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Water Quality Assessment of a Groundwater Basin in Bangladesh for Irrigation Use

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Abstract: Quality of water is a pre-requisite for the success of an irrigation project. With this view, an effort was made to assess the groundwater quality of a hydrological basin in Bangladesh. Common problems for poor quality irrigation water were cited and the water quality parameter indices determined were precisely evaluated and interpreted. From the analytical result it was observed that the compositions of the groundwater samples were within the permissible range of irrigation use, except an increased Cl^- values, responsible for toxicity problem. Standard water quality parameter indices like pH, EC, SAR, SSP, RSBC, KR, PI, MAR and TH were also found within the acceptable range of crop production. RSC values were higher (3.26 to 4.16 meq L^{-1}) than the permissible limit (>2.5 meq L^{-1}) due to higher HCO_3^- content in the irrigation water that may induce some permeability problem. Arsenic was traced and at one location it was found (0.2 to 0.3 mg L^{-1}) above the danger limit (>0.05 mg L^{-1}). However, except these minor discrepancies the groundwater of the study locations was categorized as excellent to good quality and seemed to be suitable for crop production.

Key words: Groundwater, quality, irrigation, parameter indices, crop production

INTRODUCTION

Water is vital for the existence of human beings and other all forms of life. Barring deep groundwater, it is ceaselessly cycled by nature through atmosphere, terrasphere and biosphere. Water resources are harnessed for various purposes for the benefit of mankind like; drinking, irrigation, municipal and industrial uses, hydropower generation, flood management, fish farming, navigation, ecological needs, recreation, etc.

Although the natural supply is adequate in absolute terms, it is not available at right time, place, quantity and quality (Sood *et al*., 1998). Surface water pollution is widespread all over the world. Moreover, pollutant sources from land use and poorly managed agriculture is causing widespread deterioration of groundwater.

Irrigated agriculture is dependent on adequate water supply of usable quality. Quality is defined by certain physical, chemical and biological characteristics. Conceptually, water quality refers to the characteristics of supply water that will influence its suitability for a specific use i.e., how well the quality meets the needs of the user. Water quality problems, however, are often complex and a combination of problems that may affect crop production more severely than a single problem in isolation. The more complex the problem, the more difficult it is to formulate an economical management program for solution. In irrigation water evaluation, emphasis is placed on the chemical and physical characteristics of the water and only rarely are any other factors considered important. Water quality concerns have often been neglected because good quality water supplies have been plentiful and readily available. But this situation is changing now in many areas (Ayers and Westcot, 1985). Eventually problems like falling of water table, water logging, etc. were highlighted by some researchers in India and Bangladesh due to poor quality water used for irrigation (Sood *et al*., 1998: Talukder *et al*., 1998).

In Bangladesh, rainfall is mostly concentrated in the monsoon (May-August). Moreover, having very limited surface water availability groundwater constitutes the only dependable source of water for irrigation in dry season (November to April). For all the purposes, either in urban and rural areas, groundwater is withdrawn by different types of lifting devices viz. Deep Tubewells (DTWs), Shallow Tubewells (STWs), Manually Operated Shallow Tubewells for Irrigation Systems (MOSTIS), Hand Tubewells (HTWs), etc. In addition, now-a-days rice has dramatically captured its monopoly cultivation in the most irrigated areas of the country consuming major share of the irrigation water. Higher crop yield has only been targeted by heavy abstraction of this resource, totally ignoring its present and long-term consequences. Thus, the extensive use of groundwater has already

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showed problems regarding the water quality (Talukder *et al*., 1998). As groundwater is the only limiting resource for further intensification of agriculture, its rational use should be insured in terms of quality and quantity. Several research papers (BWDB, 1976; Khan *et al*., 1977; Khan and Basak, 1986; Khan *et al*., 1989; Biswas *et al*., 1991; Zaman and Mohiuddin, 1995; Zaman and Majid, 1995; Mridha *et al*., 1996; Talukder *et al*., 1998; Talukder *et al*., 1999; Zaman *et al*., 2001; Khan *et al*., 2002) have characterized the spatial variability coupled with varying information and indications on different water quality constituents in different locations of Bangladesh. Nevertheless, location specific spatial distribution must be known to judge the quality of groundwater for its suitability of irrigation use in any irrigation scheme. Because it was reported that a considerable variation was found in the composition of underground water within the same village in India (Sood *et al*., 1998). With this view, an attempt was made to analyze the groundwater quality of a hydrological basin in Bangladesh to address the following objectives

