ASSESSMENT OF IRRIGATION WATER QUALITY BY USING PRINCIPAL COMPONENT ANALYSIS IN AN ARSENIC AFFECTED AREA OF BANGLADESH

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ABSTRACT

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The irrigation water quality was assessed around Budhol union under the district of Brahmanbaria in Bangladesh where underground water is highly arsenic (As) contaminated. Three types (surface, shallow tube well and deep tube well) of irrigation water samples were collected for physio-chemical analyses, which included pH, EC, TDS, Ca, Mg, Na, K, Fe, Zn, Cu, Mn, P, B, As, CO_3, HCO_3, Cl, SO_4 and NO_3. Comparative study and the distribution pattern of anionic and cationic constituents were performed for three types of arsenic contaminated irrigation water sources. Among the water sources, surface irrigation water was found less arsenic and manganese toxicity for irrigation. On the other hand, shallow tube wells water used for irrigation purpose contain more soluble arsenic then surface water and deep tube wells. Depth of tube well is correlated with arsenic concentration of well water. In order to understand the distribution of individual geochemical variables in the irrigation water samples collected from the sites affected by arsenic toxicity, principal component analysis was performed. The results of principal component analysis showed that geochemical variables have tendency to accumulate into three distinct groups. Well Depth, As and Mn were belongs to one group, which indicate that WD might have positive effect on As and Mn.

Key words: Arsenic contaminated area, irrigation water quality, principal component analysis.

INTRODUCTION

Arsenic contamination in ground water is a severe problem in Bangladesh. It has been suspected to be the biggest arsenic calamity in the world. Out of 64 administrative districts, 59 are contaminated to arsenic. As a result, 80 million people are now at risk and 10,000 people have shown the symptoms of arsenicosis.

Water is the next important input to fertilizer for crop production. If it is polluted, it may be dangerous for plants, animals as well as for human being. In Bangladesh, about 80% of total water is used for irrigation purpose. So, before using water for irrigation, its quality, which is equally important to its quantity, should be assessed so that it could not create any health hazard. If low quality of water is utilized for irrigation, soluble salts and /or other toxic elements like As may accumulate in the soil thus deteriorating soil properties and crop quality (Hossain and Ahmed, 1999).

In addition to the immediate concern of As in drinking water, the arsenic contamination might have a detrimental effect on land & agricultural sustainability. Irrigation with As contaminated ground water to rice & other crops may increase its concentration & eventually As may enter into food chain through crop uptake (Islam *et al.,* 2004).

As mobilization in groundwater also appears to be triggered by intensive extraction of groundwater for irrigation and application of phosphate fertilizer (Acharyya *et al.,* 2000). On the other hand, Harvey *et al.,* (2002) reported that As mobilization is associated with recent inflow of C due to large scale irrigation pumping. It is therefore evident that As mobilization in Bangladesh groundwater is a complex natural geochemical processes.

Groundwater has also been used extensively for irrigation (Ravenscroft *et al.,* 2002), which greatly increasing agricultural productivity in the region. Unfortunately, the groundwater is often laden with As of natural origin, and chronic As poisoning is now widespread in the local population (Smith *et al.,* 2000). Bangladeshi farmers began irrigation their land by shallow tube wells so that rice, the country's main staple food, could be grown during the six dry months of the year when monsoon flooding abates. In an arsenic effected area, villagers divert shallow tube well (which actually installed for safe drinking water) water on to crop as irrigation water, which may accumulate in crop roots and stems and ultimately As may enter into food chain.

Most of the arable lands are irrigated with ground water that comes from shallow tube well (STW) and deep tube well (DTW). Some farmers often use pond water for irrigation purpose. As DTW is very expensive to install, so large portion of irrigation water comes from STWs in dry season. Studies have shown that grain crops and water loving root crops readily take up As and there is a high possibility to take As by plants from soil or irrigation water, which eventually transfers to humans. Further studies are needed, especially surrounding the effects of arsenic on main crops and vegetables (Islam *et al.,* 2004).

Now a day, it is critically important to understand the factors controlling As mobilization, both to assess risks posed by As-enriched natural waters and to design more effective remediation. The fate of As in the environment is primarily controlled by the physicochemical properties. The high variability of As concentrations determined at various type of irrigation water wells at the sampling sites. However, the fate of As in the agricultural area in the Ganges delta is not known yet. Therefore, in this study principal component analysis was done to clarify the general variation patterns of geochemical variables occurring in irrigation water collected from various sites of an As affected area of Bangladesh, to improve the environmental methodology for assessment of the degree and pattern of pollution in a certain type of soil.

