Groundwater quality of different locations of Bangladesh.

Calidad de agua subterránea en diferentes localidades de Bangladesh.

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ABSTRACT

On the basis of groundwater chemistry, an evaluation of groundwater for domestic and irrigation purposes was carried out for different regions of Bangladesh. Using the chemical compositions and different quality parameters, irrigation quality was assessed using six different techniques: USDA method, FAO guidelines, Water-Types approach, Combined approach proposed by Al-Bassam et al., Ali, and GOB guidelines. Drinking quality was judged by WHO provisional guidelines and GOB guidelines. The results indicated that concentrations of major cations and anions of most groundwater samples were within allowable limit. Except one location (i.e. Barisal), the water for irrigation purpose are suitable to marginally suitable considering salinity and sodicity. For drinking purpose, all except two locations (i.e. Sunamgonj and Barisal, where iron is a concern) are found suitable. At these locations, other aquifer layer with low Fe can be searched for safer Fe level. Alternatively, Fe removal system can be assembled for collecting drinking water.

Keywords: Groundwater, Hydrochemistry, Quality parameters, Integrated quality assessment.

RESUMEN

Sobre la base de la química del agua subterránea, se llevó a cabo una evaluación del agua subterránea para fines domésticos y de riego en diferentes regiones de Bangladesh. Utilizando las composiciones químicas y los diferentes parámetros de calidad, se evaluó la calidad del riego utilizando seis técnicas

diferentes: método USDA, directrices FAO, enfoque de Tipos de Agua, enfoque combinado propuesto por Al-Bassam et al., Ali, y directrices GOB. La calidad de la bebida se juzgó según las directrices provisionales de la OMS y las directrices del GOB. Los resultados indicaron que las concentraciones de los principales cationes y aniones de la mayoría de las muestras de aguas subterráneas estaban dentro del límite permitido. Excepto en una ubicación (es decir, Barisal), el agua para fines de irrigación es adecuada para considerar marginalmente la salinidad y la sodicidad. Para el propósito de beber, todos, excepto dos lugares (es decir, Sunamgonj y Barisal, donde el hierro es una preocupación) se encuentran adecuados. En estos lugares, se puede buscar otro nivel de Fe más seguro en otras capas del acuífero con bajo contenido de Fe. Alternativamente, el sistema de extracción de Fe se puede ensamblar para recolectar agua potable.
Palabras clave: aguas subterráneas, hidroquímica, parámetros de calidad, evaluación integrada de la calidad.

INTRODUCTION

Water is one of the most important natural resources to sustain life. Ascertaining its quality is very crucial before use for drinking, agricultural, aquatic life, recreational, or industrial purposes. However, all viable water bodies are not suitable for all different uses. Water quality indices (WQIs) have been developed to assess the suitability of water for a variety of uses (Ayers and Westcot, 1985; Richards, 1954). These indices reflect the status of water quality in lakes, streams, rivers, reservoirs and groundwater. The concept of WQIs is based on the comparison of the water quality parameters with respective regulatory standards. Irrigated agriculture is dependent on an adequate water supply of usable quality.

The concentration and composition of the dissolved constituents in water determine its suitability for irrigation purposes (Ali, 2010; Todd, 1980; Eaton, 1950). Moreover, suitability of water for irrigation depends on total concentration of the soluble salts, relative proportion of the major constituents (that is sodium, calcium and magnesium) and the effect of some mineral constituents on both the soil and plants (Wilcox, 1955). The quality characteristics normally studied are: different cations and anions, EC, pH, total dissolved salts (TDS), toxic and heavy element and different composite indices (e.g. sodium percentage (SP), Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC) and Permeability index (PI)) (Khan et al., 2003; Reddy, 2013; Biswas et al., 2002). Water quality is very important for the suitability of groundwater for drinking and irrigation purpose (Sarkar et al., 2002).

Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts (Ali, 2011). The most influential water quality guideline on crop productivity is the water salinity hazard as measured by electrical conductivity, EC (Ayers and Westcot, 1985). The primary effect of high EC water on crop productivity is the inability of the plant to compete with ions in the soil solution for water (physiological drought). SAR is an important parameter for the determination of suitability of irrigation water because it is responsible for the sodium hazard. The waters are classified by USDA in relation to irrigation based in the ranges of SAR values (Richards, 1954). Doneen (1962) evolved a criterion for assessing the suitability of water for irrigation based on the permeability index. Accordingly, waters can be classified as Class I, Class II and Class III orders. Class I and Class II waters are categorized as good for irrigation with 75% or more maximum permeability. Class III water are unsuitable with 25% of maximum permeability. Ali (2010) suggested water quality class for irrigation based on sodium, salinity and toxicity effect of major toxic elements.

In developing countries, the majority of the people use the water of shallow wells and boreholes which have high contamination (WHO, 2017). The poor or marginal quality water has effects on health and life expectancy, and also on soil and crop (Chitmanat and Traichaiyapon, 2010). Quality of water can vary over spatial and temporal scale. Thus, it is important to check the quality of water for agricultural, domestic and industrial uses.

Different researchers studied the quality of water for irrigation and other purposes at different physiographic locations. Sarkar et al. (2002) investigated the suitability of groundwater of Magura district of Bangladesh, covering four Upazilas, for irrigation use. They did water sampling before irrigation pumping started (Nov.) and during the peak pumping period (Feb.). They found that almost all samples were good to excellent except slightly increased iron and chloride in two locations. They observed no distinct variation in the chemical composition due to pumping effect except the Magnesium content, which showed slightly increased value during the pumping period. Sarkar et al. (2003) studied the quality of water with respect to irrigation purpose at some micro-basins of BINA sub-station areas, namely: Iswardi, Rangpur, Magura, Satkhira and Comilla. They found the quality grade from good to excellent, meaning no restriction for crop production.