- To determine different water quality constituents in groundwater in the study areas and
- To assess its irrigation suitability for sustainable crop production

MATERIALS AND METHODS

Study site and sampling: The study was conducted in Pabna district comprising of 8 thanas. The area belongs to the Ganges River Floodplain having calcareous dark gray soil. It presumes that rainfall ranges roughly 1500 to 2000 mm against the country's 3000 mm mean annual rainfall. Groundwater supplies within 100 m from the surface vary in availability from place to place. They appear generally to be satisfactory, but several 'dead zones' have been identified where the resources are not adequate to support intensive tube-well development (Anonymous, 1988). Recently it is reported that suction mode pumps sometimes become inoperative specially in the western part of the district due to low rainfall and extensive groundwater withdrawal during the dry and peak irrigation period of January to April. However, year round rainfall, evaporation and net changes in the water table depth monitored at one location are shown in Fig. 1.

Water samples were collected randomly in two consecutive years from 18 tubewells distributed in 8 thanas of the district. In 2002-03, water samples were collected from 6 DTWs and 12 HTWs at the end of May. But in 2003-04, water samples were collected from 7 DTWs, 10 STWs and 1 HTW at the middle of March, as the frequency of irrigation is the maximum during this month. Water samples were collected in dry and clean plastic containers. Prior to sampling, the containers were ringed well with sampling water. The samples were collected only after the tubewells had pumped for at least 30 min to avoid stagnant or contaminated water sampling. After collection of water, the containers' mouths were sealed tightly. The containers were kept airtight and labeled properly to avoid complication in identification. The water samples were then carried to the Bangladesh Institute of Nuclear Agriculture (BINA) laboratory and preserved in a cool room for analysis.

Constituents of groundwater and its chemical analysis: Groundwater generally contains various soluble minerals and salts. The major ions present in irrigation water are calcium, magnesium, sodium, bicarbonate, sulphate and chloride. Other ions that may be found in low concentrations are potassium, carbonate, nitrate, iron, boron and silica, etc. Some of these ions are more or less beneficial and few ions in excess amounts are more or less detrimental for crop growth and soil properties (Quddus and Zaman, 1996). It was reported that irrigation with poor quality irrigation water reduces soil productivity, changes soil physical and chemical properties, creates crop toxicity and ultimately reduces yield (Talukder *et al*., 1998).

The groundwater samples of the study area were chemically analyzed in order to find their suitability for irrigation purposes. The samples were analyzed for pH, Electrical Conductivity (EC), soluble cations including Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}), Potasium (K^{+}), Iron (Fe^{2+}) and Arsenic (As^{3+}); the anions including Carbonate (CO_3^{2-}), Bicarbonate (HCO_3^{-}) and Chloride (Cl^{-}). pH, EC and As^{3+} were determined by digital

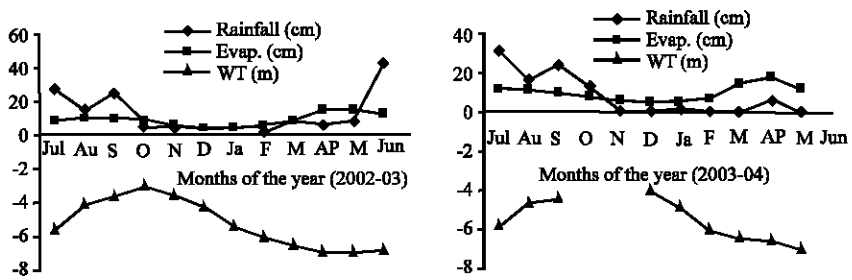

Fig. 1: Water table hydrograph of the study locations

pH meter, conductivity bridge and field kit method, respectively. While Ca^{2+}, Mg^{2+}, Na^{+}, Fe^{2+} and K^{+} were determined by atomic absorption spectrophotometer. Analyses of rest of the constituents were undertaken following the methods outlined by Richards (1968).

