International Scholars Journals

International Journal of Irrigation and Water Management ISSN 5423-5294 Vol. 6 (6), pp. 001-012, June, 2019. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Arsenic contamination of aquifers: A detailed investigation on irrigation and portability

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Accepted 21 February, 2019

A series of experiment on water samples at different depths of aquifer was conducted to find out the suitability for irrigation and drinking water quality in relation to arsenic contamination. All the groundwater samples in deep aquifer for irrigation were almost good in respect of electrical conductivity (EC), normal in respect of sodium adsorption ratio (SAR), satisfactory in respect to residual sodium bi-carbonate (RSBC), good in respect of permeability index (PI), soft to very hard with respect to total hardness (TH), good to doubtful for soluble sodium percentage (SSP) and practically neutral to slightly alkaline in respect of pH. Excepting a few, the water samples were not harmful to soil in respect of magnesium adsorption ratio (MAR) and Kelly's ratio (KR). Iron concentrations were far below the recommended upper limit of irrigation water except magnesium. All water quality parameters were found to be correlated with each other. Most of the groundwater samples at shallow aquifer were not suitable for drinking purpose in relation to arsenic (< 0.05 mgL^{-1}) in that area.

Key words: Groundwater, irrigation, arsenic, aquifer.

INTRODUCTION

Groundwater is extensively used as a reliable and dependable source for irrigation. It is now generally recognized that the quality of ground water is just as important as its quantity. All ground water contain salts in solution that are derived from the location and past movement of water. Water while moving through underground geologic formation, may have various minerals dissolved in it. The type and concentration of salts depend on the environment, movement and source of the ground water. The poor quality of irrigation water affects the crop growth directly and reduces the crop yield drastically. This also damages physical properties of the irrigated soil by accumulating harmful and toxic elements in the soil which ultimately destroys productivity of agricultural land (Talukder and Alam, 1995, Shirazi et al., 2010). The use of irrigation water from aquifer has great influence on crop production depending on the type and quantity of dissolved salts. Various soil and cropping problems may arise with the use of poor quality water and special management practices may then be required to maintain sufficient crop production (Khan, 1990). The most common soil problems that are the basis for quality evaluations are those related to the total salinity, water infiltration rate, toxicity and other miscellaneous problems (Ayres and Wescot, 1985). Farmers sometimes test soil but they never test water for its quality. It is unknown to most of the farmers of Bangladesh that utilization of low quality of water for irrigation undoubtedly deteriorates soil productivity, which adversely affects crop production. Besides irrigation, quality of water should be assessed for drinking, domestic and industrial use. Bangladesh has made tremendous progress towards achieving its goal of food grain self-sufficiency. Substantial increases in irrigated area and use of modern rice varieties have lead to rapid production growth in Bangladesh in the last decade. Irrigated area is increasing day by day due to extensive use of groundwater. In Bangladesh, the total irrigated area is about 3.83 million ha and of them, 71% is irrigated by groundwater (Zaman, 2000). Irrigated agriculture is depending on an adequate water supply of

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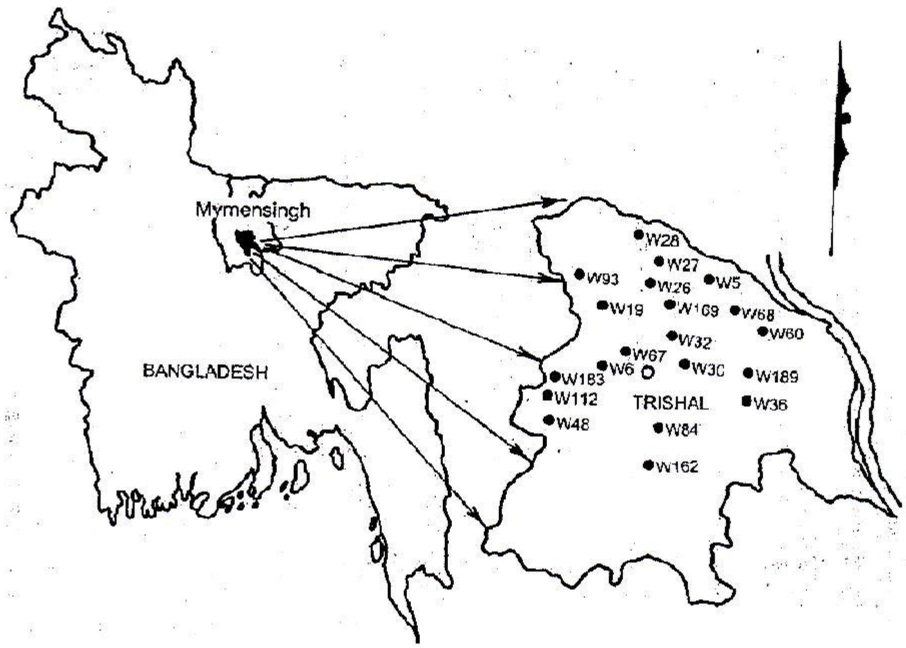

Figure 1. Location of deep tube wells for water samples collection in the study area.