But the quality of water can vary with location, mainly due to change in sub-surface composition/mineral type, over-lying recharge strata, use of agro-chemicals, source of pollutants, etc. (Ali, 2011). So, the quality of one location can not be extrapolated to other sites. Even the quality grade of water of the same location can vary over time. The objective of the present study was to investigate the quality of groundwater of different micro-basins of BINA established new sub-station areas for irrigation and drinking purposes.

MATERIALS AND METHODS

Study location: sampling of water was done from different regions (agro-ecological and hydrological regions), BINA sub-station areas (Fig. 1). The latitude and longitude of the areas and main features are provided in Table 1.

Table 1. Latitude, longitude and main characteristics of the sampling areas

Sl	Location/Station	Latitude (degree)	Longitude (degree)	Main characteristics of the area
1	Khagrachari	23.11	91.98	High-land, hilly area. Cropping in the hill-slope is pre-dominant.
2	Noakhali	22.86	91.09	Coastal area, alluvial deposit in the sea. Salinity in soil and groundwater is pre-dominant.
3	Sunamganj	25.06	91.39	Low-land area. About 90% of the area goes under water during wet/monsoon period. Mainly one rice crop grows during dry, winter period.
4	Chapai-nawabganj	24.59	88.27	Comparatively dry area of the country, hot during summer. Water-table is declining due to irrigated rice crop during Rabi season (Jan.-April).
5	Jamalpur	24.93	89.93	Flat land. Almost all crops grow here. Water-table is nearly steady state.
6	Nalitabari	25.02	90.01	Flat land. Almost all crops grow here. Water-table is nearly steady state.
7	Barishal	24.75	90.33	Low-land area. About 90% of the area goes under water during wet/monsoon period. Mainly one rice crop grows during dry, winter period.
8	Gopalgonj	23.00	89.82	Flat land. Almost all crops grow here.

Sampling and analyses: water samples were collected nearly at the end of irrigation period (May 5-15) in the year 2015, and during peak irrigation pumping (15-20 April) in 2016. Samples were collected in polyethylene bottles of 250ml capacity. Prior to their filling with sampled water, these bottles were rinsed to minimize the chance of any contamination. The samples were stored at refrigerator at 4^0C up to the time of analysis.

Different cations, anions, heavy metals (Na, Ca, K, Mg, Cl, P, S, Fe, Mn, Zn, Cu, B, As, Pb, Cd, Ni, Cr) and different parameters such as EC, pH, $CO_3^{- -}$, HCO_3^{-} were determined. The pH and electrical conductivity (EC) were determined at the site with the help of a pH-meter and a portable EC-meter, respectively. The $CO_3^{- -}$ and HCO_3^{-} were determined using titration method, and other cations and anions were determined using 'Atomic Absorption Spectro-photometry' method (*model: TG990, UK*).

Composite parameters/indices: the composite parameters used to categorize the quality of water are Sodium Absorption Ratio (SAR) (Richards, 1954), Residual sodium carbonate (RSC), Kelley's ratio (KR), Total hardness (TH), Salt index (SI), Total dissolved solid (TDS) (Roghunath, 1987).

Methods for evaluation of water quality for irrigation: there are three major methods for the evaluation of water quality for irrigation, i.e. United States Department of Agriculture (USDA) method (Richards, 1954), Food and Agriculture organization (FAO) method (Ayers and Westcot, 1985), and Water-Types methods (based on the dominant dissolved ions) (Al-Bassam and Al-Rumikhani, 2003).

The USDA system is mainly based on a combined ECw and sodium adsorption ratio (SARw) with four classes for each. The FAO technique is a three class system based on ECw, water infiltration and specific ion toxicity of Na, Cl^-, B, NO_3^- and HCO_3^-; and assign levels of restriction to their use as none, slight to moderate and severe.

The third method adopted to classify the irrigation waters is Water-Types. In this method, four major cations namely sodium, magnesium, calcium, potassium and sulpher; and three major anions namely carbonate, bicarbonate, and chloride were analyzed and used to assess water-type in each well. For each sample, the dominant cations and anions, expressed in mg/l, are used to designate the type of water. For instance, if Na and Cl are the most prevalent pair of cation and anion in the water from a well, then the dominant type of water for this well has Na–Cl. The water-type method caters only for the type of salts in the water, but without putting any limits for EC or SAR content.

The USDA, FAO and 'Water-Types guidelines' for the assessment of the quality of irrigation water are established systems. However, the USDA and FAO methods agree on the evaluation criteria of EC and SAR, but differ in the number and limits of classes; the FAO system incorporates ion toxicity and infiltration of water as influenced by both EC and SAR (as SAR increases, infiltration rate decreases). The USDA method appears to be the most recognized worldwide since it has been based on actual field trials conducted by a specialized salinity laboratory. The FAO method is generally a compromising approach of the USDA method where the FAO class one is a combination of both EC classes 1 and 2 of the USDA system; the slight to moderate FAO class covers both classes 3 and 4 of the USDA system.

In addition to the above judgment methods, the integrated classification suggested by Al-Bassam and Al-Rumikhani (2003); the one suggested by Ali (2010); and the criteria set by Government of Bangladesh (GOB, 1997) were also used to categorize the quality type.

The integrated hydrochemical method for classification of water quality (Al-Bassam and Al-Rumikhani, 2003) matches the class-limits of both USDA and FAO methods for their common criterion – the salinity status, and categorization into three groups.

Judging the quality for drinking purpose: the quality for drinking purpose was judged according to WHO (2011) guideline and the guideline set by the government of Bangladesh (GOB 1997).

RESULTS AND DISCUSSION

The quality parameters (elemental and composite) for different locations for the year 2015 and 2016 are presented in Table 2 and Table 3, respectively.

