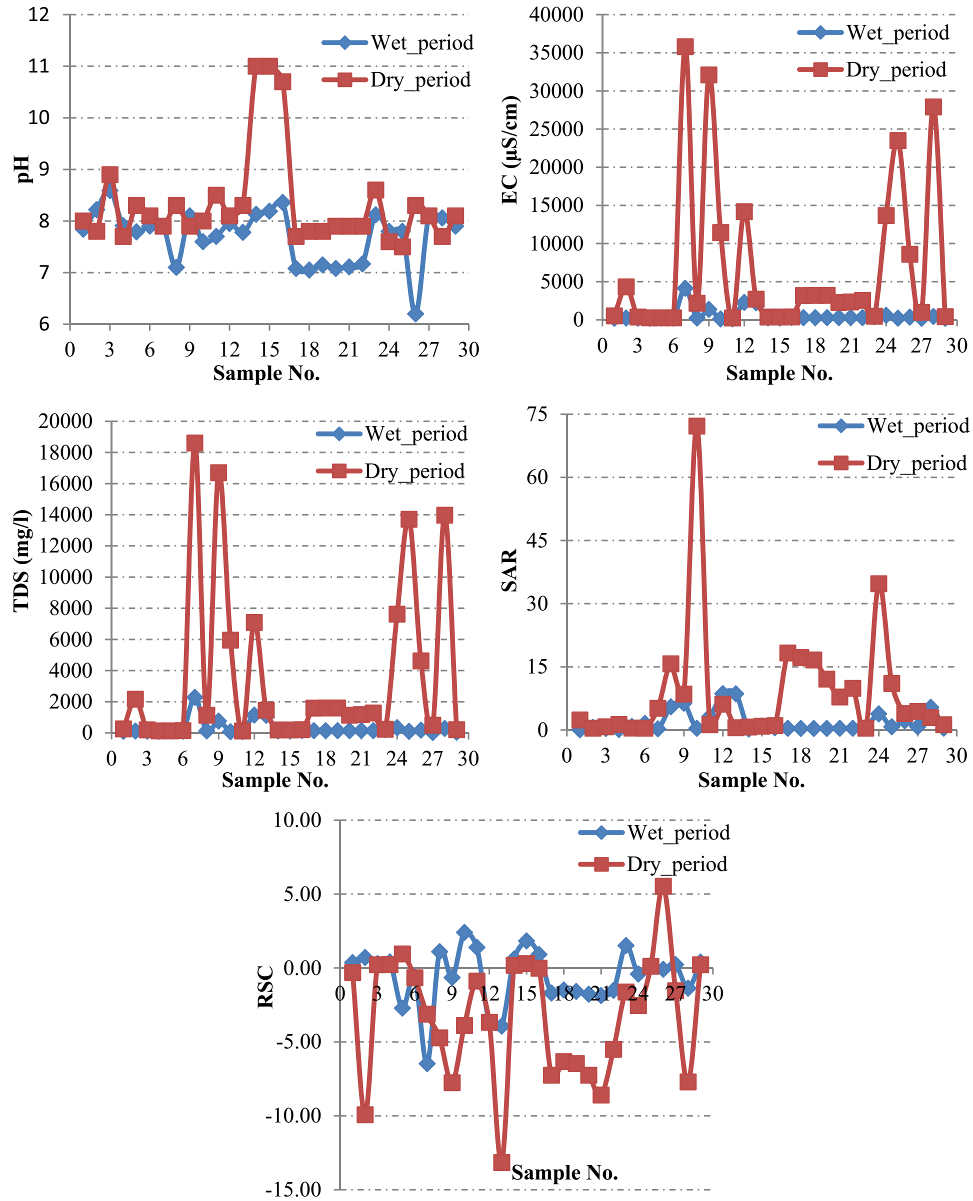

Fig. 2 Graphical representation of the surface water quality in the coastal area in Bangladesh

11 with an average value of 8.32 during February–April. It was found that out of 33 water samples, 32 samples in the wet period and 26 samples in the dry period are within the permissible limit for irrigated agriculture (Table 1). Bangladesh government allowed the higher ranges. Therefore, 33 samples in the wet period and 30 samples in the dry period are within the permissible limit (Table 2; Appendix 1 and Appendix 2; Fig. 2).