usable quality. Water quality has often been neglected because good quality supplies have been plentiful and readily available in Bangladesh. Now this situation is changing. Irrigated agriculture in Bangladesh has already started showing problems regarding quality (Talukder et al., 1990, Cheng et al., 2005). Groundwater is generally free from pathogens and widely used by the people for drinking and cooking purposes. Groundwater extraction is intimately connected with food security in Bangladesh. Despite recent success in providing biologically safe drinking water to nearly ninety percent of the population of Bangladesh has achieved, the recognition of arsenic contamination in tube wells in various parts of the country has raised a major concern regarding public health. The detection of high level of arsenic contamination in shallow tube wells has caused serious problems for supplying safe water for drinking and domestic use. It was reported that 0.22 million people have been suffering from arsenic related diseases ranging from melanosis to skin cancer. Daily consumption of water with greater than 50 µg/L of arsenic can lead to problems with skin, and circulatory and nervous systems. If arsenic goes up to higher toxic levels, organ cancers, neural disorders and organ damage can occur (MacDonald, 1999). Arsenic poisoning is one of the most important problems of Bangladesh. It is more important for public health than for livestock. Arsenic contamination in Bangladesh was first detected in 1993 by the Department of Public Health Engineering (DPHE) of the government of Bangladesh in Chapainawabgonj district, although it was identified as early as 1983 in West Bengal, India (Chowdhury, 2001). Since then, more and more of it had been confirmed creating serious health concern. About 95 million people are vulnerable as the groundwater in 47 districts out of 64 is contaminated by arsenic. Arsenic patients have been identified in 30 districts (Chowdhury, 2001; Bundschuh, 2000; Scott et al., 2010). After being aware of deadly disease arsenic poisoning, millions of men, women and children living In the arsenic affected areas of country's 59 districts out of 64 have been fighting to conquer the ongoing battle against the 'arsenic curse' (Hossain, 2001). But it is still a long way for the Bangladesh people, desperately looking for alternate source of arsenic-free safe drinking water in their own localities, to go solve the crisis that already turned into a catastrophe on a vast scale. This study was, therefore, undertaken to determine the suitability of groundwater for irrigation and arsenic for drinking purpose of the study area.

MATERIALS AND METHODS

Collection of water and soil samples

A study was conducted at Trishal upazila under Mymensingh district of Bangladesh to determine the irrigation and drinking water quality of different depth of aquifer. Twenty samples were collected from twenty randomly selected deep tube wells (> 100 m) covering the study area (Figure 1). Twenty soil samples were also collected at 60 cm depth surrounding the deep tube wells to find out the physico-chemical properties of soil in the study area. In total, 43 water samples were collected from shallow aquifer of hand tube wells (< 15 m) to find out the irrigation water quality as well as 30 samples were analysed for arsenic status of the study area. Generally, deep tube wells are used for irrigation and hand tube wells are used for drinking purpose. Five hundred milliliters of water was collected from each tube well in plastic container. Samples were collected at least after 30 min continuous pumping. Care was taken so that no air could enter into the container. Soil and water samples were labeled and then transferred immediately to the laboratory for chemical analysis.

Water quality parameters

Quantities of arsenic were measured by German arsenic tool kits and other parameters were calculated by the following formulas.

Sodium adsorption ratio

Sodium adsorption ratio (SAR) was calculated by the following equation given by Richards (1954).

$$SAR = \frac{NA}{\sqrt{(CA+MG)/2}} \quad (1)$$

where all ions are expressed in meq/L

Soluble sodium percentage

The soluble sodium percentage (SSP) was calculated by the following equation (Todd, 1980)

$$SSP = \frac{NA+K}{CA+MG+NA+K} \cdot 100 \quad (2)$$

Permeability index

The permeability Index (PI) was calculated according to Doneen (1962) by the following equation.

$$PI = \frac{NA + \sqrt{HCO_3}}{CA+MG+NA} \cdot 100 \quad (3)$$

Residual sodium bi-carbonate

The residual sodium bi-carbonate (RSBC) was calculated by the following equation (Gupta and Gupta, 1987).

$$RSBC = HCO_3 - CA \quad (4)$$

Total hardness

Total hardness (TH) was calculated by the following equation (Raghunath, 1987).

$$TH = (CA + MG) \cdot 50 \quad (5)$$

Magnesium adsorption ratio (MAR)

Magnesium adsorption ratio (MAR) was calculated by the equation (Szobolces and Darab, 1968)

$$MAR = \frac{MG}{CA+MG} \cdot 100 \quad (6)$$

Kelly's ratio (KR)

The Kelly's ratio was calculated using the equation (Kelly, 1963)

$$KR = \frac{NA}{CA+MG} \quad (7)$$

RESULTS AND DISCUSSION

The chemical composition of deep aquifer of the study area is presented in Table 1. The electrical conductivity (EC) of water samples varied from 253 to 480 µs/cm. All the water were normal (200 to 1000 µs/cm) according to EC hazard classification made by Gupta (1979). Similar results were found by Khan and Basak (1986) and Sharifullah (1990). The pH values of water samples varied from 6.84 to 8.15 which are practically neutral to alkaline. The normal range of pH in irrigation water varies from 6.0 to 8.5 (Ayres and Wescot, 1985). Potassium (K) varied from 0.017 to 0.065 meq/L. Ammonium nitrate (NH_4-N) ranged from 0.42 to 1.26 µg/ml, which is also below the maximum recommended limit (3 µg/ml) for irrigation use. The results are in close conformity with the findings of Hossain (1992). The concentration of nitrate (NO_3) and sulphur (S), varied from 0.35 to 1.62 and 22 to 44 µg/ml, respectively, which are below the recommended maximum limit. The values of carbonate (CO_3), bi-carbonate (HCO_3) and iron (Fe) varied from 0.10 to 0.30, 1.10 to 3.84 meq/l and 0.01 to 0.05, µg/ml, respectively. These values are also within the maximum recommended maximum. Composition of sodium, calcium and magnesium of deep aquifer are presented in Figure 2. The total sodium (Na), calcium (Ca) and magnesium (Mg), varied from 1.00 to 4.12, 0.20 to 1.50 and 0.60 to 1.72 meq/l, respectively. The concentrations of all cations were below the recommended maximum limits (Ayres and Wescot, 1985) for irrigation use. Phosphorus, boron and manganese composition of deep aquifer are presented in Figure 3. Phosphorus (P), and boron (B) varied from 0.40 to 1.90 and 2.10 to 5.20 µg/ml, respectively, which are below the recommended maximum limit. The values of manganese (Mn) varied from 0.03 to 0.88 µg/ml. These values are not within the maximum recommended maximum limit. The maximum recommended value of manganese in irrigation water is 0.20 µg/ml (Ayres and Wescot, 1985). Most of the water samples had manganese concentration above the maximum limit.