Interpretation for irrigation use

Classification according to USDA method: the distribution of EC and SAR values for the locations within 'USDA salinity classification (C) and sodicity hazards (S) diagram' for the year 2015 and 2016 are shown in Fig.2 and Fig.3, respectively. Here, C1, C2, C3, C4 class refers to low, medium, high and very high salinity hazard, respectively. Similarly, S1, S2, S3, S4 class refers to low, medium, high and very high sodium (alkali) hazard, respectively.

Year 2015: among the wells, five out of eight fall within C2-S1 class (i.e. medium salinity and low sodium (alkali) hazard) (Fig.2). Two wells (Chapainawabgonj and Gopalgonj) fall within C3-S1 class (i.e. high salinity and low sodium hazard). Long-term irrigation with this water should be practiced with caution, and crop cultivars should be selected having moderate tolerance level of salinity. Special measures to control the salinity hazard are needed, including leaching and adequate drainage.

Only one well (Barisal) falls within C3-S2 class (i.e. high salinity and medium sodium hazard). At this location, irrigation with this water can not be recommended without ameliorative measures. The water may cause infiltration problems, especially with heavy textured and poorly drained soils.

Year 2016: in the year 2016, similar trend was observed (Fig.3) with some higher values of SAR for the locations of Khagrachari and Barisal.

Classification according to FAO guideline

Year 2015 : when we consider FAO guideline, based on the elemental, SAR, and TDS values; the water are suitable for irrigation at all locations except Barishal and Sunamgonj. At Barishal, the Na content is high, and consequently the SAR value is high (6.2). At Sunamgonj, iron was found as 6.87 ppm (which can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum) (Ayers and Westcot, 1985).

Year 2016: considering the results of 2016, the water are suitable for irrigation at all locations except Barishal and Sunamgonj. At Barishal, the Na content is high, and consequently the SAR value is high (11.7). At Sunamgonj, iron (5.71 ppm) was found slightly higher than the FAO non-restricted limit (5 ppm).

Table 2. Water quality parameters at different BINA sub-station areas (during 5-15 May, 2015)

Location	Source	Basic/elemental Parameters																
		pH	EC (dS/m)	Cl^- (ppm)	HCO_3 (ppm)	K (ppm)	Na (ppm)	Ca (ppm)	Mg (ppm)	P (ppm)	K (ppm)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	B (ppm)	Pb (ppm)
Khagrachari	DTW (s)	8.1	0.44	1.10	1.90	2.00	38.8	15.8	2.119	0.19	2.00	1.04	0.28	0.11	0.06	0.001	0.03	0.000
Noakhali	HTW	7.7	0.51	0.85	2.53	5.71	27.7	13.9	8.183	0.86	5.71	0.98	3.46	0.07	0.04	0.002	0.06	0.000
Sunamganj	DTW (s)	7.4	0.36	1.60	2.15	1.36	19.4	16.6	4.713	1.04	1.35	0.14	6.87	0.48	0.002	0.003	0.06	0.000
Chapai-nawabganj	DTW (s)	7.3	0.89	1.60	3.65	0.82	33.3	41.6	20.07	0.07	0.82	1.56	0.12	0.81	0.02	0.005	0.02	0.009
Jamalpur	DTW	7.1	0.25	2.20	1.15	0.91	8.35	15.3	3.463	0.18	0.91	0.56	0.47	0.14	0.04	0.001	0.05	0.005
Nalitabari	DTW (s)	7.4	0.27	2.10	1.78	1.34	13.9	18.0	3.963	0.49	1.34	0.38	3.90	0.26	0.02	0.002	0.06	0.005
Barishal	DTW (SRTI)	8.3	1.01	2.70	3.03	1.84	111	22.2	1.256	0.21	1.84	0.70	0.11	0.00 7	0.000	0.001	0.15	0.008
Gopalgonj	DTW (s)	8.1	0.97	2.20	4.40	5.72	27.7	48. 6	21.95	1.22	5.72	0.42	4.45	0.16	0.01	0.004	0.09	0.010
No restriction for Irrigation (FAO, 1985)		6.5 - 8.4	< 0.7 dS/m	< 92 mg/l	<91 Ppm								<5 ppm	<0.2 ppm	<2.0 ppm	<0.2 ppm		<5.0 ppm
Permi. Limit for Irrigation (GOB, 1997)		6.0 - 8.5	1.2 dS/m	600 mg/l	200 Ppm	NYS	NYS	NYS	NYS	15 ppm	NYS		2 ppm	5 ppm	10 ppm	3 ppm	<2 ppm	0.1 ppm
Permi.Limit for drinking (WHO, 2011)		NE G	NEG	NEG	-	NEG	NEG				NEG		NEG	NEG	NEG	2 ppm	2.4 ppm	0.01 ppm
Permi.Limit for drinking (GOB, 1997)		6.5 - 8.5	0.6-1 dS/m	600 ppm	-	12 ppm	200 ppm	75 ppm	30-50 ppm	0 ppm	12 ppm		0.3-1.0 ppm	0.1	5	1.0	1.0	0.05

NYS = Not yet standardized; NEG = Not established guideline value; * Not based on FAO, but based on Raghunath (1988).

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Table 2. Continuation.