The EC value of the river water ranges from 34,800 to 109.4 μS/cm during wet period, while it varies from 57,300 to 253 μS/cm during dry period. The samples collected from or near the Bay of Bengal (Sea)/estuarine, the value of EC both in dry and wet periods is very high. These values can be considered as extreme values. In general, the EC value in dry period is higher compared to that in the wet period. This is due to more sea-water intrusions into country side for decreased upstream flow. According to Bangladesh standard, 25 samples in the wet period and 12 samples in the dry period are within the permissible limit for irrigated agriculture (Table 2; Appendix 1 and Appendix 2; Fig. 2). In this context, it can easily be concluded that in terms of EC value, most of the river water is suitable for irrigation during wet period, while it is inappropriate without any treatment during dry period (UCCC 1974). In addition to EC, it is also important to consider the TDS in surface water. Many of the toxic solid materials may be dissolved in the water which may cause harm to the plants (Matthess 1982). As EC and TDS values are interrelated and can be calculated by equation, both the values are indicative of the intensity of salinity of water in the absence of non-ionic dissolved

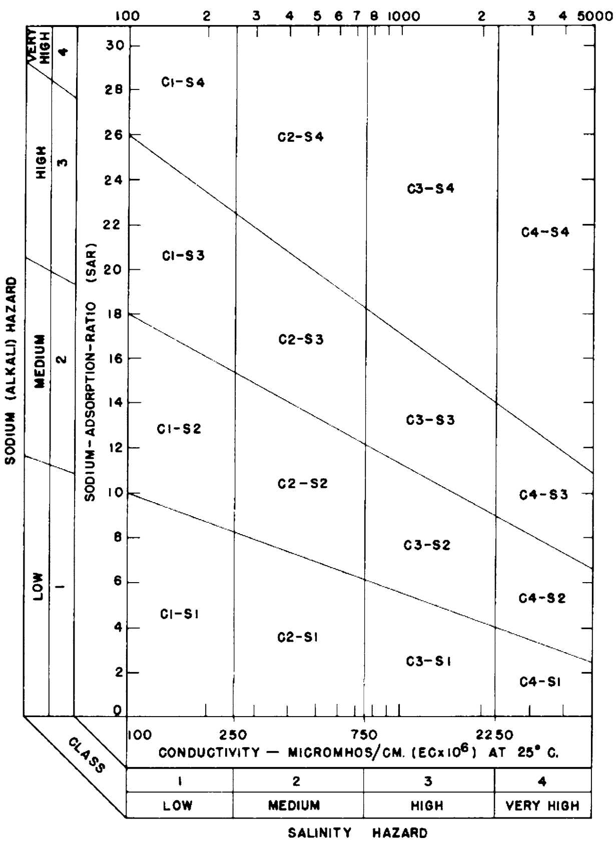

Fig. 3 Diagram for the classification of irrigation waters (Richards 1954)

Table 1 Guideline for irrigation water quality. Source: (FAO 1976)

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity (affects crop water availability)				
EC_w (or)	μS/cm	< 700	700–3000	> 3000
TDS	mg/l	< 450	450–2000	> 2000
Infiltration (affects the rate of infiltration of water into the soil. Evaluate using EC_w and SAR together)				
SAR	and EC_w			
= 0–3	=	> 700	700–200	< 200
= 3–6	=	> 1200	1200–300	< 300
= 6–12	=	> 1900	1900–500	< 500
= 12–20	=	> 2900	2900–1300	< 1300
= 20–40	=	> 5000	5000–2900	< 2900
pH		Normal Range 6.5–8.4		

EC_w electrical conductivity (of water), *TDS* total dissolved solids, *SAR* sodium absorption ratio