The quality of deep aquifer irrigation water and its classification based on various parameters are given in Tables 2 and 3. Sodium adsorption ratio (SAR) of the

Table 1. Chemical composition of deep aquifer.

DTW No.	EC (µs/cm)	pH	K (me/l)	NH_4-N (µg/ml)	NO_3 (µg/ml)	S (µg/ml)	CO_3 (meq/L)	HCO_3 (meq/L)	Fe (mg/ml)
32	328	7.67	0.029	1.26	1.20	26	0.20	1.30	0.01
6	253	7.32	0.031	1.26	1.06	24	0.10	1.10	0.03
28	480	7.04	0.055	1.20	1.62	25	0.10	1.25	0.04
189	320	7.40	0.017	0.70	0.92	27	0.30	1.45	0.04
19	323	8.04	0.026	0.56	0.63	24	0.20	1.65	0.01
36	333	8.13	0.045	0.98	0.92	24	0.20	2.36	0.03
48	324	7.50	0.021	0.98	0.49	32	0.20	2.45	0.01
67	313	8.15	0.026	0.70	0.63	44	0.10	1.65	0.01
169	296	7.97	0.018	1.12	0.77	24	0.10	1.55	0.02
183	328	7.97	0.026	1.26	0.63	26	0.30	3.84	0.03
162	296	7.53	0.019	1.26	0.49	30	0.20	2.46	0.04
27	356	7.96	0.020	1.26	0.92	30	0.10	1.42	0.04
5	330	7.68	0.070	0.70	0.35	27	0.20	1.20	0.04
112	288	6.84	0.065	0.98	0.49	24	0.20	1.13	0.02
30	330	7.70	0.019	0.84	0.49	22	0.30	1.12	0.01
26	293	7.51	0.018	0.98	0.63	22	0.30	1.10	0.03
60	473	7.44	0.065	0.98	1.20	23	0.20	1.10	0.05
68	344	7.34	0.028	0.84	0.49	30	0.20	1.40	0.05
84	280	7.38	0.029	0.42	0.63	36	0.20	1.30	0.04
93	341	7.60	0.065	0.90	0.50	23	0.20	1.20	0.04
Average	333.75	7.61	0.067	0.96	0.75	27.15	0.195	1.60	0.029
SD	57.08	0.35	0.015	0.25	0.32	5.40	0.07	0.69	0.014

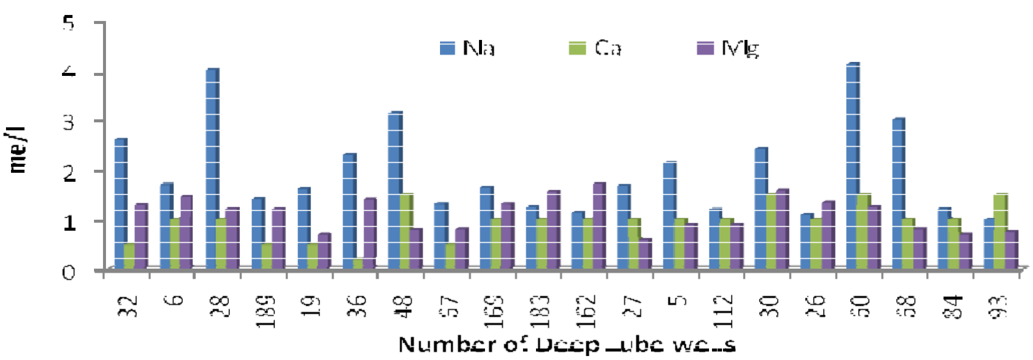

Figure 2. Sodium, calcium and magnesium composition of deep aquifer.

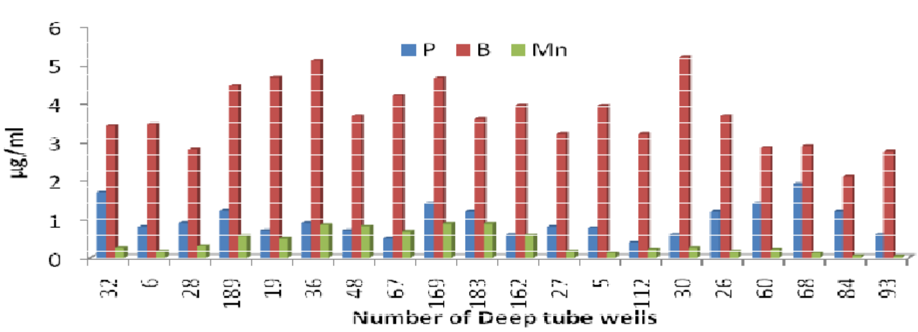

Figure 3. Phosphorus, boron and manganese composition of deep aquifer.