Location	Source	Composite parameters						
		SAR	TDS (ppm)	KR	RC	TotalHardness	% Na	SI
Khagrachari	DTW	2.43	64.5	1.75	-0.93	48.2	64.3	-60.4
Noakhali	HTW	1.46	68.8	0.88	-1.33	68.3	49.7	-62.1
Sunamganj	DTW	1.08	54.8	0.69	-1.18	61.0	41.9	-83.9
Chapai-nawabganj	DTW	1.06	102.7	0.39	-3.67	186.5	28.3	-191.1
Jamalpur	DTW	0.50	33.1	0.35	-1.03	52.4	26.9	-88.2
Nalitabari	DTW	0.77	46.7	0.49	-1.20	61.4	34.2	-96.2
Barishal	DTW (SRTI)	6.20	143.5	3.98	-1.16	60.6	80.1	-19.2
Gopalgonj	DTW	0.83	120.4	0.29	-4.16	211.6	24.2	-230.3
No restriction for Irrigation (FAO, 1985)		< 3	<450 ppm	< 1*	<1.25*	<210 ppm*		<0.0*
Permi. Limit for Irrigation (GOB, 1997)		2.3	2100 ppm			-		
Permi.Limit for drinking (WHO, 2011)			NEG			NEG		
Permi.Limit for drinking (GOB, 1997)		-	1000			200-500 ppm		

NYS = Not yet standardized; NEG = Not established guideline value; * Not based on FAO, but based on Raghunath (1988).

Table 3. Water quality parameters at different locations (during 15-20 April, 2016)

Location	Source	Basic/elemental Parameters																	
		p^H	EC (dS/m)	Cl^- (ppm)	HCO_3 (ppm)	K (ppm)	Na (ppm)	Ca (ppm)	Mg (ppm)	P (ppm)	S (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	B (ppm)	Pb (ppm)	Cd	Ni
Khagrachari	DTW			1.13	1.00	1.85	56.32	11.62	3.012	0.27	2.594	1.407	0.091	0.03	0.001	0.085	0.0	0.002	0.003
Noakhali	HTW			0.62	2.50	5.29	35.31	9.55	20.292	0.55	0.144	4.403	0.191	0.033	0	0.157	0.0	0.0	0.0
Sunamganj	DTW			0.87	4.00	1.30	27.53	7.47	7.411	1.40	0.865	5.714	0.295	0.008	0.002	0.086	0.0	0	0.005
Chapai-nawabganj	DTW			0.62	3.13	0.95	38.17	74.72	27.68	0.09	3.459	0.895	0.601	0.03	0.004	0.064	0.008	0.002	0.0
Jamalpur	DTW			0.62	1.25	0.82	8.01	6.23	6.01	0.41	0.144	1.773	0.225	0.016	0.003	0.052	0.012	0.002	0.0
Nalitabari	DTW			1.62	2.62	1.21	15.93	7.89	6.43	0.66	0.144	3.635	0.201	0.052	0.001	0.074		0	0.0
Barishal	DTW (SRTI)			1.5	3.13	1.76	180.6	12.45	3.369	0.29	1.009	0.399	0.04	0.006	0.008	0.235	0.017	0.002	0.0
Gopalgonj	DTW			0.87	1.87	4.89	38.31	91.32	33.158	1.76	0.144	7.194	0.234	0.007	0.006	0.161	0.005	0	0.004
No restriction for Irrigation (FAO, 1985)		6.5 - 8.4	< 0.7 dS/m	< 92 mg/l	<91 ppm							<5 ppm	<0.2 ppm	<2.0 ppm	<0.2 ppm		<5.0 ppm	0.01	0.20
Permi. Limit for Irrigation (GOB, 1997)		6.0 - 8.5	1.2 dS/m	600 mg/l	200 ppm	NYS	NYS	NYS	NYS	15 ppm		2 ppm	5 ppm	10 ppm	3 ppm	<2 ppm	0.1 ppm		
Permi.Limit for drinking (WHO, 2011)		NEG	NEG	NEG	-	NEG	NEG					NEG	NEG	NEG	2 ppm	2.4 ppm	0.01 ppm	0.003	0.07
Permi.Limit for drinking (GOB, 1997)		6.5 - 8.5	0.6-1 dS/m	600 ppm	-	12 ppm	200 ppm	75 ppm	30-50 ppm	0 ppm		0.3-1.0 ppm	0.1	5	1.0	1.0	0.05		

NYS = Not yet standardized; NEG = Not established guideline value; * Not based on FAO, but based on Raghunath (1988).

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Table 3. Continuation

Location	Source	Composite parameters						
		SAR	TDS (ppm)	KR	RC	TotalHardness	% Na	SI
Khagrachari	DTW	3.8	78.91	2.95	0.17	41.41	75.07	-22.6
Noakhali	HTW	1.48	77.77	0.72	0.35	107.3	43.77	-33.6
Sunamganj	DTW	1.71	54.92	1.22	3.02	49.15	55.59	-31.3
Chapai-nawabganj	DTW	0.96	148.8	0.28	-2.9	300.5	21.88	-347
Jamalpur	DTW	0.55	24.94	0.43	0.44	40.29	31.42	-44.8
Nalitabari	DTW	1.02	39.13	0.75	1.7	46.16	43.94	-44.9
Barishal	DTW (SRTI)	11.7	203.3	8.73	2.23	44.95	89.78	97.71
Gopalgonj	DTW	0.87	179	0.23	-5.4	364.5	19.71	-427
No restriction for Irrigation (FAO, 1985)		< 3	<450 ppm	< 1*	<1.25*	<210 ppm*		<0.0*
Permi. Limit for Irrigation (GOB, 1997)		2.3	2100 Ppm			-		
Permi.Limit for drinking (WHO, 2011)			NEG			NEG		
Permi.Limit for drinking (GOB, 1997)		-	1000			200-500 ppm		

Classification according to GOB guideline

Year 2015: when we considered the guideline values of GOB (1997), iron level was higher at Noakhali, Sunamgonj, Nalitabari and Gopalgonj. Other parameters were within permissible limit.

Year 2016: in 2016, similar trend of iron level was observed (higher at Noakhali, Sunamgonj, Nalitabari and Gopalgonj). Other parameters were within permissible limit.