Table 2 Water quality standard for irrigation in Bangladesh Source: (GoB 1997)

Parameters	Units	Irrigation limit	Parameters	Units	Irrigation limit
pH		6.0–9.0	Bicarbonate (HCO_3)	mg/l	200
EC	μs/cm	1200	Carbonate (CO_3)	mg/l	–
TDS	mg/l	2100	Chloride (Cl)	mg/l	600
Calcium (Ca)	mg/l	–	Nitrate (NO_3)	mg/l	–
Magnesium (Mg)	mg/l	–	Phosphate (PO_4)	mg/l	10
Sodium (Na)	mg/l	–	Sulphate (SO_4)	mg/l	–
Potassium (K)	mg/l	–	Boron (B)	mg/l	2
Iron (Fe)	mg/l	1–2	Arsenic (As)	mg/l	1
Manganese (Mn)	mg/l	5			

Table 3 Suitability of water for irrigation with respect to RSC value source: (PNWE 2007)

RSC class	RSC (meq/L)	RSC irrigation hazard
Class 1, low	below 0	No RSC- associated problems
Class 2, medium	0–1.0	Monitor infiltration and soil pH; amendment may or may not be necessary; check SAR. Generally safe for irrigation
Class 3, high	1.0–2.5	Monitor infiltration and soil pH; amendment with acid or gypsum likely is necessary. Marginal as an irrigation source
Class 4, very high	above 2.5	Monitor infiltration and soil pH; amendment with acid or gypsum is necessary. Usually unsuitable for irrigation without amendment

RSC Residual sodium carbonate

components (Michael 1992). The applied irrigated water to the soil introduces and increases salt contents into the root zone. Plant roots use water and very little salts from the soil solution. When water evaporates from the soil surface, the salts remain in the root zone. As a result in the gradual accumulation of salts in the root zone causes of salinity hazards, water deficiency, toxicity, and other problems (FAO 2007). The suitability of water for irrigation depends on the presence of total amount of salts. In addition to that the kind of salts and the type of crops are also important. Various soil and cropping problems develop as the total salt content increases, and special management practices may be required to attain crop yields at desired level (FAO 2007). It needs continuous monitoring to manage the high saline water for irrigation. Practices which aid in remedying salinity problems are the leaching. Leaching means diluting high salinity water with low salinity water to leach the excess salts from the soil with excess water.

Water permeability, also known as infiltration, can be decreased under certain salinity and Na condition. The SAR is an indicator of the amount of sodium (Na) in the water relative to calcium (Ca) and magnesium (Mg). A situation that hampers permeability affects the fertility and it reduces the crop yield (Gupta 2005). Water permeability depends on both parameters EC and SAR. There are two terms to explain the irrigation water permeability and Na hazard: first, SAR (Sodium Absorption Ratio) and second, RSC (Residual Sodium Carbonate). It was found that out of 33 water samples, 19 samples fall within the water quality classification stand 'low', 9 samples fall within the water quality classification stand 'medium', and rest of the samples stand for high RSC value in the wet period, while 25 samples fall within the water quality classification stand 'low', 7 samples fall within the water quality classification stand 'medium', and 1 sample stand for high RSC value in the dry period (Table 3; Appendix 1 and Appendix 2; Fig. 2). Staffs of United States Salinity Laboratory have classified salinity of irrigation waters using a quality diagram. It divides irrigation waters into 16 classes, with reference to SAR as an index of sodium hazard along *Y*-axis and EC as an index of salinity hazard along *X*-axis (Fig. 3). It is found that out of 33 water samples, 14 water samples is categorized into "C_1S_1" or "low" and 11 water samples is categorized into "C_2S_1" during wet period. Such water can be used safely for irrigation purposes (Richards 1954), whereas 11 water samples are categorized into "C_2S_1" and the rest of the samples fall into high salinity and sodium hazard classification during dry period. This high saline water cannot be used safely for irrigation rather it needs treatments (Wilcox 1955).