MATERIALS AND METHODS

Study area
The study area is located in the Southeastern part of Bangladesh, under the district of Brahmanbaria. The soil type is non-calcareous alluvium type. The region is belongs to the aquifer of Late Pleistocene coarse sands, gravels and cobbles of the Tista and Brahmaputra megna-fans and basal fan delta gravels along the incised Brahmaputra channel (BGS & DPHE, 2001). Deep tube well, shallow tube well and pond are used for irrigation in this area.

Procedure for water sample collection
Water samples were collected from 5 ponds, 7 shallow tube wells, and 6 deep tube wells at Budhol union under the district of Brahmanbaria during the month of March 2003. For each sample site, three samples were taken for chemical analysis. Water samples were collected in one liter plastic bottle. The ground water samples were collected at running condition of the tube wells and surface water samples were drawn from midstream at 0-15 cm below the surface of pond water. The collected water samples were tightly sealed as early as possible to avoid exposure to air. Water sampling techniques were followed as outlined by Hunt and Wilson (1986) and APHA (1989). The chemical analyses were conducted at the Agricultural Chemistry Laboratory, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh.

Methods used for chemical analysis
The pH and electrical conductivity (EC) values were determined electrometrically using digital pH and digital conductivity meter (Ghosh *et al*., 1983). Total dissolved soli
ds (TDSs) were estimated by weighing the solid residue obtained by evaporation of a measured volume of water samples to dryness (Chopra and Kanwar, 1980). Potassium and sodium were determined by flame emission spectrophotometer (Golterman, 1971). Calcium, magnesium, iron, zinc, copper and manganese were analyzed directly by atomic absorption spectrophotometer (APHA, 1989). Bicarbonate was determined by acidimetric titration (Chopra and Kanwar, 1980) while chloride was determined by argentometric titration (APHA, 1989). Phosphorus, boron and nitrate were determined colorimetrically (Ghosh et *al*., 1983 and APHA, 1989) whereas sulphate was analyzed turbidimetrically (Wolf, 1982). As was analyzed directly by atomic absorption spectrophotometer with hydride generator (APHA, 1989).

Determination of irrigation water classification
The classification of irrigation water quality was carried out according to sanitary classification criteria in U.S as follows (Agriculture Handbook 2001, U.S. Dept. of Agriculture).

Statistical Analysis

Principal Component Analysis (PCA)
The purpose of PCA is usually to determine a few linear combinations of the original variables, which can be used for summarizing the data with minimal loss of information. Principal components were computed by factors that are the eigenvectors of the correlation matrix of the original data. PCA as the multivariate analytical tool is used to reduce a set of original variables and to extract a small number of latent factors (principal components, PCs) for analyzing relationships among the observed variables. The number of factors extracted from the variables was determined by a scree test according to Kaiser's rule. This criterion retains only factors with eigenvalues that exceed one. Throughout the study the software packages SPSS 12.0 and Excel Statistics 5.0 were used. Our intention was to get as many positive loadings as possible in order to achieve a more meaningful and interpretable solution.

Factor Loading

The contribution of the original variables to the extracted principal component is proportional to the linear combinations of original variables. These contributions are called "Factor Loading". When several variables have large loadings on a principal component, they may be interpreted as being strongly associated with each other and significant in that principal component. On the other hand, a small loading of variables on a principal component indicates that the variable is not associated with the principal component. Principal component analysis and factor analysis have been used for irrigation water quality, which are under the influences of many factors (Table. 4) during the chemical analysis. Three factors were extracted from the irrigation water samples, as shown in Table. 4.

The PCA methods contained in the statistical SPSS program was applied to the chemical concentration data in order to study the geochemistry variables capable of promoting a characterization of the hydrochemistry of the region and to identify the fundamental factors that govern the general behavior of the irrigation water sources.

RESULTS AND DISCUSSION

Recommended limit of As in drinking and irrigation water

The maximum level of arsenic in irrigation water recommended by the Food and Agriculture Organization (FAO) is 0.1 mg/L. The World Health Organization (WHO) recommends that the maximum level of arsenic in drinking water should not exceed 0.01 mg/L (10ppb). The reduction of the World Health Organization (WHO) provisional guideline value for As concentration in drinking water from 50 μgL^{-1} to a provisional $10\mu gL^{-1}$ in 1993 (WHO, 1993), and the reduction in 2002 of the USEPA Maximum Admissible Concentration (MAC) to $10\mu gL^{-1}$, has been made in response to growing concern about this poisonous carcinogen and raised awareness of the dangers of As in drinking water. Some developing countries like Bangladesh still accept the level of 0.05 mg/L in their national standards for drinking water.