Classification according to elements: the distribution of water-type of the wells are listed in Table 4. For the year 2015, Na-HCO_3 dominates (50 % of the studied wells) over Ca-HCO_3 and Ca-Cl_2 types. For the year 2016, Na-HCO_3 dominates (75 % of the studied wells) over Ca-HCO_3. K-salt and Mg-salt type are missing for both the years. Different salts may affect plant growth differently.

Table 4. Classification of the water quality according to water-types

Year	Type of water	Number of wells	% well	Locations
2015	Na – HCO_3	04	50 %	Khagrachari, Noakhali, Shunamgonj, Barisal
	Ca - HCO_3	02	25 %	Chapainowabgonj, Gopalgonj
	Ca – Cl_2	02	25 %	Jamalpur, Nalitabari
2016	Na – HCO_3	06	75 %	Khagrachari, Noakhali, Shunamgonj, Barisal, Jamalpur, Nalitabari
	Ca - HCO_3	02	25 %	Chapainowabgonj, Gopalgonj

Integrated classification of Al-Bassam et al. (2003): a slight modification of “Water-type” of original class as suggested by Al-Bassam et al. (2003) was done in the way that, “Ca-HCO_3” type was added in Group II and “Na-HCO_3” type was added in Group III, to accommodate the existing/present ‘water-type’.

According to the present forms of combination, 2 wells fall under ‘suitable for irrigation’, 2 wells under ‘conditionally suitable’, and remaining 4 under ‘unsuitable’ (Table 5) in 2015. In 2016, 2 wells under ‘conditionally suitable’, and remaining 6 under ‘unsuitable’.

Table 5. Integrated classification (a modified form of Al-Bassam et al., 2003) of water quality of the selected wells£

Group	Combination			Irrigation water class	Number of well in 2015	Number of well in 2016
	USDA class	FAO class	Water-type			
Group I	C1-S1 C2-S1	Non-restrictive	Ca-Cl_2	Suitable for irrigation	02	-
Group II	C1-S2 C2-S2 C3-S1 C3-S2	Slight restriction	Mg-Cl_2, Ca-HCO_3	Conditionally suitable	02	02
Group III	C1-S3 C1-S4 C2-S3 C2-S4 C3-S3 C3-S4 C4-S1 C4-S2 C4-S3 C4-S4	Moderate to severe restriction	Na-Cl_2, Na-HCO_3	Unsuitable	04	06

£: The wells which do not fulfill the criteria of the 3 combinations of Group I and Group II, fall within Group III.

Classification according to Ali (2010): this classification is based on the elemental limits of pH, EC, HCO_3, Cl; composit index SAR; and toxic elements such Fe, As, and Pb. In 2015, when compared with elemental limits, Fe exceeds 5.0 ppm in one location (Sunamgonj) and falls in "very bad" category; one location (Gopalgonj) falls under "Bad" category; four under "Moderate' and one under "Good" category (Table 6). In 2016, almost similar trend was observed with slight variation in elemental values, and hence also in quality class.

Table 6. Water quality class for different wells as suggested by Ali (2010) £

Water quality class	Range of parameters / elements									No. of wells in 2015	No. of wells in 2016
	pH	EC (dS/m)	SAR	As (ppm)	Cl (meq/l)	B (ppm)	HCO_3 (meq/l)	Pb (pm)	Fe (ppm)		
Excellent	6.8-7.2	<0.2	<2.0	Nill	<2.0	<0.5	<1.0	Nill	<1.0	-	-
Good	6.5-7.5	0.2-0.5	2-3	<0.001	2-3	0.5-0.7	1.0-1.5	0-.05	1.0-2.0	01	02
Moderate	6.2-7.8	0.5-1.0	3-6	0.001-0.05	3-6	0.7-2.0	1.5-5.0	0.05-1.0	2.0-4.0	04	03
Bad	6.0-6.2, 7.8-8.0	1.0-3.0	6-9	0.05-0.01	6-9	2-3	5.0-8.0	1.0-3.0	4.0-5.0	02	01
Very bad	<6.0, >8.0	>3.0	>9	>0.01	>9	>3	>8.0	>3.0	>5.0	01	02

£ Assuming average condition of climate, soil, drainage, crop tolerancy, management, human tolerancy, and surface irrigation system.