From the analysis of the standard deviations (SD) of the collected samples, it can be seen that the SD during dry period is higher compared to that in the wet period for the same parameters. It means that dry period's parameters are more deviated from the average value. It is also seen that SD value is high for few parameters both in wet and dry periods. It indicates that more water samples are necessary to analyze and to come into conclusions.

Conclusions

Population and food demand in Bangladesh are increasing, while the production in the coastal area is decreasing due to salinity. The scenarios are expected to be intensified due to the effects of climate change and sea-level rise in the future. This study shows that surface water in the coastal districts of Bangladesh is overall suitable for irrigation during October–December, while the river water is inappropriate during February–April without any treatment. Type of crops is also very important to explain the suitability of irrigation water. On the basis of SAR and RSC, overall, no permeability problem was found in the coastal surface water during wet period, while during dry period, permeability is so far a problem in few areas. This study investigates that the near the coast the higher the salinity problem in the coastal area. This research also implies that the salinity in the coastal area is the main problem as described in the other literatures. Ganges study clearly identifies that the upstream flow is decreasing due to Frakka barrage in India. Policy makers should focus to increase the river flow in the dry period, while they will ensure the utilization of the surface water during wet period. It causes the more saline water intrusion during dry period. Ten out of 19 coastal districts of Bangladesh are considered in this study. The samples collected from the rest nine districts are not well oriented. Therefore, this study does not cover the whole coastal zone of Bangladesh. More samples from the coastal zone should be taken continuously over the year. In this context, this study suggests.

- Minimum required flow in the coastal rivers must be determined before extracting the water during dry period.
- Rice is the main crop in the coastal area. Mainly, the flooding method to cultivate the rice is used. It needs excess water. Therefore, agriculture efficiency must be improved. It will reduce the demand of water.
- An integrated plan needs to be developed. The plan will mainly focus the small area rather than the whole coastal zone at a time. Area-based solution will be more effective. Artificial tank can be built to preserve the water.
- Sufficient water must be harvested during wet period. Water coarse area needs to be increased, i.e., pond, lake, etc. to hold the water during rainy period. Seepage loss must be controlled.
- Adaptation is very important to manage the water resources. Crop pattern and timing should be changed to adjust the situation. Salt tolerant variety needs to be widely cultivated.
- As upstream water flow reduced due to Frakka barrage, another barrage inside Bangladesh can increase the head in the Ganges. It will ensure the more upstream flow; thus, the saline problem will be managed with time. Improved diplomatic relationship with India can help to increase the flow into trans-boundary rivers as well.

These initiatives can be taken under Bangladesh delta plan 2100.

Acknowledgements I wish to express my deepest thanks to Officials of the director, Ground water and Surface water hydrology circles of BWDB for providing me surface water data and other technical matters related to my study.

Appendix 1: Water quality data and analysis

Surface water, wet season, physical and chemical parameters (October–December)

SI. no.	District	Upazila	River	Date of sampling	pH	EC (µS/cm)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Sodium absorption ratio (SAR)[1]	Residual sodium carbonate (RSC)[2]	Restriction on use (Table 1) SAR and EC_W	Restriction on use (Table 3) RSC	Classification of irrigation waters EC_W and SAR (Fig. 3)
1	Barguna	Amtoli	Burissor Paira	06.10.2012	7.84	203	101.2	11.95	2.87	0.77	0	73.2	0.05	0.37	M	M	C_1S_1
2	Barguna	Barguna Sadar1	Burissor Paira	07.10.2012	8.22	222	113.4	12.77	3.07	9.02	0	97.6	0.59	0.71	M	M	C_1S_1
3	Barguna	Barguna Sadar2	Biskhali	07.10.2012	8.59	215	109.5	15.28	5.43	6.59	0	91.5	0.37	0.29	M	M	C_1S_1
4	Barguna	Betagi	Rajgonj	08.10.2012	7.91	201	99.5	11.73	3.77	1.71	0	79.3	0.11	0.40	M	M	C_1S_1
5	Barisal	Babuganj	Shondha	27.10.2013	7.79	227	113.4	75.54	6.58	27.6	0	97.6	0.82	− 2.72	M	L	C_1S_1
6	Barisal	Uzirpur	Shondha	27.10.2013	7.9	220	110	23.63	8.88	34.72	0	79.3	1.54	− 0.61	M	L	C_1S_1
7	Chit-tagong	Anowara	Karnofuli	14.09.2012	7.9	4140	2277	47.4	74.43	12.58	0	122	0.27	− 6.47	N	L	C_4S_1
8	Chit-tagong	Baskhali	Shangu	14.09.2012	7.1	224	121	7.43	4	74.9	0	109.8	5.51	1.10	S	H	C_1S_1