Table 2. Irrigation water quality at deep aquifer.

S/N	DTW No	SAR	SSP	RSBC	PI	TH
1	32	3.75	59.49	0.80	85.19	89.50
2	6	1.53	41.30	0.10	65.86	123.00
3	28	3.78	64.51	0.25	82.15	111.50
4	189	1.58	47.00	0.95	86.18	81.00
5	19	2.08	51.47	1.15	82.98	60.00
6	36	2.56	59.16	2.16	97.45	80.50
7	48	2.93	57.89	0.95	86.53	114.50
8	67	1.64	50.06	1.15	99.23	65.00
9	169	1.52	41.47	0.55	72.72	116.00
10	183	1.10	33.10	2.04	84.25	128.00
11	162	0.98	29.64	1.46	69.94	136.00
12	27	1.88	51.51	0.42	87.50	60.00
13	5	2.19	43.65	0.20	79.94	95.00
14	112	1.23	37.91	0.13	72.90	95.00
15	30	1.95	44.02	-0.38	63.09	154.00
16	26	1.01	32.00	0.10	62.02	117.00
17	60	3.50	59.03	-0.40	75.00	138.00
18	68	3.16	62.13	0.40	87.04	90.00
19	84	1.33	40.94	0.30	80.88	85.00
20	93	0.94	31.92	-0.30	64.30	112.50
	Average	1.94	47.80	0.75	79.28	103.60
	SD	0.94	11.04	0.72	10.79	26.36

groundwater sample was in the range of 0.94 to 3.78 as given in Table 2. In respect of sodium hazard, all the samples were normal (Table 3), that is, excellent category according to Gupta (1979). The results are in conformity with the findings of Khan and Basak (1986) and Sharifullah (1990). The soluble sodium percentage (SSP) of the water samples ranged from 29.64 to 64.51 (Table 2) and the quality of water were excellent to doubtful but unsuitable water samples were not found (Table 3). In terms of residual sodium bi-carbonate (RSBC), all the water samples were satisfactory (Table 3) according to Gupta (1979), having RSBC values varying from -0.40 to 2.16 meq/L (Table 2). The results are in conformity with the findings of Islam and Farid (1991) and Hossain (1992). In respect of permeability index (PI), all the water samples were good (Table 3) according to Raghunath (1987). This water might not create any permeability problem. Total hardness (TH) of water samples varied from 60 to 136 (Table 2) which are classified as slightly to moderately hard. This classification is also made on the basis of Raghunath (1987).

The physico-chemical properties of the soil which are collected from the surroundings areas of the selected deep tube wells are presented in Table 4. However, the average pH of EC, organic carbon, total-N, phosphorus and potassium were 6.49 to 66.05 µs/cm, 1.044%, 0.095%, 24.45 ppm and 133.33 ppm, respectively. Texturally, the soil was silty clay to clay loam. The pH values of soil samples varied from 5.42 to 7.77 which are slightly acidic to slightly alkaline. When pH value is 7, the soil is neutral and is best for crop production. But pH values ranged from 6.5 to 7.5 which are good for crop to absorb most of the nutrients from the soil. Thus the soils of the study area are good for crop production. EC of the soil samples varied from 52 to 98 µs/cm which are excellent for soil according to salinity hazard classification (Ayres and Wescot, 1985). The organic carbon (OC) of the soil samples ranged from 0.61 to 1.61%. The results are in conformity with the findings of Talukder et al. (1990). They found that the organic carbon in that area varies from 0.50 to 1.30. The phosphorus (P) of the soil sample ranged from 10 to 38 ppm and is satisfactory for crop production. The potassium (K) of the soil sample ranged from 108.4 to 152.8 ppm and is also satisfactory for crop production.

The amount of chemical constituents of the collected shallow groundwater samples which were obtained from the laboratory analysis are presented in Table 5. The quality parameters and classifications of the water samples for irrigation use are presented in Tables 6 to 7. The total sodium, potassium, calcium and magnesium varied from 1.69 to 2.70, 0.11 to 0.33, 0.20 to 5.0 and 0.64 to 1.93 meq/L, respectively (Table 5). The concentrations of all cations were below the recommended limits for irrigation use except magnesium; according to standard criteria, NH_4-N ranged from 1.40 to 1.96 ppm which is below the recommended maximum limit for irrigation water. Carbonate and bi-carbonate concentrations varied from 0.08 to 0.54 and 0.73 to 2.07 meq/L, respectively. The concentration of nitrate (NO_3-N), sulphur and phosphorous varied from 0.28 to 0.70, 0.49 to 2.34 and 0.002 to 0.057 ppm, respectively (Table 5). All the anion concentrations were below the recommended maximum limits for irrigation water according to standard criteria. The pH of the water samples in the study area were found to be varied from 6.53 to 7.57 which are practically neutral to slightly alkaline. Normal range of pH in irrigation water varies from 6.0 to 8.5 (Ayres and Wescot, 1985). The pH values were well within the normal range of irrigation quality according to standard criteria. Although the pH is not directly related to soil, plant and animal health, but has been applied widely and successfully over many years to ensure the wholesomeness of water. The electrical conductivity of the groundwater samples was in the range of 216 to 447 µs/cm.