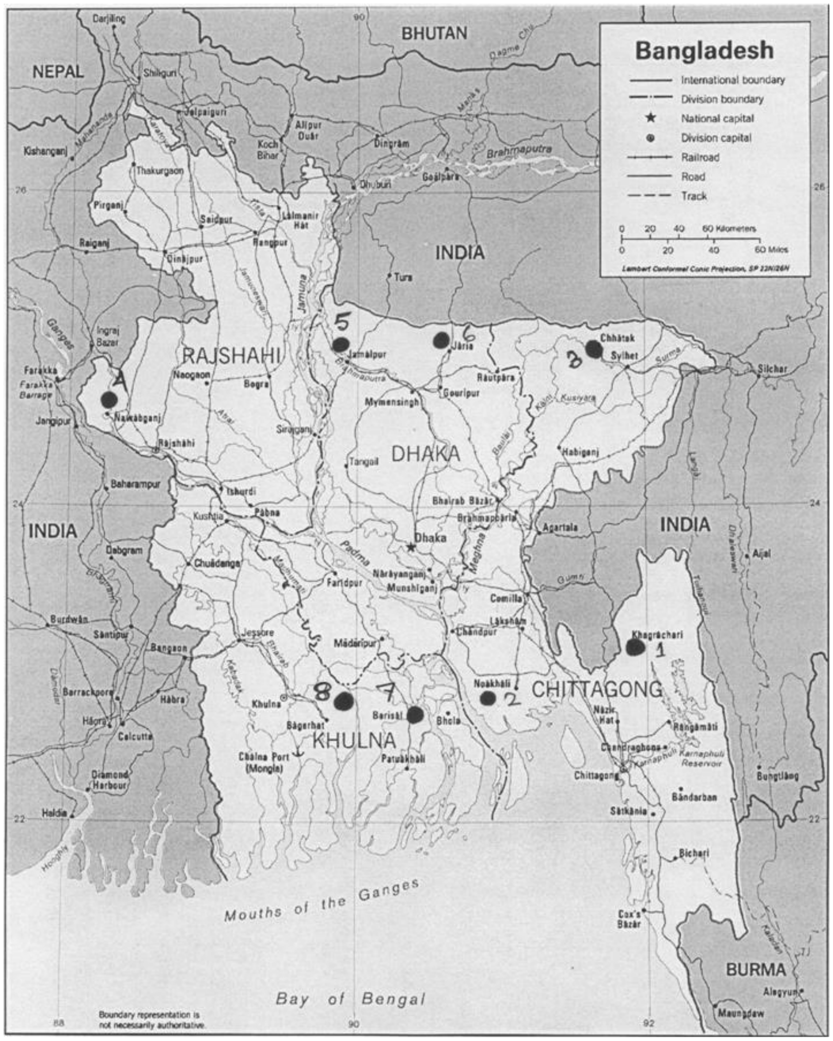

Fig.1. Map of Bangladesh showing the locations of water sampling (black marks)

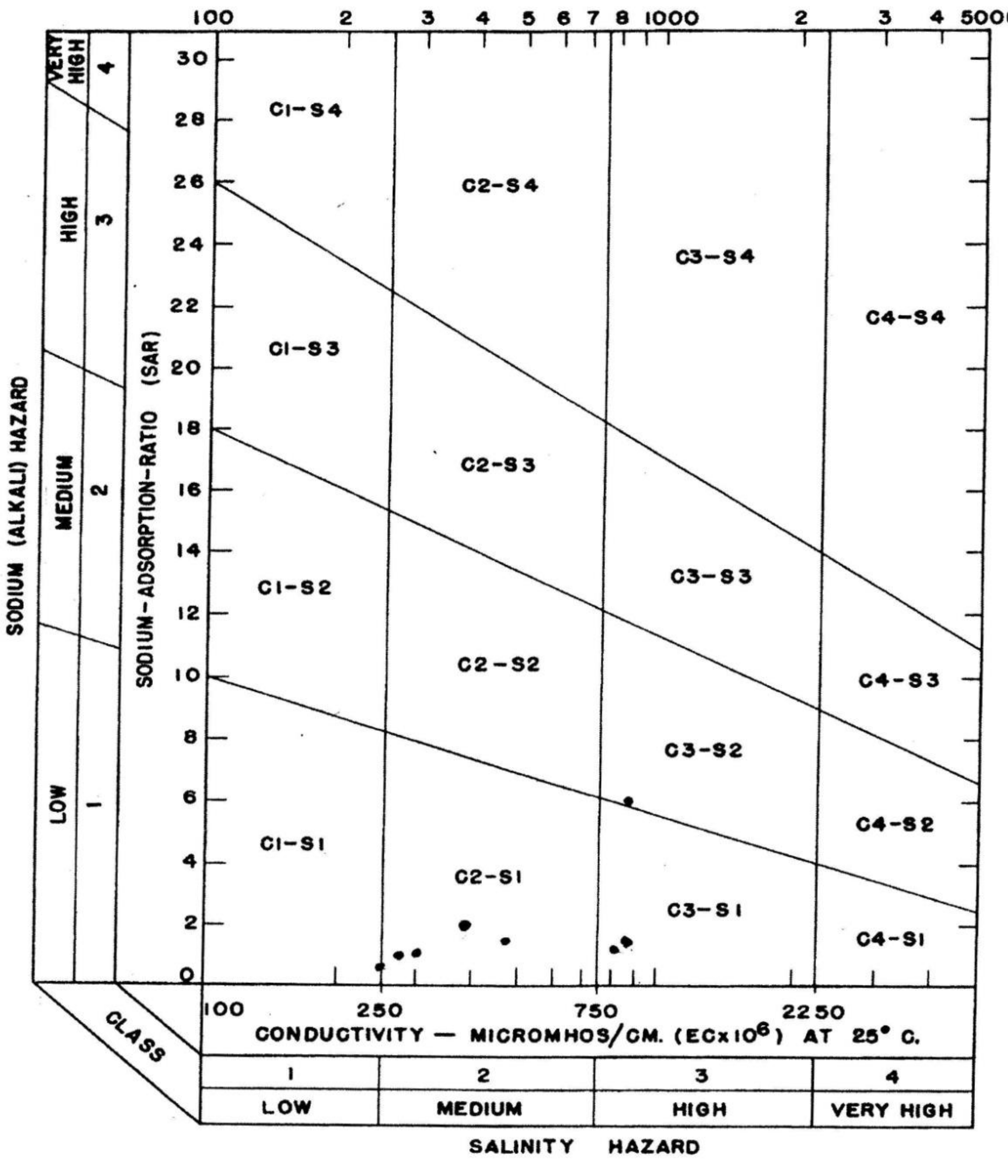

Fig.2. USDA Diagram showing data points (black marked) for the classification of irrigation water for 2015