SI. no.	District	Upazila	River	Date of sampling	pH	EC (µS/cm)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	CO_3^{2-} (mg/l)	HCO_3^{-} (mg/l)	Sodium absorption ratio (SAR)[1]	Residual sodium carbonate (RSC)[2]	Restriction on use (Table 1) SAR and EC_W	Restriction on use (Table 3) RSC	Classification of irrigation waters EC_W and SAR (Fig. 3)
9	Chittagong	Mirersarai	Feni	16.09.2012	8.1	1369	753	15.185	30.37	185.56	0	158.6	6.33	− 0.65	M	L	C_3S_2
10	Chittagong	Patia	Karnofuli	15.09.2012	7.6	109.4	70	6.44	3.35	4.93	0	183	0.39	2.40	S	H	C_1S_1
–	Cox's bazar	Cox's Bazar Sadar	Bay of Bengal	11.09.2012	7.9	*34,800*	*18,440*	2.64	51.825	217.8	0	122	*6.40*	*− 2.38*	–	–	–
–	Cox's bazar	Moheshkhali	Bay of Bengal	15.09.2012	8	*19,290*	*10,609.5*	88.6	1.3	281.78	0	48.8	*8.13*	*− 3.74*	–	–	–
11	Cox's bazar	Chakaria	Bay of Bengal	13.09.2012	7.7	122.2	78.2	8.22	4.87	46.5	0	134.2	3.18	1.39	S	H	C_1S_1
–	Cox's bazar	Teknaf	Bay of Bengal	12.09.2012	7.7	*28,070*	*18,230*	2.0865	22.6	152.4	0	109.8	*6.70*	*− 0.16*	–	–	–
12	Feni	Sonagazi1	Choto Feni	01.10.2012	7.95	2280	1141	33.2	45.41	325.3	0	103.7	8.62	− 3.68	N	L	C_4S_3
13	Feni	Sonagazi2	Muhuri	01.10.2012	7.78	2250	1127	31.96	45.56	322	0	85.4	8.57	− 3.93	N	L	C_3S_2
14	Gopalganj	Gopalgonj Sadar	Madhimoti	20.10.2012	8.13	250	124.9	13.79	5.46	3.43	1.5	103.7	0.20	0.61	M	M	C_1S_1
15	Gopalganj	Kashiani	Madhimoti	20.10.2012	8.19	250	125.1	13.37	7.96	17.78	1.5	189.1	0.95	1.83	M	H	C_1S_1
16	Gopalganj	Tungipara	Madhimoti	19.10.2012	8.36	299	149.5	14.26	5.17	8.83	1.5	122	0.51	0.91	M	M	C_2S_1
17	Khulna	Khulna Sadar	Bhairab River	30.08.2013	7.08	273	136.5	41.8	13.47	10.79	0	91.5	0.37	− 1.69	M	L	C_2S_1
18	Khulna	Khulna Sadar	Bhairab River	30.08.2013	7.05	286	143	44.16	13.2	10	0	109.8	0.34	− 1.49	M	L	C_2S_1
19	Khulna	Khulna Sadar	Bhairab River	30.08.2013	7.15	273	139.7	49.73	13.44	10.81	0	122	0.35	− 1.59	M	L	C_2S_1
20	Khulna	Khulna Sadar	Bhairab River	30.08.2013	7.08	287	143.3	50.9	14.97	11.45	0	122	0.36	− 1.77	M	L	C_2S_1
21	Khulna	Khulna Sadar	Bhairab River	30.08.2013	7.11	291	145.3	48.33	14.05	12.21	0	103.7	0.40	− 1.87	M	L	C_2S_1
22	Khulna	Khulna Sadar	Bhairab River	30.08.2013	7.17	280	139.9	44.62	14.47	11.31	0	115.9	0.38	− 1.52	M	L	C_2S_1
23	Laksmipur	Ramgati	Meghna	29.09.2012	8.12	403	202	7.83	9.06	10.67	1.5	158.6	0.62	1.52	M	H	C_2S_1