Irrigation water quality: Irrigation water quality varies greatly upon the types and quantity of dissolved salts. Thus, water for irrigation suitability is determined not only by the total amount of salt percent but also by the kind of salt. According to Michael (1978) and Raghunath (1987), the irrigation water quality is judged by the four most accepted criteria. These are; i) total dissolved solids (TDS) i.e., the total salt concentration measured by EC ii) relative proportion of sodium to other cations, expressed by Sodium Adsorption Ratio (SAR) iii) concentration of certain specific elements like sodium (Na^{+}), chloride (Cl^{-}) or and boron (B^{+}) contents and iv) residual sodium carbonate (RSC). Michael (1978) also expressed the suitability of irrigation water (SIW) as:

$$SIW = f\,(QSPCD)$$

Where, Q is quality of irrigation water, S is soil type, P is salt tolerance characteristics of the plant, C is climate and D is drainage characteristics of the soil. Beside these, other factors like water table depth, presence of soil hard pan, calcium carbonate content in the soil and potassium and nitrate ions also indirectly influence the suitability of irrigation water (Michael, 1978). Furthermore, Ayers and Westcot (1985) explained that use of poor quality irrigation water creates four types of problems as; salinity, water infiltration rate (permeability), toxicity and miscellaneous. Including pH, EC, TDS, Fe^{2+} and As^{3+}, the following parameters were also considered for judging the quality of irrigation water.

Richards (1968) expressed SAR (sodium adsorption ratio) as;

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \quad (1)$$

Todd (1980) expressed SSP (soluble sodium percent) as;

$$SSP = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100 \quad (2)$$

Eaton (1950) suggested RSC (residual sodium carbonate) as;

$$RSC = (CO_3^{--} + HCO_3^{-}) - (Ca^{2+} + Mg^{2+}) \quad (3)$$

Gupta and Gupta (1987) defined RSBC (residual sodium bi-carbonate) as;

$$RSBC = HCO^{-}_{3} - Ca^{2+} \quad (4)$$

Kelley (1963) expressed KR (Kelley's ratio) as;

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \quad (5)$$

According to Doonen (1962), PI (permeability index) was calculated as;

$$PI = \frac{Na^{+} + \sqrt{HCO^{-}_{3}}}{Ca^{2+} + Mg^{2+}} \times 100 \quad (6)$$

Raghunath (1987) expressed MAR (magnesium adsorption ratio) as;

$$MAR = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad (7)$$

According to Raghunath (1987), TH (total hardness) was calculated as;

$$TH = (Ca^{2+} + Mg^{2+}) \times 50 \quad (8)$$

All the ionic concentrations are in milli-equivalent per litre (meq L^{-1}).

RESULTS AND DISCUSSION

Salinity problem: A salinity problem exists if salt accumulates in the crop root zone to such an extent that the crop is no longer able to extract sufficient water from the salty soil solution and plant shows symptoms similar to those of drought such as wilting, or a darker, bluish-green color, etc. In such a stage, plant osmotic pressure increases and plants wilt permanently under 15 to 20 bar (Raghunath, 1987). So, salinity affects crop water availability and reduces crop yield which follows the equation (Maas and Hoffman, 1977) as:

$$Y = 100 - b\,(EC_e - a)$$

Where Y is relative crop yield (%), EC_e is salinity of the soil solution extract (dS m^{-1}), a is salinity threshold value and b is yield loss per unit increase in salinity.