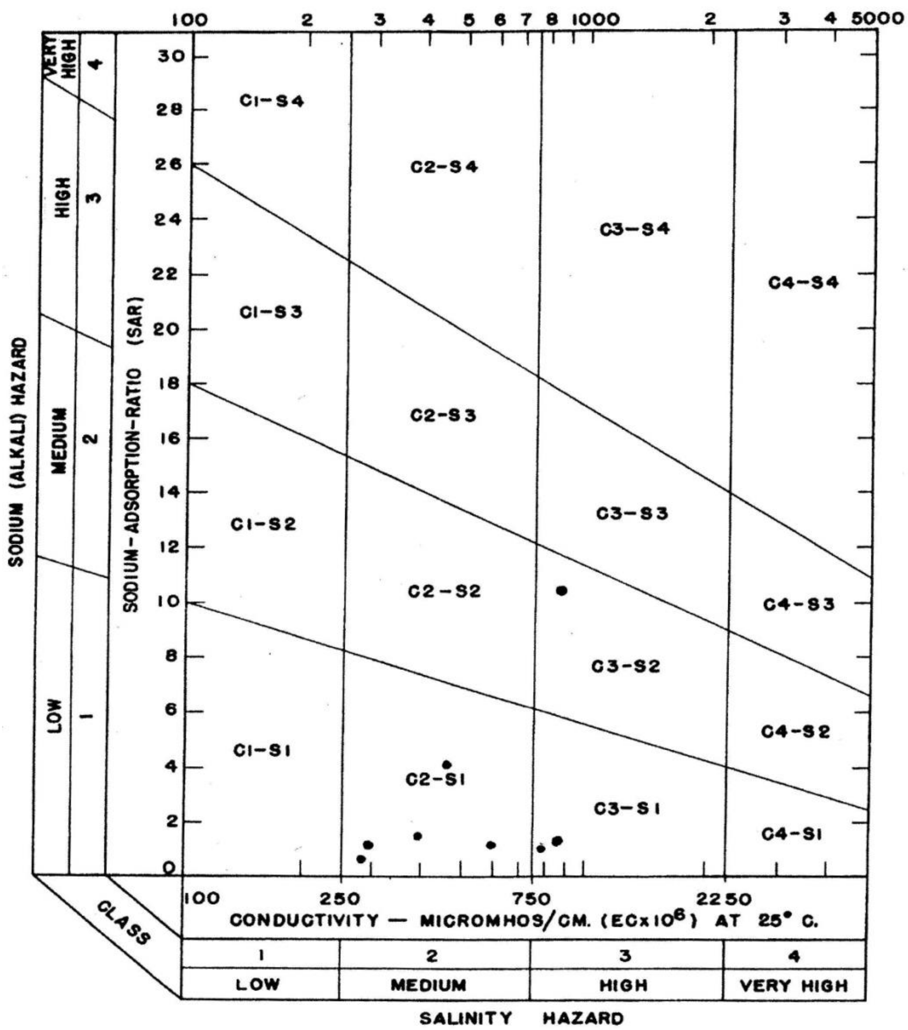

Fig.3. USDA Diagram showing data points (black marked) for the classification of irrigation water for 2016

Interpretation for drinking water quality

Classification according to WHO guideline: In the present WHO guideline (WHO, 2011; fourth edition), the guideline values have not been established for the following naturally occurring chemicals: Br, Cl, H_2S, Fe, Mn, Mo, K, Na, SO_4, P^H, TSS (total dissolved solid) and Hardness. The WHO mentioned the reason for not establishing a guideline value that, the elements occur in drinking water at concentrations well below those of health concern and may affect acceptability of drinking water if guideline values are established.

In 2015, the values of Cd, Ni, Cr were found nil against the WHO (2011) provisional guideline value of 0.003, 0.07 and 0.05 ppm, respectively. The Cu, B and Pb were within permissible limit (Table 2).

In 2016, the values of Cd and Ni were found less than the WHO (2011) recommended maximum concentration at all locations. The values of Pb was found little higher at Barisal and Jamalpur against the WHO (2011) provisional guideline value (Table 3). Use of chemicals in agricultural practices in those areas should be monitored and controlled carefully. Considering the other given guideline values of WHO, the water for all locations are safe for drinking.

Classification according to GOB guideline

Year 2015: when we consider the guideline values of GOB (1997), P level is higher at all locations; Iron level is higher at Noakhali, Sunamgonj, Nalitabari and Gopalgonj; Mn level is higher at all locations except Noakhali and Barishal. Other parameters are within permissible limit.

Year 2016: in 2016, the Pb level is lower at all locations; Iron level is higher at all locations except Barisal and Chapainawabganj; Mn level is higher at all locations except Noakhali and Barishal. Other parameters are within permissible limit.

DISCUSSION

Water has the property/ability to suspend, absorb and dissolve different elements and compounds. During the path of water-cycle, while seeps from the porous soil, it dissolves salts, gases, metals, organic compounds, minerals, nitrates and sulphates (Mirecki and Parks, 1994; Manzoor et al., 2006; Manning, 1997). Thus, groundwater quality is governed by contamination activities (agricultural/industrial/mining), natural as well as anthropogenic factors, nature of the rocks (or geological formation), climatic factor (specially rainfall, thereby recharge rate), dissolved salts and disposal system, etc. (Peterson and Kennedy, 1997; Sayyed and Sayadi, 2011; Ali, 2016).

Among the study locations, the groundwater quality at Noakhali and Barisal is saline due to nature of geological formation – alluvial deposit in the saline estuary of the Bay of Bengal. The high concentration of salts dissolved in soil-water will greatly reduce the availability of water to the plants through the osmotic effect (where the water may leave the plant to the soil solution causing dehydration and consequently affect the plant).

Crops which can adjust/tolerate high salinity, can only be cultivated there. In Khagrachari (hilly area), groundwater quality depends on the rocks types, a little higher iron is present. In Jamalpur, where intensive agricultural practices are taking place, applied fertilizers/pesticides may have impact on groundwater quality; therefore should be carefully monitored and controlled.