Out of 43 samples, two samples were in excellent class and the rest 41 samples were in good class (Table 7) according to electrical conductivity hazard classification made by Gupta (1979). Sodium adsorption ratios of the groundwater samples were in the range of 1.14 to 3.60 (Table 6). In respect of the sodium hazard, all the samples were in normal range, that is, excellent category according to Gupta (1979). In terms of residual sodium bi-carbonate (RSBC), all the water samples were found

Table 3. Classification of irrigation water quality at deep aquifer.

S/N	Class					
	SAR	pH	SSP	PI	RSBC	TH
1	Normal	Slightly alkaline	Permissible	Good	Satisfactory	Slightly hard
2	Normal	Practically neutral	Permissible	Good	Satisfactory	Moderately hard
3	Normal	Practically neutral	Doubtful	Good	Satisfactory	Moderately hard
4	Normal	Practically neutral	Permissible	Good	Satisfactory	Slightly hard
5	Normal	Alkaline	Permissible	Good	Satisfactory	Slightly hard
6	Normal	Alkaline	Permissible	Good	Satisfactory	Slightly hard
7	Normal	Practically neutral	Permissible	Good	Satisfactory	Slightly hard
8	Normal	Alkaline	Permissible	Good	Satisfactory	Moderately hard
9	Normal	Slightly alkaline	Permissible	Good	Satisfactory	Slightly hard
10	Normal	Slightly alkaline	Good	Good	Satisfactory	Moderately hard
11	Normal	Practically neutral	Good	Good	Satisfactory	Moderately hard
12	Normal	Slightly alkaline	Permissible	Good	Satisfactory	Slightly hard
13	Normal	Slightly alkaline	Permissible	Good	Satisfactory	Slightly hard
14	Normal	Practically neutral	Good	Good	Satisfactory	Slightly hard
15	Normal	Practically neutral	Permissible	Good	Satisfactory	Moderately hard
16	Normal	Practically neutral	Good	Good	Satisfactory	Moderately hard
17	Normal	Practically neutral	Permissible	Good	Satisfactory	Moderately hard
18	Normal	Practically neutral	Doubtful	Good	Satisfactory	Slightly hard
19	Normal	Practically neutral	Permissible	Good	Satisfactory	Slightly hard
20	Normal	Slightly alkaline	Good	Good	Satisfactory	Moderately hard

Table 4. Physico-chemical properties of soil of the study area.

S/N	DTW No.	pH	EC (μs/cm)	Organic carbon (%)	Total-N (%)	Phosphorus (ppm)	Potassium (ppm)	Textural class
1	32	7.50	54	0.882	0.088	12	114.6	Clay loam
2	6	7.44	61	0.971	0.074	15	120.2	Clay loam
3	28	7.20	72	1.181	0.113	14	124.6	Clay loam
4	189	7.45	58	1.028	0.116	11	116.4	Clay loam
5	19	6.12	52	1.179	0.103	10	125.6	Silty clay
6	36	6.00	76	1.231	0.109	18	108.4	Silty clay
7	48	6.96	71	1.079	0.112	30	136.1	Loam
8	67	7.31	62	1.612	0.081	36	142.6	Loam
9	169	6.88	59	1.032	0.059	38	148.3	Loam
10	183	6.65	98	0.998	0.075	31	135.6	Loam
11	162	7.77	65	1.321	0.098	19	140.7	Loam
12	27	6.41	69	1.021	0.096	22	148.8	Loam
13	5	6.12	68	0.987	0.109	28	138.9	Loam
14	112	5.54	71	0.921	0.085	38	124.6	Loam
15	30	5.65	65	0.613	0.106	29	133.3	Loam
16	26	6.35	62	0.725	0.081	28	149.6	Loam
17	60	5.42	59	0.988	0.075	18	152.8	Loam
18	68	5.44	58	1.072	0.101	26	122.8	Loam
19	84	5.75	62	1.013	0.108	36	143.3	Loam
20	93	5.42	69	1.021	0.105	30	138.8	Clay loam
Average		6.49	66.05	1.044	0.095	24.45	133.33	
SD		0.77	10.14	0.207	0.016	9.32	12.89	

Table 5. Chemical properties of shallow aquifer at the study area.