From Table 2, it was found that EC values of groundwater samples at all locations varied from 0.55 to 1.10 dS m^{-1} in 2002-03 and 0.64 to 1.06 dS m^{-1} in 2003-04 with an average of 0.79 dS m^{-1} in both the years. EC is the indicator of salinity whose level is determined depending on the Total Dissolved Solids (TDS) i.e., total concentration of dissolved salts present in the irrigation water. From the studied samples, it showed that EC values were less than 0.70 dS m^{-1} in 22% samples (4 out of

Table 1: Limits of some important parameter indices for rating groundwater quality and its suitability in irrigation use

Category	Groundwater quality indices: EC (dS m^{-1})	RSC (meq L^{-1})	SAR	SSP	Suitability for irrigation*
I	<0.7	<1.25	<10	<20	Excellent
II	0.7-3.0	1.25-2.5	10-18	20-40	good
III	>3.0	>2.5	18-26	40-80	fair
IV	-	-	>26	>80	poor

*According to Ayers and Westcot (1985), Eaton (1950), Todd (1980) and Wilcox (1955), respectively

Table 2: Chemical constituents of the studied irrigation water samples

Chemical constituents	Year/2002-03		Year/2003-04	
	Range	Average	Range	Average
pH	6.71-7.07	6.94	7.75-8.09	7.97
EC (dS m^{-1})	0.55-1.10	0.79	0.64-1.06	0.79
Ca^{2+} (meq L^{-1})	1.91-4.82	3.40	0.67-6.29	3.49
Mg^{2+} (meq L^{-1})	0.83-1.23	1.11	0.23-0.59	0.42
Na^{+} (meq L^{-1})	0.43-1.15	0.80	0.59-1.59	1.03
K^{+} (meq L^{-1})	0.02-0.09	0.05	0.93-2.95	1.66
Fe^{2+} (meq L^{-1})	0.21-1.74	0.74	0.10-1.33	0.62
As^{3+} (meq L^{-1})	0.0-0.3	0.049	0.0-0.20	0.031
CO_3^{2-} (meq L^{-1})	0.0-0.0	0.00	0.0-0.0	0.00
HCO_3^{-} (meq L^{-1})	5.25-9.75	7.77	6.25-11.50	8.07
Cl^{-} (meq L^{-1})	1.13-7.75	3.78	2.38-7.75	5.13

18 samples) and 0.71 to 1.10 dS m^{-1} in 78% samples (14 out of 18 samples) in both the years (Table 3). Even though in majority (78%) of the cases, EC was 0.71 to 1.10 dS m^{-1}, the salinity was not prevalent than sodicity in the area. In earlier studies similar EC values were found in nearby areas and in other locations of the country except the coastal belt (Sarkar *et al.*, 2002, 2003; Khan *et al.*, 1977, 1989; Khan and Basak, 1986). In the saline area (coastal belt) of Khulna district higher salinity (3.39 to 5.58 dS m^{-1}) was reported in irrigation water (Uddin *et al.*, 2001). Prolonged irrigation with saline water also causes secondary problems as; crusting of seedbeds, excessive weeds, nutritional disorders and drowning of the crop, rotting of seeds and poor crop stands in low-lying wet spots. One serious side effect of an infiltration problem is the potential to develop disease and vector (mosquito) problem. However, in respect of salinity, the quality of the water samples in the study areas was found excellent to good for irrigation use as the criteria set by Ayers and Westcot (1985) produced in Table 1.

Permeability problem: It occurs when normal infiltration rate of soil is appreciably reduced and hinders moisture supply to crops, which is responsible for two most water quality factors as; salinity of water and its sodium content relative to calcium and magnesium. High salinity water increases infiltration rate. Conversely, low salinity water or water with high sodium to calcium ratio decreases infiltration (Ayers and Westcot, 1985). Relative proportions of other different cations or balance of some cations and anaions defined previously by SAR, SSP, KR, MAR, RSC, RSBC, etc. are also the indicators of permeability problem.