Comparison of Physical and chemical properties of three kind of irrigation water

All waters contain varying amount of different constituents of cations and anions. Among them, the main soluble cations are Ca, Mg, Na and K, and anions are Cl, SO_4, CO_3 and HCO_3 (Rahman and Zaman, 1995). Out of the soluble constituents, Ca, Mg, Na, Cl, SO_4, HCO_3 and B are prime importance in judging the water quality for irrigation (Michael, 1978). Some of these ions are beneficial and few ions in excess amounts are more or less detrimental for plant growth and soil properties (Quddus and Zaman, 1996).

The chemical composition and quality classification of irrigation water are presented in Tables 1-3. The pH of water samples varied from 6.71 to 7.84 indicating slightly acidic to slightly alkaline in nature and was within the safe limit for irrigation. The recommended pH limit of irrigation water is 6.0-8.5 (Ayers and Westcot, 1985). The P^H of pond water (6.71 to 7.21) was comparatively lower than that of shallow tube well water (6.97 to 7.36) and deep tube well water (6.78 to 7.84). One pond water, 2 shallow tube well water and 1 deep tube well water sample were slightly acidic in nature and this might be due to the presence of lower amounts of Ca, Mg, Na and HCO_3. Rest 14 water samples were slightly alkaline in nature. EC values of water samples were ranged from 196 to 483 μScm^{-1} indicating low (C_1) and medium (C2) salinity classes after Richards (1968). Regarding EC values, sample no. 1 and 2 are 'excellent' (EC<250 μScm^{-1}) and remaining water samples are 'good' (EC=250-750 μScm^{-1}) in quality (Wilcox, 1955). The amount of total dissolved solids (TDS) ranged from 130 to 359 mgL^{-1}. Water containing TDS less than 1000 mgL^{-1} is considered to be of 'fresh water' category (Raghunath, 1987) and accordingly all water samples were rated as 'fresh water'. Zaman and Majid (1995) also found similar result. The pond water has less mean TDS values (208 mgL^{-1}) than STW water (248 mgL^{-1}) and DTW water (236 mgL^{-1}). Ground water contains higher amount of various ionic constituents than surface water. This finding confirmed the results of Sen *et al*., 2000.

Table 1. P^H, EC, TDS and anionic constituents of surface and ground water of sample site

Sl. No.	Location	Source	P^H	EC μScm^{-1}	TDS mgL^{-1}	NO3 mgL^{-1}	SO4 mgL^{-1}	HCO3 meL^{-1}	Cl meL^{-1}
1	Malihata	Pond/surface water	7.08	196	130	0.16	0.23	0.8	1.0
2	Nandanpur	Pond/surface water	6.71	219	146	0.33	0.40	0.8	1.2
3	Khatihata	Pond/surface water	7.20	276	213	0.12	0.19	1.2	1.4
4	Janghilsar	Pond/surface water	7.21	270	192	0.19	0.10	1.6	2.0
5	Sutiara	Pond/surface water	7.03	483	359	0.30	0.15	2.4	2.2
6	Budhal	STW	7.15	333	236	0.30	0.45	2.0	1.6
7	Betbaria	STW	7.35	375	257	0.29	0.32	2.4	1.6
8	Chhatian	STW	7.03	355	249	0.37	0.19	1.8	2.0
9	Nandanpur	STW	7.10	392	275	0.22	0.26	2.2	1.8
10	Khatihata	STW	6.97	411	290	0.42	0.17	2.2	2.0
11	Sutiara	STW	6.99	323	224	0.16	0.09	2.0	1.6
12	Chandiara	STW	7.36	290	206	0.19	0.12	1.8	1.6
13	Budhal	DTW	7.30	312	221	0.24	0.16	2.0	1.6
14	Chhatian	DTW	7.41	366	261	0.27	0.14	1.8	1.8
15	Malihata	DTW	7.84	270	196	0.27	0.13	1.4	1.6
16	Khatihata	DTW	7.13	333	244	0.20	0.17	1.4	1.4
17	Sutiara	DTW	6.78	364	277	0.23	0.16	1.6	1.4
18	Nandanpur	DTW	7.60	327	218	0.26	0.32	1.0	1.0
Mean				327.50	233.00	0.25	0.21	1.69	1.60
SD				69.11	52.79	0.08	0.10	0.51	0.30
CV%				21.10	22.66	32.00	47.62	30.18	18.75

Legend : DTW-Deep Tube Well, STW- Shallow Tube Well.