SI. no.	District	Upazila	River	Date of sampling	pH	EC (μS/cm)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	CO_3^{2-} (mg/l)	HCO_3^{-} (mg/l)	Sodium absorption ratio (SAR)[1]	Residual sodium carbonate (RSC)[2]	Restriction on use (Table 1) SAR and EC_W	Restriction on use (Table 3) RSC	Classification of irrigation waters EC_W and SAR (Fig. 3)
24	Noakhali	Companigonj	Choto Feni	13.10.2012	7.8	595	333.2	7.83	16.03	80.8	0	79.3	3.80	− 0.41	M	L	C_2S_1
25	Noakhali	Hatia1	Meghna	23.12.2012	7.8	210	96.4	9.95	10.05	14	0	91.5	0.75	0.18	M	M	C_1S_1
–	Noakhali	Hatia2	Meghna	23.12.2012	8.13	*13,430*	*7480*	86.5	11.3	148.83	0	97.6	*3.99*	*− 3.65*	–	–	–
26	Noakhali	Hatia3	Meghna	14.10.2012	6.2	351	175.3	6.64	9.29	36.93	0	61	2.17	− 0.09	M	L	C_2S_1
27	Patuakhali	Dasmina	Tetulia	10.10.2012	8.1	188.5	25.2	10.16	4.37	11.38	0	67.1	0.75	0.23	S	M	C_1S_1
28	Patuakhali	Kalapara	Andhar-rmanik	05.10.2012	8.06	441	281	16.87	22.23	142.57	0	79.3	5.37	− 1.37	M	L	C_2S_1
29	Patuakhali	Mirzagonj	Paira	09.10.2012	7.9	195.7	34.7	11.38	4.05	6.23	0	79.3	0.40	0.40	S	M	C_1S_1
	Average				7.71	574.3	296.9	23.87	14.3	50.0	0.207	107.3	1.8645	− 0.60414			
	Range				8.59 to 6.20	34,800 to 109.4	18,440 to 25.2	88.60 to 2.09	74.43 to 1.30	325.3 to 0.77	1.50 to 0	189.10 to 48.80	8.62 to 0.05	2.4 to − 6.47			
	Standard deviation				0.44	880.45	474.7	18.54	16.05	86.85	0.526	32.55	2.5559	1.926,751			

Symbols M, N, S, L, H, and VH represent "Moderate/Medium", "None", "Severe", "Low", "High", and "Very High", respectively

Italic values can be considered as extreme values

(SAR) = $\frac{Na^+}{\sqrt{0.5(Ca^{++}+Mg^{++})}}$ (all ions in meq/l) (PNWE 2007)

(RSC) = $(CO_3^{--} + HCO_3^{-})-(Ca^{++},\ Mg^{++-})$ (all ions in meq/l) (PNWE 2007)

Appendix 2

Surface water, dry season, physical and chemical parameters (February–April)