S/N	pH	EC (μs/cm)	NH_4-N (ppm)	NO_3-N (ppm)	Phosphorus (ppm)	Potassium (meq/l)	Sulphur (ppm)	Ca (meq/l)	Na (meq/l)	CO_3 (meq/l)	HCO_3 (meq/l)	Mg (meq/l)
1	6.71	247	1.40	0.56	0.015	0.14	1.15	0.80	1.93	0.18	0.97	1.10
2	7.20	286	1.54	0.56	0.011	0.15	0.62	0.40	2.38	0.24	1.52	0.95
3	6.96	263	1.82	0.42	0.007	0.12	1.48	0.20	2.06	0.24	1.15	0.85
4	7.36	290	1.68	0.70	0.007	0.16	0.69	0.40	2.38	0.24	1.52	0.69
5	7.04	367	1.54	0.42	0.037	0.14	0.82	0.60	2.38	0.54	1.64	0.88
6	7.00	292	1.82	0.56	0.034	0.12	1.39	0.20	2.06	0.18	1.34	1.10
7	7.19	272	1.68	0.42	0.026	0.12	1.48	0.20	2.04	0.18	1.06	0.99
8	7.37	286	1.40	0.56	0.007	0.14	0.57	0.20	2.26	0.48	0.97	0.98
9	7.38	264	1.54	0.42	0.011	0.12	1.14	0.20	2.38	0.42	0.97	1.03
10	7.18	250	1.54	0.56	0.026	0.12	1.14	0.20	2.12	0.42	0.73	1.23
11	7.18	268	1.82	0.42	0.005	0.12	0.74	0.40	1.69	0.36	1.22	1.15
12	7.11	255	1.96	0.56	0.003	0.13	0.98	0.40	2.16	0.30	1.09	1.08
13	7.00	250	1.82	0.43	0.030	0.14	1.39	0.40	2.18	0.24	1.34	1.09
14	7.15	263	1.96	0.56	0.034	0.15	1.14	0.60	2.18	0.36	1.22	0.95
15	7.37	306	1.82	0.56	0.026	0.17	0.77	0.60	2.34	0.30	1.52	0.78
16	7.45	300	1.68	0.44	0.015	0.11	1.60	0.80	2.30	0.30	1.46	0.91
17	7.32	332	1.82	0.28	0.011	0.13	0.90	1.40	1.96	0.30	1.22	0.86
18	7.50	440	1.96	0.43	0.003	0.15	0.95	3.80	2.28	0.36	2.07	1.35
19	7.10	447	1.54	0.70	0.005	0.15	0.98	4.60	2.36	0.30	1.89	1.28
20	7.39	288	1.82	0.56	0.019	0.17	0.49	0.60	2.44	0.24	1.52	1.19
21	7.34	282	1.54	0.54	0.003	0.15	0.78	0.60	2.38	0.24	1.40	1.11
22	7.37	350	1.68	0.43	0.002	0.17	0.53	0.40	2.60	0.30	1.52	1.27
23	7.40	362	1.82	0.56	0.009	0.12	0.86	0.60	2.68	0.36	1.70	0.75
24	7.43	266	1.68	0.56	0.004	0.13	0.69	0.40	2.24	0.24	1.22	0.81
25	7.47	337	1.82	0.43	0.004	0.15	0.53	0.60	2.56	0.36	1.58	0.91
26	7.53	250	1.96	0.42	0.002	0.15	0.78	0.20	2.26	0.30	1.15	0.77
27	7.34	329	1.82	0.56	0.006	0.15	0.66	0.40	2.54	0.30	1.58	0.96
28	7.35	316	1.82	0.70	0.002	0.15	0.53	0.40	2.50	0.42	1.40	0.83
29	7.32	316	1.96	0.42	0.017	0.33	0.74	0.40	2.48	0.36	1.46	0.99
30	6.53	422	1.68	0.43	0.004	0.15	1.80	5.00	2.02	0.24	0.91	1.19
31	7.37	309	1.82	0.56	0.004	0.17	0.74	0.80	2.48	0.30	1.46	1.93
32	7.54	348	1.96	0.42	0.006	0.13	1.44	0.60	2.52	0.48	1.40	0.88
33	7.30	314	1.68	0.42	0.080	0.11	0.66	0.40	2.60	0.42	1.64	0.97
34	7.35	397	1.82	0.43	0.040	0.11	0.78	0.40	2.66	0.08	2.01	0.69
35	7.43	402	1.68	0.56	0.067	0.14	0.69	2.40	2.70	0.48	1.76	1.53

Table 5. Contnd.

36	7.57	317	1.82	0.56	0.040	0.11	0.62	2.60	2.60	0.30	1.83	1.00
37	6.95	216	1.54	0.43	0.027	0.18	0.49	0.80	2.00	0.12	1.58	1.00
38	7.40	388	1.68	0.42	0.057	0.15	0.69	2.40	2.64	0.30	0.85	1.23
39	7.50	282	1.96	0.56	0.042	0.15	0.90	1.00	2.36	0.36	1.80	0.64
40	7.42	273	1.82	0.56	0.020	0.17	0.90	0.60	2.42	0.42	1.22	0.66
41	7.32	271	1.82	0.42	0.012	0.15	2.11	0.20	2.38	0.24	1.30	0.81
42	7.25	274	1.68	0.42	0.002	0.17	2.00	0.80	2.44	0.31	1.34	0.82
43	7.47	358	1.82	0.42	0.040	0.11	2.34	1.20	2.58	0.28	1.64	0.64
Range	6.53-7.57	216-447	1.40-1.96	0.28-0.70	0.002-0.057	0.11-0.33	0.49-2.35	0.20-5.00	1.69-2.70	0.08-0.54	0.73-2.07	0.64-1.93

Table 6. Shallow aquifer water quality parameters of the study area.

S/N	SAR	SSP	PI	RSBC	TH	MAR	KR
1	1.98	52.14	76.10	0.17	95.00	57.89	1.01
2	2.89	65.20	96.89	1.12	67.50	70.37	1.76
3	2.84	67.49	100.71	0.95	52.50	80.95	1.96
4	3.22	69.97	104.11	1.12	54.50	63.30	2.18
5	2.77	63.00	94.83	1.04	74.00	59.45	1.60
6	2.55	62.64	95.76	1.14	65.00	84.61	1.58
7	2.64	64.47	95.03	0.86	59.50	83.19	1.71
8	2.94	67.03	94.32	0.77	59.00	83.05	1.91
9	3.03	67.02	93.21	0.77	61.50	83.73	1.93
10	2.50	61.03	83.75	0.53	71.50	86.10	1.48
11	1.92	53.86	86.25	0.82	77.50	74.19	1.09
12	2.51	60.74	88.02	0.69	74.00	72.97	1.45
13	2.52	60.89	90.94	0.94	74.50	73.15	1.46
14	2.47	60.05	88.05	0.62	77.50	61.29	1.40
15	2.81	64.52	96.04	0.92	69.00	56.52	1.69
16	2.48	58.49	87.48	0.66	85.50	53.21	1.34
17	1.83	47.93	72.45	-0.18	113.50	38.32	0.86
18	1.42	32.05	50.05	-1.73	257.50	26.21	0.44
19	1.37	29.91	45.33	-2.71	294.00	21.76	0.40
20	2.57	59.31	86.82	0.92	89.50	66.48	1.36
21	2.57	59.67	87.12	0.80	85.50	64.91	1.39
22	2.84	67.38	89.76	1.12	83.50	76.08	1.55
23	3.26	67.46	98.85	1.10	67.50	55.55	1.98

Table 6. Contnd.