Concentration of different elements shown in Table 2 showed that in the water samples Na^{+} was 0.43 to 1.59 meq L^{-1}. Soils containing large proportion of sodium (Na^{+}) with carbonate and chloride or sulphate are termed as alkali or saline soils, respectively (Todd, 1980). Presence of sodium (Na^{+}) in irrigation water reacts with soil to reduce soil permeability and its repeated use makes the soil impermeable, while high sodium leads to development of alkali soil. An alkali soil has a pH value of 8.5 or more with 15% or more SSP and has an unfavorable structure, puddles easily and restricts aeration (Raghunath, 1987). High sodium saturation also directly causes calcium deficiency. In the water samples Ca^{2+}, Mg^{2+} and K^{+} contents were found in the range of 0.67 to 6.29 meq L^{-1}, 0.23 to 1.23 meq L^{-1} and 0.02 to 2.95 meq L^{-1}, respectively. Frequent irrigation with high sodium (Na^{+}) water for a considerable duration makes the soil plastic and sticky in wet condition and form clods and crust on drying condition. In contrast, presence of calcium (Ca^{2+}) or/and magnesium (Mg^{2+}) salt in irrigation water retards the evil effects of sodium by increasing the permeability of the soil (Punmia and Lal, 1981; Asaduzzaman, 1985). Moreover, in case of low salt water, it dissolves and leaches most of the soluble minerals, including calcium from the surface soil (Ayers and Westcot, 1985). Sodium content relative to calcium and magnesium content, commonly known as Sodium Absorption Ratio (SAR) also influences infiltration rate of water. So, low SAR is always desirable. In the studied samples SAR values ranged below 1 (Table 4) and classified as excellent according to the criteria set by Todd (1980) in Table 1. Hence, according to SAR the groundwater tested was suitable for crop production

At the same level of salinity and SAR, adsorbtion of sodium by soils and clay minerals is more at higher Mg^{2+}: Ca^{2+} ratios. This is because the bonding energy of magnesium is less than that of calcium, allowing more sodium adsorbtion and it happens when the ratio exceeds more than 4 (Michael, 1978). It was also reported that soils containing high levels of exchangeable magnesium causes infiltration problem (Ayers and Westcot, 1985). In the present study the ratio of Mg^{2+} and Ca^{2+} did not exceed 1.0 (Table 4). The result, thus, indicated a good proportion of Ca^{2+} and Mg^{2+}, which maintains a good structural and tilth condition with no permeability problem of the soil in the study areas.

Presence of excessive sodium (Na^{+}) in irrigation water also promotes soil dispersion and structural break down when sodium (Na^{+}) to calcium (Ca^{2+}) ratio exceeds 3:1. Such a high Na^{+} : Ca^{2+} ratio (>3: 1) also results in severe water infiltration problem, mainly due to lack of sufficient Ca^{2+} to counter the dispersing effect of Na^{+}. Excessive Na^{+}

Table 3: Spatial distribution of the chemical constituents in the studied irrigation water samples

Parameters	Percent of water samples 2002-03	2003-04
pH	6-7 (72 %) and 7-8 (28 %)	7-8 (56 %) and 8 - 8.09 (44 %)
EC ($dS\ m^{-1}$)	<0.70 (22 %) and 0.70 - 1.10 (78 %)	<0.70 (22 %) and 0.70 - 1.06 (78 %)
Ca^{2+} ($meq\ L^{-1}$)	1-2 (6%) and 2-5 (96%)	1-2 (11%), 2-5 (77%) and 5-7 (12%)
Mg^{2+} ($meq\ L^{-1}$)	<1 (11%) and 1-2 (89%)	<1 (100%)
Na^{+} ($meq\ L^{-1}$)	<1 (78%) and 1-2 (22%)	<1 (50%) and 1-2 (50%)
K^{+} ($meq\ L^{-1}$)	<1 (100%)	<1 (13%), 1-2 (62%) and 2-3 (25%)
Fe^{2+} ($meq\ L^{-1}$)	<1 (83%) and 1-2 (17%)	<1 (81%) and 1-2 (19%)
As^{3+} ($meq\ L^{-1}$)	Nil (56%), 0.01- 0.03 (39%) and 0.03 - 0.3 (5%)	Nil (50%), 0.01 (44%) and 0.2 (6%)
CO_3^{2-} ($meq\ L^{-1}$)	Nil (100%)	Nil (100%)
HCO_3^{-} ($meq\ L^{-1}$)	<6 (11%), 6-8 (44%) and 8-10 (45%)	6-8 (63%), 8-10 (25%) and 10-12 (12%)
Cl^{-}($meq\ L^{-1}$)	<4 (61%) and 4-8 (39%)	<4 (19%) and 4-8 (81%)

also creates problems in crop water uptake, poor seedling emergence, lack of aeration, plant and root diseases, etc. (Ayers and Wastcot, 1985). The study revealed that Na^+ and Ca^{2+} ratio was below 1:1 (Table 4), indicating the groundwater suitable for crop production and not to create any problem mentioned above.