Ca and Mg content water samples varied from 0.21 to 0.89 meL^{-1} and 0.17 to 0.92 meL^{-1} respectively (Table 2). Ca and Mg were dominant in ground water than in surface water. K and Na content of water samples ranged from 0.05 to 0.17 and 0.15 to 0.55 meL^{-1} respectively. The concentrations of Ca, Mg, K and Na in water samples were suitable for irrigation (Todd, 1980). Fe, Zn, Mn and Cu contents of water samples were from 0.047 to 2.718, 0.001 to 0.090, 0 to 2.098 and 0 to 0.003 mgL^{-1} respectively (Table 2). Fe, Zn and Cu contents of water samples were found within the safe limit for irrigation where the recommended limits of Fe, Zn and Cu were 5.0, 2.0 and 0.20 mgL^{-1} (Ayers and Westcot, 1985). Mn toxicities were detected in 3 shallow tube well water (sample no. 6, 7 & 8) and 3 deep tube well water (15, 16 & 18) where Mn concentrations were found above the recommended limit (Mn=0.20 mgL^{-1}) after Ayers and Westcot (1985). Presence of high Mn in tube well waters of this area indicating reductive dissolution of oxyhydroxide of Mn as one of the factors of As mobilization, which is in agreement with the findings of Bhattacharjee et al., 2005.

Table 2. Cationic constituents of ground and surface water of Budhol.

Sl. No.	Ca meL^{-1}	Mg meL^{-1}	K meL^{-1}	Na meL^{-1}	Fe mgL^{-1}	Zn mgL^{-1}	Mn mgL^{-1}	Cu mgL^{-1}	P mgL^{-1}	B mgL^{-1}	As mgL^{-1}
1.	0.21	0.17	0.05	0.19	2.032	0.009	0.001	0	0.68	0.004	0.004
2.	0.27	0.22	0.17	0.26	2.718	0.90	0.001	0	0.64	0.002	0.010
3.	0.41	0.22	0.16	0.28	0.047	0.004	0.001	0.001	0.78	0.003	0.009
4.	0.35	0.29	0.08	0.15	0.480	0.021	0.166	0	0.76	0.003	0.004
5.	0.89	0.92	0.09	0.55	0.490	0.023	0.010	0	0.82	0.005	0.094
6.	0.46	0.40	0.05	0.36	0.396	0.071	0.366	0.001	0.60	0.001	0.258
7.	0.77	0.61	0.06	0.41	0.707	0.001	2.098	0	0.82	0.003	0.380
8.	0.56	0.51	0.05	0.44	0.154	0.046	0.439	0	0.68	0	0.180
9.	0.61	0.92	0.07	0.39	0.261	0.037	0.002	0.003	0.70	0.007	0.245
10.	0.71	0.91	0.10	0.29	0.578	0.023	0.003	0	0.60	0.010	0.207
11.	0.45	0.49	0.07	0.24	0.101	0.016	0.001	0	0.66	0.002	0.233
12.	0.35	0.41	0.06	0.18	0.465	0.058	0.002	0	0.74	0.005	0.245
13.	0.49	0.68	0.06	0.25	0.296	0.051	0.007	0	0.80	0.001	0.293
14.	0.56	0.91	0.06	0.33	0.296	0.046	0.001	0.001	0.82	0	0.385
15.	0.28	0.29	0.05	0.16	0.518	0.074	0.415	0	0.76	0.006	0.004
16.	0.57	0.38	0.05	0.26	0.435	0.022	0.521	0	0.78	0.002	0.009
17.	0.71	0.76	0.07	0.33	1.898	0.012	0.060	0	0.74	0.004	0.011
18.	0.62	0.38	0.07	0.20	0.184	0.053	0.761	0	0.72	0.001	0.315
Mean	0.52	0.53	0.08	0.29	0.665	0.037	0.270	0.0003	0.73	0.003	0.160
SD	0.19	0.26	0.04	0.11	0.75	0.026	0.513	0.0008	0.07	0.003	0.142
CV (%)	36.54	49.06	50.00	37.93	112.78	70.27	190.00	266.67	9.59	100.00	88.75