24	2.88	66.20	96.94	0.82	60.50	66.94	1.85
25	2.94	64.21	93.78	0.98	75.50	60.26	1.69
26	3.24	71.30	103.16	0.95	48.50	79.38	2.32
27	3.08	66.41	97.35	1.18	68.00	70.58	1.86
28	3.18	68.29	98.74	1.00	61.50	67.47	2.03
29	2.97	66.90	95.30	1.06	69.50	71.22	1.78
30	1.14	25.95	36.22	-4.09	309.50	19.22	0.36
31	2.12	49.25	70.79	0.66	136.50	70.69	0.91
32	2.92	64.16	92.58	0.80	74.00	59.45	1.70
33	3.14	66.42	97.74	1.24	68.50	70.80	1.89
34	3.60	71.76	108.74	1.61	54.50	63.30	2.44
35	1.92	41.94	60.73	-0.64	169.50	38.93	0.68
36	1.93	42.94	63.75	-0.77	180.00	27.77	0.72
37	2.10	54.77	85.71	0.78	90.00	55.55	1.11
38	1.95	43.45	56.80	-1.55	181.50	33.88	0.72
39	2.60	60.48	93.36	0.89	82.00	39.02	1.43
40	3.05	67.27	95.77	0.62	63.00	52.38	1.92
41	3.34	71.46	103.84	1.10	50.50	80.19	2.35
42	2.71	61.70	88.61	0.54	81.00	50.61	1.50
43	2.68	59.38	87.34	0.44	92.00	34.78	1.40
Range	1.14-3.60	25.95-71.76	45.33-108.74	-4.09-1.61	48.50-309.50	19.22-86.10	0.36-2.44

Table 7. Irrigation water quality classification of shallow aquifer.

S/N	EC	SAR	SSP	RSBC	TH
1	Excellent	Normal	Permissible	Satisfactory	Slightly hard
2	Good	Normal	Doubtful	Satisfactory	Slightly hard
3	Good	Normal	Doubtful	Satisfactory	Slightly hard
4	Good	Normal	Doubtful	Satisfactory	Slightly hard
5	Good	Normal	Doubtful	Satisfactory	Slightly hard
6	Good	Normal	Doubtful	Satisfactory	Slightly hard
7	Good	Normal	Doubtful	Satisfactory	Slightly hard
8	Good	Normal	Doubtful	Satisfactory	Slightly hard
9	Good	Normal	Doubtful	Satisfactory	Slightly hard
10	Good	Normal	Doubtful	Satisfactory	Slightly hard
11	Good	Normal	Permissible	Satisfactory	Slightly hard

Table 7. Contnd.

12	Good	Normal	Doubtful	Satisfactory	Slightly hard
13	Good	Normal	Doubtful	Satisfactory	Slightly hard
14	Good	Normal	Doubtful	Satisfactory	Slightly hard
15	Good	Normal	Doubtful	Satisfactory	Slightly hard
16	Good	Normal	Permissible	Satisfactory	Moderately hard
17	Good	Normal	Permissible	Satisfactory	Very hard
18	Good	Normal	Good	Satisfactory	Very hard
19	Good	Normal	Good	Satisfactory	Slightly hard
20	Good	Normal	Permissible	Satisfactory	Slightly hard
21	Good	Normal	Permissible	Satisfactory	Slightly hard
22	Good	Normal	Doubtful	Satisfactory	Slightly hard
23	Good	Normal	Doubtful	Satisfactory	Slightly hard
24	Good	Normal	Doubtful	Satisfactory	Slightly hard
25	Good	Normal	Doubtful	Satisfactory	Soft
26	Good	Normal	Doubtful	Satisfactory	Slightly hard
27	Good	Normal	Doubtful	Satisfactory	Slightly hard
28	Good	Normal	Doubtful	Satisfactory	Slightly hard
29	Good	Normal	Doubtful	Satisfactory	Very hard
30	Good	Normal	Good	Satisfactory	Moderately hard
31	Good	Normal	Permissible	Satisfactory	Slightly hard
32	Good	Normal	Doubtful	Satisfactory	Slightly hard
33	Good	Normal	Doubtful	Satisfactory	Slightly hard
34	Good	Normal	Doubtful	Satisfactory	Moderately hard
35	Good	Normal	Permissible	Satisfactory	Moderately hard
36	Good	Normal	Permissible	Satisfactory	Slightly hard
37	Excellent	Normal	Permissible	Satisfactory	Moderately hard
38	Good	Normal	Permissible	Satisfactory	Slightly hard
39	Good	Normal	Doubtful	Satisfactory	Slightly hard
40	Good	Normal	Doubtful	Satisfactory	Slightly hard
41	Good	Normal	Doubtful	Satisfactory	Slightly hard
42	Good	Normal	Doubtful	Satisfactory	Slightly hard
43	Good	Normal	Doubtful	Satisfactory	Slightly hard

to be satisfactory according to Gupta and Gupta (1987) having RSBC values ranging from -4.09 to 1.61. The soluble sodium percentage (SSP) of the water samples ranged from 25.95 to 71.76. Out of 43 samples, 3 samples were good, 11 samples were permissible and the rest 29 samples were doubtful (Table 7) for irrigation use according to Wilcox (1955). The hardness of the water samples studied varied from 48.50 to 309.50 (Table 6)

Table 8. Correlation matrix among the standard parameters of suitability classification of shallow aquifer.