Average Kelly's Ratio (KR) was found as 0.18 and 0.26 in 2003 and 2004, respectively (Table 4). Kelley (1963) suggested that this ratio for irrigation water should not exceed 1.0. Earlier research results reported that KR value varied from 0.03 to 1.16 in the nearby Natore district (Mridha *et al.*, 1996). Thus, the KR at this location was far below the recommended limit showing a good balance of Na^+ with Ca^{2+} and K^+. This also indicates a good tilth condition of the soil with no permeability problem.

In the study area, the water samples contained almost nil to trance amount of CO_3^{2-}. But HCO_3^- contents were found to vary from 5.25 to 9.75 with an average of 7.77 $meq\ L^{-1}$ in 2003. While in 2004 it was found to vary from 6.25 to 11.50 with an average of 8.07 $meq\ L^{-1}$ (Table 2). It was reported that irrigation waters rich in bicarbonate content tend to precipitate insoluble calcium and magnesium in the soil as their precipitates, which ultimately leaves higher sodium proportion and increase SAR values (Michael, 1978) as;

$$2HCO^-_3 + Ca^{2+} \rightleftharpoons CaCO^-_3 + H_2O + CO_2 \uparrow$$

It was reported that although ordinarily bicarbonate is not thought to be a toxic ion, but it is reported to cause zinc deficiency in rice and is severe when it exceeds 2 $meq\ L^{-1}$ in water used for flooding and growing paddy rice (Ayers and Westcot, 1985).

The values of other parameter indices were elucidated in Table 4. The average RSC value of the water samples was found as 3.26 and 4.16 $meq\ L^{-1}$ in 2003 and 2004, respectively. The positive RSC values indicated that dissolved Ca^{2+} and Mg^{2+} were less than that of CO_3^- and HCO_3^- contents. According to Eaton (1950), the study results indicated higher values of RSC (Table 1) than the restricted limit (>2.5 $meq\ L^{-1}$) which apparently seemed to create permeability problem. RSBC of the samples varied from 4.37 to 4.58 $meq\ L^{-1}$ in the consecutive two years, which was satisfactory (<5 $mg\ L^{-1}$) according to the criteria set by Gupta and Gupta (1987). High MAR causes a harmful effect to soil when it exceeds 50. But in the present study, MAR was less than 50 causing no harmful effect to soil (Gupta and Gupta, 1987). Average TH of the samples were 225.5 and 195.5 $meq\ L^{-1}$, respectively which indicated the water as moderately hard (Raghunath, 1987). Moreover, PI of the samples was below 1 and according to Doonen's chart (Raghunath, 1987), the water was good for irrigation use.

Table 4: Some important parameter values used for rating of the groundwater quality of the studied irrigation water samples

Parameters	Respective values of the water quality parameters Year/2002-03	Year/2003-04
SAR	0.53	0.74
SSP (%)	16.00	41.00
RSC ($meq\ L^{-1}$)	3.26	4.16
RSBC	4.37	4.58
KR	0.18	0.26
PI	0.68	0.78
MAR	24.60	10.74
TH	225.50	195.50
Mg^{2+}:Ca^{2+}	0.32:1	0.12:1
Na^{+}:Ca^{2+}	0.23:1	0.29:1

Toxicity problem: Presence of certain specific elements in soil or water creates some problems like toxicity. The usual toxic ions in irrigation water are sodium, chloride and boron. Toxicity problem is different from a salinity problem, which occurs within the plant itself and is not caused by water-shortage. It normally results when these ions are taken up by plants and accumulate in the leaves during water transpiration to an extent that results in damage to the plant, whose degree depends on time, concentration, crop sensitivity and crop water use. Toxicity often accompanies or complicates a salinity or infiltration problem although it may appear even when salinity is low (Ayers and Westcot, 1985).