SI. no.	District	Upazila	River	Date of sampling	pH	EC (µS/cm)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Sodium absorption ratio (SAR)[1]	Residual sodium carbonate (RSC)[2]	Restriction on use (Table 1) SAR and EC_W	Restriction on use (Table 3) RSC	Classification of irrigation waters EC_W and SAR (Fig. 3)
1	Barguna	Amtoli	Burissor Paira	09.03.2012	8	515	258	15.64	13.78	53.58	0	97.6	2.38	− 0.31	M	L	C_2S_1
2	Barguna	Barguna Sadar1	Burissor Paira	8.03.2012	7.8	4320	2160	55.64	111	23.42	1.5	115.9	0.42	− 9.93	N	L	C_4S_1
3	Barguna	Barguna Sadar2	Biskhali	10.03.2012	8.9	371	201	13.16	8.78	14.65	0	97.6	0.77	0.22	M	M	C_2S_1
4	Barguna	Betagi	Rajgonj	08.03.2012	7.7	268	128.7	14.74	10.76	27.41	1.5	109.8	1.32	0.23	M	M	C_2S_1
5	Barisal	Babuganj	Sondha	03.02.2013	8.3	266	131.9	0.16	9.09	6.49	0	103.7	0.46	0.95	M	M	C_2S_1
6	Barisal	Uzirpur	Sondha	04.02.2013	8.1	271	149.05	16.96	18.4	10.6	0	103.7	0.42	− 0.66	M	L	C_2S_1
7	Chittagong	Anowara	Karnofuli	19.04.2012	7.9	35800	18,600	30.2	63	216.8	1.5	213.5	5.16	− 3.12	N	L	C_4S_2
8	Chittagong	Baskhali	Sangu	20.04.2012	8.3	2180	1135	27.95	55.2	622.4	0	73.2	15.73	− 4.72	M	L	C_3S_3
9	Chittagong	Mirersarai	Feni	18.04.2012	7.9	32,100	16,700	128	70.88	484.4	1.5	268.4	8.52	− 7.76	N	L	C_4S_3
10	Chittagong	Patia	Karnofuli	20.04.2012	8	11,440	5950	75.35	13.7	2595.8	0	61	72.17	− 3.89	N	L	C_4S_4
–	Cox's bazar	Cox'sBazar Sadar	Bay of Bengal	20.02.2012	7.9	*57,300*	*28,600*	284.2	98.75	143.1	1.5	189.1	*1.86*	*− 19.15*	–	–	–
–	Cox's bazar	Moheshkhali	Bay of Bengal	19.02.2012	8.6	*55,900*	*27,900*	116.0	99.08	686	1.5	152.5	*11.30*	*− 11.37*	–	–	–
11	Cox's bazar	Chakaria	Bay of Bengal	20.02.2012	8.5	253	126	41.26	15.59	37.18	1.5	146.4	1.25	− 0.89	M	L	C_2S_1
–	Cox's bazar	Teknaf	Bay of Bengal	18.02.2012	8.2	*53,900*	*26,700*	98.4	30.09	835.3	1.5	152.5	*18.90*	*− 4.84*	–	–	–
12	Feni	Sonagazi1	Choto Feni	17.04.2012	8.1	14,180	7090	95.22	17.3	247.3	0	152.5	6.12	− 3.68	N	L	C_4S_2
13	Feni	Sonagazi	Muhuri	24.03.2013	8.3	2700	1450	10.12	166.6	32.7	0	61	0.53	− 13.16	N	L	C_4S_1
14	Gopalganj	Gopalgonj Sadar	Madhumoti	28.03.2012	11	374	194.2	16.11	13.07	15.47	1.5	122	0.69	0.17	M	M	C_2S_1
15	Gopalganj	Kashiani	Madhumoti	26.03.2012	11	361	187.8	14.71	16	20.67	1.5	140.3	0.89	0.30	M	M	C_2S_1
16	Gopalganj	Tungipara	Madhumoti	27.03.2012	10.7	391	203	16.92	16.1	25.07	1.5	128.1	1.05	− 0.02	M	L	C_2S_1