Boron concentration of water samples ranged from 0 to 0.010 mgL⁻¹. According to water quality classification after Wilcox (1955), all water was within the safe limit (B<0.75 mgL⁻¹) and graded as 'excellent' for irrigation. This finding confirmed the result of Zaman and Rahman (1997). P content (0.60 to 0.82 mgL⁻¹) in all water was not problematic for irrigating agricultural crops on all soils, where the maximum recommended concentration of P was 2.0 mgL⁻¹ (Ayers and Westcot, 1985). As content of water samples varied from 0.004 to 0.385 mgL⁻¹. Maximum permissible limit of As in irrigation water is 0.10 mgL⁻¹. Accordingly all shallow tube well water (sl. no. 6-12) and 3 deep tube well water (sl. no. 13, 14 & 18) were unsuitable for irrigation. All pond water (sl. no. 1-5) and rest 3 deep tube well water (15-17) were suitable for irrigation in respect of As concentration.

Table 3   Quality classification of irrigation water in Budhol.

Sample No.	SAR	SSP %	RSC meL⁻¹	H_T mgL⁻¹	Water class based on							Alkalinity and salinity hazard class
					B	TDS	EC	SAR	SSP	RSC	HT	
1.	0.43	30.65	0.42	19.00	Ex.	FW	Ex.	Ex.	Good	Suit.	Soft	C1-S1
2.	0.53	28.26	0.31	24.50	,,	,,	,,	,,	,,	,,	,,	C1-S1
3.	0.50	26.17	0.57	31.51	,,	,,	Good	,,	,,	,,	,,	C2-S1
4.	0.26	17.24	0.96	32.00	,,	,,	,,	,,	Ex.	,,	,,	C2-S1
5.	0.58	22.45	0.59	90.46	,,	,,	,,	,,	Good	,,	MH	C2-S1
6.	0.54	28.35	1.14	42.99	,,	,,	,,	,,	,,	,,	Soft	C2-S1
7.	0.49	22.16	1.02	68.99	,,	,,	,,	,,	,,	,,	,,	C2-S1
8.	0.60	28.21	0.73	53.49	,,	,,	,,	,,	,,	,,	,,	C2-S1
9.	0.45	19.60	0.67	76.43	,,	,,	,,	,,	Ex.	,,	MH	C2-S1
10.	0.32	14.43	0.58	80.94	,,	,,	,,	,,	,,	,,	,,	C2-S1
11.	0.35	19.20	1.06	46.98	,,	,,	,,	,,	,,	,,	Soft	C2-S1
12.	0.29	18.00	1.04	37.98	,,	,,	,,	,,	,,	,,	,,	C2-S1
13.	0.33	16.89	0.83	58.45	,,	,,	,,	,,	,,	,,	,,	C2-S1
14.	0.38	17.74	0.33	73.43	,,	,,	,,	,,	,,	,,	,,	C2-S1
15.	0.30	20.51	0.83	28.49	,,	,,	,,	,,	Good	,,	,,	C2-S1
16.	0.38	20.63	0.45	47.51	,,	,,	,,	,,	,,	,,	,,	C2-S1
17.	0.38	17.65	0.13	73.46	,,	,,	,,	,,	Ex.	,,	,,	C2-S1
18.	0.28	15.75	0	50.01	,,	,,	,,	,,	,,	,,	,,	C2-S1

Legend: Ex= Excellent, FW= Fresh Water, Suit. =Suitable and MH = Moderately Hard
        C1= Low Salinity, C2= Medium Salinity and S1= Low alkalinity

The NO₃ concentration of water samples varied from 0.12 to 0.42 mgL⁻¹ (Table 1). Mean NO3 content is higher in shallow tube well water (0.28 mgL⁻¹) and deep tube well water (0.25 mgL⁻¹) than in pond water (0.22 mgL⁻¹). SO₄ content of water samples ranged from 0.09 to 0.45 mgL⁻¹. SO₄ content in all water were not problematic for irrigating agricultural crops on all soils, where the maximum recommended concentration of SO₄ was 20 mgL⁻¹ (Ayers and Westcot, 1985). HCO₃ and Cl content of water samples ranged from 0.80 to 2.40 and 1.00 to 2.20 meL⁻¹ respectively. HCO₃ and Cl were dominant in ground water as compared to surface water. HCO₃ and Cl content of water samples were within the safe limit for irrigation (Ayers and Westcot, 1985). All the water samples were free from CO3.