As conclusion, the EC of two wells are high and utilization of the water thus restricted due to their high salinity. They are unsuitable for the irrigation of most crops, except the very salt-tolerant. The iron content seems higher (>5.0 ppm) in one location and 2 locations, thus a concern of soil permeability problem for long-term. The Fe content of these locations should be monitored in the future. Majority of the wells under study (except one, SAR>4.0) showed relatively low sodicity level, and reflected by a closely neutral pH range. The low to medium SAR and high EC can be managed without any water and soil treatments. Leaching the excess salts from the root zone can solve the problem. Nevertheless, organic manuring may be recommended together with the inorganic fertilizers.

Overall, except one location (i.e. Barisal), the water for irrigation purpose are suitable to marginally suitable considering salinity and sodicity. For drinking purpose, all except 2 locations (i.e. Sunamgonj and Barisal, where iron is a concern) are suitable. At these locations, other aquifer layer with low Fe can be searched for safer Fe level. Alternatively, Fe removal system can be assembled for collecting drinking water.

REFERENCES

Al-Bassam, A.M., &Al-Rumikhani, Y.A. 2003. Integrated hydrochemical method of water quality assessment for irrigation in arid areas: application to the Jilh aquifer, Saudi Arabia. *J. African Earth Sci,* 36:345–356

Ali, M.H. 2010. Water – An element of irrigation (Chapter 6). *In*: Fundamentals of Irrigation & On-farm Water Management, Volume 1. Springer, New York.

Ali, M.H. 2011. Pollution of Water Resources From Agricultural Fields & Its Control(Chapter 7). *In*: Practices of Irrigation & On-farm Water Management, Volume 2. Springer, New York.

Ali, M.H.2016. Groundwater Recharge (Chapter 3). *In:* Principles and Practices of Water Resources Development and Management. Nova Science Publishers, Inc, NY.

Ayers, R.S., &Westcot D.W. 1985. Water quality for agriculture. FAO Irrigation and Drainage Paper 29 Rev.1, FAO, Rome, 174 p.

Biswas, S.N., Mohabey H,& Malik M.L. 2002. Assessment of the Irrigation Water Quality of River Ganga in Haridwar District. *Asian J. Chem.,* 16.

Chitmanat C., &Traichaiyaporn S. 2010. Spatial and temporal variations of physical-chemical water quality and some heavy metals in water, sediments and fish of the Mae Kuang River, Northern Thailand. International Journal of Agriculture and Biology 12: 816-820.

Doneen, L.D. 1962.The influence of crop and soil on percolating water. Proc. 1961 Biennial Conference on Groundwater Recharge.

Eaton, F.M. 1950. Significance of carbonates in irrigation waters. *Soil Sci.* 69: 123–133.

GOB (1997) Water Quality Standards for Drinking water and Irrigation. Ministry of Environment and Forest, Government of Bangladesh (GOB), Bangladesh Gazette, August 28, 1997, as Environmental Rule under Environmental Conservation Act, 1995.

Khan, F., Husain T.,&Lumb A. 2003. Water quality evaluation and trend analysis in selected watersheds of the Atlantic region of Canada.*Env.Monit. Ass.,* 88: 221–242

Manning J.C.1997. Applied principles of hydrology. Upper Saddle River, NJ: Prentice Hall.

Manzoor S., Shah M.H., Shaheen N., Khalique A., &Jaffar M. 2006. Multivariate analysis of trace metals in textile effluents in relation to soil and groundwater. *J. Hazard. Mat.* 137: 31-37.

Mirecki JE, &Parks W.S. 1994. Leachate geochemistry at a municipal landfill, Memphis, Tennessee. *Ground Wat.* 32: 390.

Peterson N, &Kennedy M. 1997. Water quality trends and geological mass balance. John Whiley and Sons, pp: 139-179.

Raghunath, H.M. 1987. Ground Water (2nd Edition). Wiley Estern Limited, New Delhi, p. 559.

Reddy, K.S. 2013. Assessment of groundwater quality for irrigation of Bhaskar Rao Kunta watershed, Nalgonda District, India. *Int. J. Wat. Res.Env. Eng. 5:* 418-425

Richards, L.A. 1954. Diagnosis and improvement of saline and alkali soils. USDA Agricultural Handbook No.60, US Department of Agriculture, Washington D.C., 160 p.

Sarkar, A. A., Ali M. H., &Hassan A.A. 2002. Suitability of groundwater for irrigation use in four Upazilas of Magura District. J. of the Institution of Engineers, Bangladesh, Vol. 29/AE, No.1: 93 – 100

Sarkar, A. A., Hassan A.A., Ali M. H., &Karim N.N. 2003. Studies on groundwater potentials for some micro-basins of BINA: I. An assessment of water quality for irrigation. J. of the Institution of Engineers, Bangladesh, Vol. 30/AE, 1: 51 - 60

Sayyed MRG, &Sayadi M.H. 2011 Variations in the heavy metal accumulations within the surface soils from the Chitgar industrial area of Tehran. *Proc IntAcadEcol Environ Sci* 1: 36-46.

Todd, D.K. 1980. Groundwater Hydrology, 2nd Ed., John Wiley and Sons, New York. p.535.

WHO, 2011. Guidelines for drinking water quality. 4th edn. WHO press, p.564.

WHO, 2017. WHO Guidelines for Drinking-water Quality. WHO Department of Public Health, Environmental and Social Determinants of Health. Regional Workshop on Radioactivity in Food, Drinking Water and Commodities: Implementing the International Basic Safety Standards. Buenos Aires, Argentina, 21-23 March 2017.

Wilcox, L.V. 1948. The quality of water for irrigation use. USDA Agri. Tech. Bull. 1962, Washington D.C.