SI. no.	District	Upazila	River	Date of sampling	pH	EC (µS/cm)	TDS (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Na^{+} (mg/l)	CO_3^{2-} (mg/l)	HCO_3^{-} (mg/l)	Sodium absorption ratio (SAR)[1]	Residual sodium carbonate (RSC)[2]	Restriction on use (Table 1) SAR and EC_W	Restriction on use (Table 3) RSC	Classification of irrigation waters EC_W and SAR (Fig. 3)
17	Khulna	Khulna Sadar	Bhairab River	02.04.2013	7.7	3180	1591	47.53	77.84	879.7	0	91.5	18.28	− 7.26	N	L	C_4S_4
18	Khulna	Khulna Sadar	Bhairab River	02.04.2013	7.8	3200	1599	40.63	74.46	799.3	0	109.8	17.23	− 6.33	N	L	C_4S_4
19	Khulna	Khulna Sadar	Bhairab River	02.04.2013	7.8	3200	1598	36.7	76	768	0	97.6	16.63	− 6.46	N	L	C_4S_4
20	Khulna	Khulna Sadar	Bhairab River	02.04.2013	7.9	2270	1137	34.82	91.67	597.5	0	122	12.08	− 7.25	M	L	C_4S_3
21	Khulna	Khulna Sadar	Bhairab River	02.04.2013	7.9	2340	1172	32.33	109.6	414.1	0	122	7.82	− 8.60	N	L	C_4S_2
22	Khulna	Khulna Sadar	Bhairab River	02.04.2013	7.9	2550	1275	46.15	59.73	432.1	0	103.7	9.90	− 5.50	N	L	C_4S_2
23	Laksmipur	Ramgati	Meghna	22.03.2013	8.6	464	232	38.2	17.83	12.28	1.5	103.7	0.41	− 1.62	M	L	C_2S_1
24	Noakhali	Companigonj	Choto Feni	18.04.2012	7.6	13,660	7620	81.5	10.56	1255	0	146.4	34.73	− 2.54	N	L	C_4S_4
25	Noakhali	Hatia1	Meghna	22.04.2012	7.5	23,500	13,710	12.37	24.02	289	0	164.7	11.05	0.11	N	M	C_4S_4
–	Noakhali	Hatia2	Meghna	21.04.2012	7.6	*27,400*	*16,160*	35	47.8	383.5	0	189.7	*9.90*	*− 2.56*	–	–	–
26	Noakhali	Hatia3	Meghna	20.04.2012	8.3	8590	4620	4.45	9.12	62.48	18	359.9	3.90	5.53	N	VH	C_4S_2
27	Patuakhali	Dasmina	Tetulia	15.03.2012	8.1	987	494	22.89	24.89	128.1	1.5	97.6	4.41	− 1.53	M	L	C_3S_1
28	Patuakhali	Kalapara	Andharmanik	13.03.2012	7.7	27,900	13,970	118.7	41.7	146.2	1.5	97.6	2.94	− 7.71	N	L	C_4S_2
29	Patuakhali	Mirzagonj	Paira	12.03.2012	8.1	422	211	14.46	9.17	25.09	0	103.7	1.27	0.23	M	M	C_2S_1
	Average				8.32	6829.4	3582.5	38.03	42.96	353.2	1.19	128.1	8.9148	− 3.28276			
	Range				11 to 7.5	57,300 to 253	28,600 to 126	284.2 to 0.16	166.6 to 8.78	2595.8 to 6.49	18 to 0	359.9 to 61	72.17 to 0.41	5.53 to − 13.16			
	Standard deviation				0.94	10,288	5416.5	32.85	40.4	543.7	3.315	61.348	14.5	4.120555			

dS/m = deciSiemen/metre in S.I. units, mmho/cm = millimmho/centi-metre, µS/cm = microSiemen/centi-metre

Italic values can be considered as extreme values

1 dS/m = 0.1 S/m = 1000 µS/cm = 1 mmhos/cm = 1000 µmhos/cm, 1µS/cm = 1 µmhos/cm

$(meq/l) = \frac{ppm\ (or\ mg/l)}{equivalent\ weight}$ [equivalent weight for Na^{+}, Ca^{++}, Mg^{++}, CO_3^{--}, and HCO_3^{-} of 23, 20, 12.2, 30, and 61, respectively, is being used here]

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