The calculated SAR values were within the range of 0.26 to 0.60 (Table 3). All water was classified as 'excellent' (SAR<10) for irrigation based on SAR criteria after Todd (1980). According to SSP values (14.43 to 30.65 %), 9 water samples were 'excellent' (SSP<20%) and rest water samples were classified as 'good' (SSP=20-40 %) in quality (Wilcox, 1955). Out of 18 samples, the RSC values of 17 samples were positive ranging from 0.13 to 1.14 meL⁻¹ and the rest 1 value (sl. no. 18) was neutral (0). The results of RSC indicated that all water samples at Budhol union were free from residual sodium carbonate (RSC) and considered as 'suitable' for irrigation (Ghosh *et al.*, 1983). Rahman and Zaman (1995) also reported similar observation. The hardness (H_T) values of water samples varied from 19.00 to 90.46 (Table 3). Based on hardness (H_T) values, 3 samples (no. 5, 9 & 10) were 'moderately hard' (H_T =75-150 mgL⁻¹) and the rest 15 samples were 'soft' (H_T<75 mgL⁻¹) in quality after Sawyer and McCarty (1967).

Relationship between boring depth of tube wells and arsenic concentration:
Out of 18 water samples, all pond water (1-5) and only 1 deep tube well water (17) were found suitable considering all the criteria. All shallow tube well water (6-12) and 5 deep tube well water were unsuitable for irrigation due to the toxicities of As and Mn. Again, it was found that shallow tube wells of which boring depth ranges between 50 to 100 m, should not use for irrigation purpose, because at this ranges As concentration remain high (Fig. 2). The BGS and DPHE (2001) reported that maximum As concentrations occur at depths between 20 and 50 m whereas samples shallower than 10m and deeper than 150m are basically As free. Striking chemical differences exist between groundwater from the shallow (<35m), presumed Holocene aquifer and from the deep (150-300m), presumed Pleistocene aquifer. Deep waters containing low dissolved As (<50μg/l) (Zheng *et al.,* 2004). The deeper aquifers have been found less contaminated in the alluvial aquifer with respect to As concentration (Tareq *et al.,* 2003). As wells with greater depths contain law As concentration, so deeper wells (boring depth more than 100m) water for irrigation is a good solution, but it should be studied.
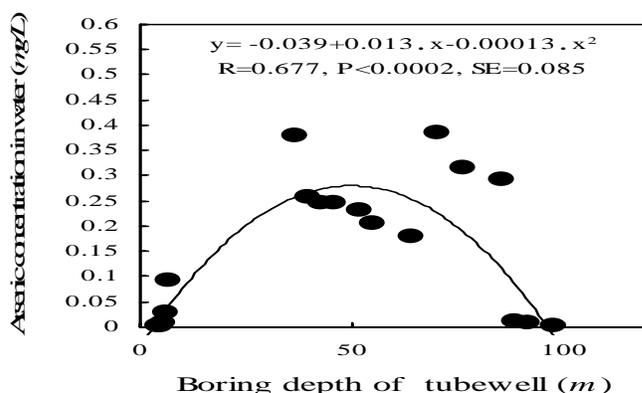

Fig. 2   Relationship between boring depth of tubewell and arsenic concentration in water.

Correlation between the chemical constituents of irrigation water
The matrix of inter-correlations among eleven variables assumed to influence on As contaminated irrigation water of an As affected area and is shown in Table 4. Inspection of the correlation matrix shows that there is a significant correlation between As and Mg (0.48), Ca and Mg (0.78), Ca and Na (0.74). There is also a significant correlation exist between Mg and Na (0.62), K and Zn (0.62), Fe and Zn (0.65). The correlations are substantial, indicating the presence of substantial general factor. Thus, factor analysis may give better results in this case. Distributions of the major cations (Ca, Mg, Na and K) show significant variations with depth as well as region. Considerable variability is noted in the levels of total As, total Fe and Mn in the groundwater samples both as a function of depth and region (Ahmed *et al.,* 2004).

Table 4 Correlation matrixes among the chemical constituents of irrigation water.