	SAR	SSP	PI	RSBC	TH	MAR	KR
SAR	1						
SSP	0.9560**	1					
PI	0.9287**	0.9854**	1				
RSBC	0.8223**	0.9128**	0.9347**	1			
TH	-0.8407**	-0.9541**	-0.9548**	-0.9566**	1		
MAR	0.6384**	0.7613**	0.7373**	0.7570**	-0.7808**	1	
KR	0.9743**	0.9612**	0.9427**	0.8001**	-0.8498**	0.7041**	1

**Significant at 1% level.

Table 9. Suitability of groundwater for drinking purpose in relation to arsenic contamination.

S/N	Presence of Arsenic	Arsenic quantity (ppm)
1	+ve	≤0.05
2	+ve	0.05-<0.10
3	-	-
4	+ve	0.05-<0.10
5	+ve	0.05-<0.11
6	+ve	≤0.05
7	-	-
8	+ve	≤0.05
9	+ve	0.06-0.12
10	+ve	≤0.05
11	+ve	≤0.05
12	+ve	≤0.05
13	+ve	0.05-<0.10
14	+ve	0.05-<0.10
15	+ve	0.08-0.20
16	-	-
17	+ve	0.05-0.10
18	+ve	≤0.05
19	+ve	0.05-<0.10
20	+ve	0.05-<0.10
21	+ve	0.05-<0.10
22	+ve	≤0.05
23	+ve	0.05-<0.10
24	+ve	0.05-<0.10
25	+ve	0.05-<0.10
26	+ve	0.05-<0.10
27	+ve	0.05-<0.10
28	+ve	≤0.05
29	+ve	≤0.05
30	-	-

which were classified as soft to very hard. This classification was made on the basis of Raghumath (1987). Hardness resulted due to the abundant presence of divalent cations such as Ca and Mg in natural waters (Todd, 1980). TH indicated the presence of higher amounts of Ca and Mg and vice-versa for the lower value of hardness (Karnath, 1987). According to Doneen (1962), the permeability index (PI) of all the water samples were found to be good (Raghunath, 1987) having PI values ranging from 45.33 to 108.74. It may be expected that the water will not create any permeability problem. MAR ratio of the water samples varied from 19.22 to 86.10 (Table 6). Gupta and Gupta (1987) mentioned that high MAR affects the soil unfavorably, a harmful effect on soils appear when MAR exceeds 50. In the present study, out of 43 samples, only 10 samples had MAR less than 50 which would cause no harm to soil and the rest were above 50 which might cause harm to soil. The Kelly's ratio for the water samples varied from 0.36 to 2.44. Kelly (1963) suggested that this ratio should not exceed unity for irrigation water. In the present study, only eight samples had KR less than 1.0 and the rest were greater than unity.

Correlation coefficient analysis was performed amongst the parameters, SAR, SSP, PI, RSBC, TH, MAR and KR in all possible combination and presented in Table 8. The results showed that SAR had high positive correlation with SSP (r = 0.956), PI (r = 0.9287), RSBC (r = 0.8223) and KR (r = 0.9743) at 1% level of significance. SAR had high negative correlation with TH (r = -0.8407) and also positive significant correlation with MAR (r = 0.6384). SSP had high positive significant correlation with PI (r = 0.9854), RSBC (r = 0.9128) and KR (r = 0.9612) at 1% level of confidence. SSP had high negative significant correlation with TH (r = -0.9541) and also positive significant correlation with MAR (r = 0.7613) at 1% level of significance. PI had high positive significant correlation with RSBC (r = 0.9347) and KR (r = 0.9427) and high negative significant correlation with TH (-0.9548) at 1% level of significance. PI was positive significant correlation with MAR (r = 0.7373) at 1% level of significance. RSBC had high negative significant correlation with TH (r = -0.9566) and high positive significant correlation with KR (r = 0.8001). RSBC was positively significantly correlated with MAR (r = 0.7570) at 1% level of significance. TH had high negative significant correlation with KR (r = -0.8498) and was negatively correlated with MAR (r = -0.7808). MAR was positively significantly correlated with KR (r = 0.7041) at 1% level of significance.

Arsenic concentration of all groundwater samples was tested and presented in Table 9. Among 30 groundwater samples, 26 water samples showed presence of arsenic beyond the safe limit (0.05 ppm) of Bangladesh. Only four water samples were found to be arsenic free. The results indicated that the shallow aquifer water of the study area was seriously polluted with arsenic toxicity and could not be use for drinking purpose without treatment.

Conclusions

Groundwater quality is an important factor for crop-soil-water relation. All the water samples were found normal for irrigation in respect of salinity (EC) and SAR, practically neutral to alkaline in respect of pH, good to doubtful in respect of SSP, slightly to very hard in respect of TH and good in respect of PI. Most of the water samples of shallow aquifer showed presence of arsenic beyond the safe limit.

ACKNOWLEDGEMENT

Financial support by the Institute of Research Management and Monitoring (IPPP), University of Malaya (UM) under UMRG research grant number RG092/10SUS is gratefully acknowledged.

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