Presence of Na^+ content in the studied samples has already been explained before but boron content in the samples could not be analyzed. The Cl^- content of the groundwater samples was found to vary from 1.13 to 7.75 meq L^{-1} (Table 2). It was reported that Cl^- value (meq L^{-1}) less than 4 is non-restricted, 4 to 10 moderately restricted and above 10 severely restricted for irrigation purposes (Ayers and Westcot, 1985). It was also reported that presence of excessive chloride in irrigation water creates toxic problems for irrigation and the degree of toxicity depends on soil type, cropping pattern, crop growth stages, irrigation practice, drainage practice, climatic condition, etc. (Asaduzzaman, 1985). It was found that the average and in majority of samples (61%) Cl^- ontent in 2003 was within non-restricted limit (<4 meq L^{-1}). But in 2004, the average Cl^- content in the samples was slightly higher (5.13 meq L^{-1}) than the non-restricted limit with majority (81%) of 4-8 meq L^{-1}. Not all crops are equally sensitive to the toxic ions. The permanent, perennial-type crops (tree crops) are the more sensitive. Damage often occurs at relatively low concentration for sensitive crops as for citrus crops. Toxicity symptoms, however, can appear on almost any crop if concentrations are high enough. Thus, it apprehends that in the study area there is some possibility of creating toxicity problem due to higher Cl^- content in irrigation water.

Miscellaneous problems: Several other problems are also associated with low quality of irrigation water. Some of these are: i) Excessive vegetative growth, lodging and delayed crop maturity ii) Deposition of bicarbonate, gypsum and iron as stains on fruits and leaves iii) Irrigation water with a pH outside the normal range may cause a nutritional imbalance or may contain a toxic ion iv) Corrosion and encrustation in pumps, tube wells and other problems in irrigation equipment v) Reduced infiltration rate in soils leading to water stagnation in crop field and infestation of various crop diseases. Beside these, low quality water causes deposition of organic and inorganic materials like sand, silt, carbonate, iron and biological growths on equipment and in wells, which restricts water passage through well screen, pipelines and outlines (Ayers and Westcot, 1985).

pH is the indicator of acidity or basicity of water. The recommended normal range of pH for irrigation water is 6.5 to 8.4 and above this range it may cause a nutritional imbalance or may contain a toxic ion. The greatest direct hazard of an abnormal pH in water is the impact on irrigation equipment, which needs to be chosen carefully. Moreover, zinc deficiency of paddy rice was reported to be associated with sodic soil and a high soil pH (Ayers and Westcot, 1985). The pH value of the water samples for all the locations were found to vary from 6.71 to 7.07 with an average of 6.94 in 2003. But in 2004 it varied from 7.75 to 8.09 with an average of 7.97 (Table 2). It was also observed that in cent percent sample pH values were spatially distributed within its recommended range (Table 3). Other researchers also reported almost same pH values in other parts of the country (Khan *et al*., 1977; Khan *et al*., 1989; Zaman and Mohiuddin, 1995). Thus, like other places, pH values in these study areas were found excellent for crop production.

In Table 2, it was found that Fe^{2+} content in all the water samples studied was less than 2 mg L^{-1}, which is below the recommended limit of 5 mg L^{-1} (Ayers and Westcot, 1985). Irrigation water containing excessive iron has harmful effect on soil as it clogs the soil pores and also may encourage the growth of iron bacteria which causes to change the certain form of dissolved iron to insoluble ferric state (Khan *et al*., 1989; Asaduzzaman, 1985). Thus, the low Fe^{2+} values (<2 mg L^{-1}) obtained in the study area indicated free of risk for the above mentioned problems.