Chemical Variables	Chemical Variables										
	As	Ca	Mg	K	Na	Fe	Zn	Mn	Cu	P	B
As	1.00										
Ca	0.38	1.00									
Mg	0.48^*	0.78^{**}	1.00								
K	-0.33	-0.12	-0.18	1.00							
Na	0.25	0.74^{**}	0.62^{**}	0.01	1.00						
Fe	-0.45	-0.28	-0.24	0.35	-0.12	1.00					
Zn	-0.20	-0.35	-0.29	0.62^{**}	-0.09	0.65^{**}	1.00				
Mn	0.35	0.32	-0.07	-0.27	0.18	-0.11	-0.14	1.00			
Cu	0.22	0.07	0.32	0.05	0.27	-0.25	-0.09	-0.18	1.00		
P	0.05	0.27	0.17	-0.13	0.12	-0.25	-0.32	0.26	-0.07	1.00	
B	-0.22	0.15	0.30	0.12	-0.02	0.08	-0.13	-0.18	0.15	-0.19	1.00

*Correlation is significant at the 0.05 level.
**Correlation is significant at the 0.01 level.

Principal component Analysis

Table 5 presented the results of factor analysis. One part of the output from a factor analysis is a matrix of factor loadings. Factor loading is the degree to which every variable correlates with a factor and the basis for imputing a label to different factors. The meanings of the rotated factors are inferred from the variables significantly loaded on their factors. A decision needs to be made regarding what constitutes a significant loading. A rule of thumb frequently used is that the absolute value of a factor loading greater than 0.3 is considered significant, greater than 0.4 is more important and greater than 0.50 is very important (Lawley and Maxwell, 1971). Thus, Varimax rotated factor loadings greater than 0.50 were underlined to assist the interpretation of the meanings of the factors.

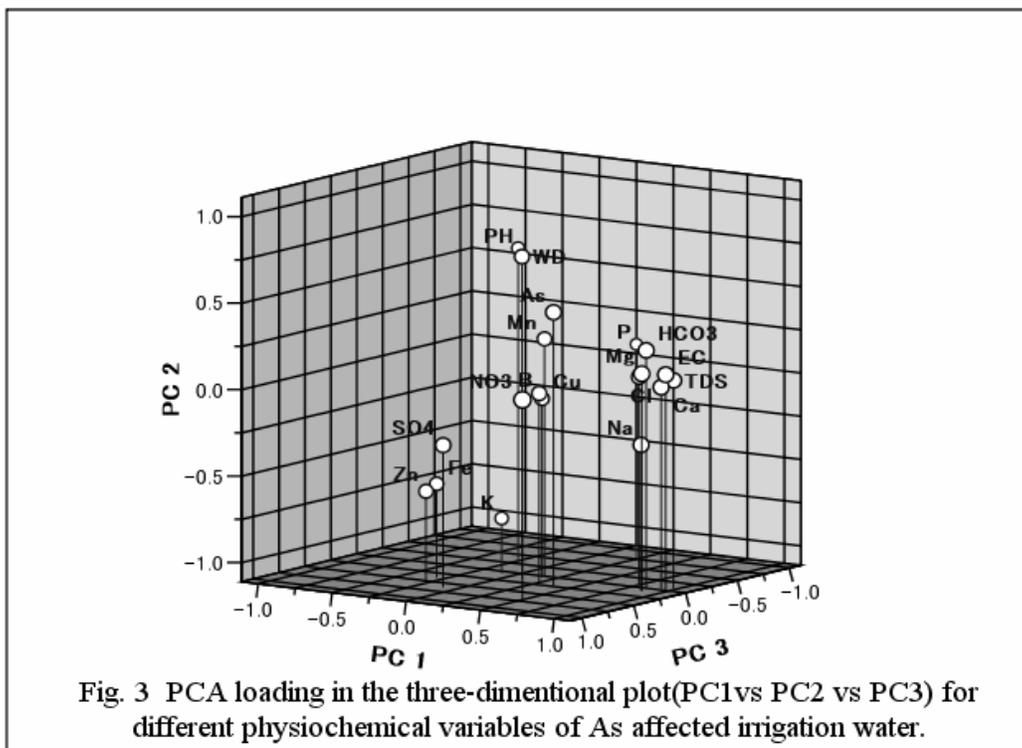Table 5   Factor loading for irrigation water quality

Constituents	Principal components		
	1	2	3
P^H	-0.087	0.795	0.264
EC	0.973	-0.082	-0.003
TDS	0.952	-0.088	-0.112
Ca	0.887	-0.089	0.054
Mg	0.888	-0.144	-0.079
K	-0.246	-0.556	-0.165
Na	0.771	-0.321	0.165
Fe	-0.490	-0.620	0.012
Zn	-0.280	-0.138	0.554
Mn	0.181	0.359	0.551
Cu	0.250	-0.090	0.050
P	0.242	0.620	-0.255
B	0.228	-0.313	-0.411
As	0.503	0.331	0.564
NO_3	0.427	-0.450	0.501
SO_4	-0.167	-0.395	0.795
HCO_3	0.890	0.078	0.004
Cl	0.740	-0.030	-0.240
Eigen value	6.426	2.591	2.256
Integrated Contribution (%)	35.7	50.1	62.64