The recommended maximum limit of As^{3+} for irrigation water is 0.10 mg L^{-1}. This limit can protect sensitive crops when grown in sandy soils. But higher concentrations can be tolerated by some crops for short periods when grown in fine-textured soils (Tanji, 1990). Moreover, toxicity effect of As^{3+} to plants varies widely, ranging from 12 mg L^{-1} for Sudan grass to less than 0.05 mg L^{-1} for rice plant (Ayers and Westcot, 1985). According to World Health Organization (WHO), the safe limit of arsenic in drinking water is also 0.05 mg L^{-1}. In the study area (Table 5), As^{3+} was found in the analyzed water samples. In 2003, out of 18 samples, As^{3+} was nil in 10 samples (56%), 0.01 mg L^{-1} in 6 samples (33%), 0.03 mg L^{-1} in one sample (6%) and 0.3 mg L^{-1} in one sample (6%). While in 2004, a slide variation was observed as out of 18 samples, it was nil in 9 samples (50 %), 0.01 mg L^{-1} in 8 samples (44%) and 0.20 mg L^{-1} in one sample (6%). Hence, in the study area arsenic was not traced in 50-56% samples, was traced (0.01 to 0.03 mg L^{-1}) but very much within the safe limit (<0.05 mg L^{-1}) in 33-44% samples. However, only in 1% sample arsenic was found (0.2 to 0.3 mg L^{-1}) above the danger limit (>0.05 mg L^{-1}). Thus, in regards to As^{3+} the groundwater in the study area was found quite suitable for both drinking and irrigation purposes leaving risk at one location that should be sealed for not to use.

Net change in water table depth: In irrigated areas, salts often originate from a saline, high water table or from salts in the applied water. The extent of salt accumulation in soil depends on irrigation water quality, irrigation

Table 5: Presence of arsenic in irrigation water at different locations of Pabna district

			Source of water		Arsenic (mg L^{-1})	
Thana	Union	Village	2002-03	2003-04	2002-03	2003-04
Ishurdi	Gopalpur	Sara	DTW	DTW	Nil	0.01
Ishurdi	Pakshi	Bagail	HTW	DTW	0.01	0.01
Ishurdi	Pakshi	Sahid Para	STW	STW	0.01	0.01
Pabna sadar	Pabna sadar	Tabunia	DTW	DTW	Nil	Nil
Do	Do	Do	DTW	DTW	Nil	Nil
Do	Do	Do	DTW	DTW	0.01	0.01
Chatmohor	Chatmohor	Pasuria	HTW	STW	Nil	0.01
Chatmohor	Chatmohor	Gonigachi	HTW	STW	0.01	0.01
Bangura	Bangura	U.Z.O.	HTW	STW	0.01	0.01
Bangura	Bangura	Hasnath	HTW	STW	0.01	Nil
Faridpur	Bilpar	Berhauliya	HTW	STW	Nil	Nil
Faridpur	Bilpar	Thana sadar	HTW	STW	Nil	Nil
Bara	Bara	College road	DTW	DTW	0.30**	0.20**
Bara	Tajar	Tajar	HTW	HTW	0.03*	0.01
Sathia	Mathapur	Mathapur	HTW	STW	Nil	Nil
Sathia	Hatbaria	Hatbaria	HTW	STW	Nil	Nil
Atgaria	Barulia	Barulia	HTW	STW	Nil	Nil
Atgaria	Dabattar	Dabattar bazar	DTW	DTW	Nil	Nil

** Harmful level (>0.05 mg L^{-1}), * Little higher than the acceptable level (0.05 mg L^{-1})

management and drainage adequacy. The hydrograph analysis of the study area represented in Fig. 1 showed that November to April rainfall was very scanty with higher evaporative rate. Consequently water table started declining from November to April with its maximum level (6 to 7 m) during the peak irrigation and scanty rainfall period of February to June. However, WT sharply responded to the monsoon rainfall and regained at the end of monsoon.

CONCLUSIONS

Investigation on the groundwater quality for the study area revealed that it was excellent to good for crop production, except few specific cases like higher bicarbonate and chlorine values, which may create some permeability and toxicity problems, respectively. Apparently it also seemed that shallow Water Table (WT) depth and monsoon (June to September) rainfall may influence the groundwater quality due to extensive agricultural practices as a non-point source. Arsenic, which is a fatal problem of the country, was also traced in the study area. At one location it was higher than the danger limit, which advocates further observation and cautions for its use.

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