In order to find possible tendencies in the samples and the discriminated power of the variables, PCA was applied. By using PCA, the n-dimensional data set can be plotted in a smaller number of dimensions, usually 2 or 3. This allows the observation of groupings of cases, which can define the structure of the data set. PCA finds

the maximum variations in the data set and forms new variables known as principal components (PCs). Each successive PC accounts for as much as the remaining variability as possible and each new variable must be totally independent of all other variables (Chatfield and Collins, 1980).

After applying PCA to our data set, three PCs were extracted. The percentage of variance explained by each PC is 35.7, 50.1 and 62.64%, respectively. According to the loadings of the variables in the first PC (Table 5), the most contributing descriptors were EC, TDS, Ca, Mg, As, HCO_3 and Cl. On the other hand, higher correlations between Mg, Ca and As were shown in the correlation matrix (Table 4). Thus Mg and Ca explained, by themselves, the observed variance and could be considered the most discriminated variables.

According to the loadings of the variables in the second PC, the most contributing descriptor was P^H and P. For the third PC, the effective contributing descriptors were Zn, Mn, As, NO_3 and SO_4. On the other hand, no significant correlation was shown between these elements correlation matrix. For arsenic values of factor loading are 0.503, 0.331 and 0.564 with positive sign for PC1, PC2 and PC3 respectively, which indicates that arsenic associated with other components and significant in every principal component (Table 5).

Fig. 3 PCA loading in the three-dimentional plot(PC1vs PC2 vs PC3) for different physiochemical variables of As affected irrigation water.

For representing the scores of the samples in the three-dimensional space defined by the calculated PCs (Fig.3), three main groups of the chemicals were detected. In Fig. 3 the 3-D loading plot (PC1 vs. PC2 vs. PC3) was presented and relationship between the variables is readily seen. The physiochemical variables were found to be distributed in three groups: NO_3, B, Cu, WD, P^H, Mn and As showed one group formed by As, attributed to the discharge of arsenic contaminated irrigation water uplifted from tube wells, second group constituted by P, Mg, HCO_3, EC, TDS, Ca, Na and Cl, might be due to an increase provoked by evaporation in the salinization process and evaporation can also contribute to high As concentrations because As is not incorporated in most evaporate minerals (Welch and Lico, 1998), and the third group constituted by Fe, Zn, K and SO_4 due to mineralization process. The most common arsenic bearing minerals in the fluvial deposits are iron and manganese oxyhyroxides, organic matters and clay minerals (Shimada, 1996; Sullivan and Aller, 1996).

An investigation was undertaken for a arsenic affected study area of Bangladesh to evaluate three types of irrigation water quality. From this study, the following conclusions could be made:

• Degree of arsenic concentration in irrigation water

Shallow Tube Well> Deep Tube Well> Pond/surface water.
- Depth of tube well and arsenic concentration relationship
  High arsenic concentration< 100 meter> Low arsenic concentration.
- Depth range, where arsenic concentration remain high is 50 meter to 100 meter.
- As and Mn toxicity were found among STW and DTW, which might be due to the presence of certain minerals and further study needed in this regards.

Therefore, if local farmer want to irrigate their field, than depth of the tube well must be more than 100 meter. It is apparent that surface (pond) water is free from all toxic substance including arsenic and farmer should use pond/surface water for irrigation. Ground water (mainly shallow tube wells) of Budhol union was contaminated with arsenic. So, it is important to avoid construction of shallow tube wells in this study area and should carefully use for irrigation unless arsenic will enter into soil and food chain through irrigation water.

Finally, the most important contribution of PCA in this study was the identification of physiochemical variation pattern in arsenic contaminated irrigation water. The findings with the help of principal components suggested being of great importance in establishing guidelines for the administration of irrigation water sources and the improvement of irrigation water quality in an arsenic affected area.

From this micro level study, we can predict a pattern in the spatial distribution of arsenic concentration in groundwater of an arsenic affected area of Bangladesh. However, mechanism of As release in groundwater is complex and more investigation is necessary.

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