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Arsenic mitigation: Water quality of dug wells and tubewells

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Arsenic concentration in very shallow and deep aquifers is comparatively lower than shallow aquifers in arsenic contaminated areas. As a result, dug wells and deep tubewells have emerged as two major water supply options for populations exposed to high levels of arsenic through drinking contaminated shallow tubewell water in Bangladesh and West Bengal (India). The concentrations of other impurities of health concern also vary with depth and other characteristics of the aquifer. Hence, shifting from one source to another may be the cause of exposure to health risk of a different nature. This paper presents an assessment of water quality of dug wells (DW) and deep tubewells (DTW) as compared to shallow tubewells (STW) for water supply. The results show that a shift from STW to DW reduces median arsenic ingestion from 151 µg/L (Mean 172µg/L) to 0.74 µg/L(mean 7.92µg/L), while DTW further reduces median arsenic ingestion to 0.41µg/L (mean 1.05µg/L). On the other hand, microbial contamination indicated by median value of Thermotolerant Coliform (TTC) count was found to be 48 cfu/100ml for DW water as compared to 0 cfu/100ml for both STW and DTW waters.

Introduction

Water supply in Bangladesh and West Bengal (India) is primarily based on groundwater sources. Groundwater is generally relatively free from pathogenic microorganisms and available in adequate quantity in shallow aquifers in the Bengal basin for development of low-cost tubewell based water supply for the rural areas. Unfortunately, the success achieved in tubewell based rural water supply has suffered a serious set-back due to presence of arsenic in groundwater in excess of acceptable levels in the shallow aquifers. It has now been estimated that about 30 million people in Bangladesh and about 7 million people in West Bengal are exposed to high levels of arsenic from drinking water (Ahmed, 2003).

While the search to devise appropriate water supply is underway, the Implementation Plan for Arsenic Mitigation in Bangladesh presently promotes some alternative technological options for arsenic-safe water supply, which include improved dug wells, surface water treatment, deep tubewells with handpumps, rainwater harvesting, arsenic removal technologies and piped water supply systems. This is a major shift in respect of selecting a source for drinking water supply and is justified by the presence of elevated levels of arsenic in the shallow tubewell (STW) water and complexities involved in the treatment of arsenic contaminated water. The options should provide water that is arsenic-safe whilst maintaining other potential health risks in the water supply at tolerable levels (Howard, 2003).

In Bangladesh and West Bengal, deep tube wells (DTW) and dug wells (DW) are preferred options for arsenic-safe water supply. In a system of stratified aquifers, a tubewell that collects water from a deeper aquifer leaving one or more water producing aquifers above, is called a deep tubewell. DW is the traditional method of groundwater withdrawal from the top layer of a water table for water supply.

This paper presents an assessment of water quality of these two water supply options as compared to existing STW. It is based on the analysis of water quality of DWs and DTWs implemented in Bangladesh under arsenic mitigation programs. The study provides an understanding of the magnitude of microbial and chemical contamination and the health risk involved in DW and DTW based water supplies.

Methodology

Sampling

The method for selecting sample water points for water quality assessment was derived from that developed for rapid assessment of drinking water quality within the WHO-UNICEF Joint Monitoring Program (Howard et al 2003). The survey methodology uses sampling with clusters that are statistically representative of the water supplies (country-wide or sub-set specific). The number of water points (N) to be sampled was determined using the following equation:

$$N = [4*P(1-P)*D]/ e^2$$

P = assumed proportion of water supplies with a water quality exceeding the target established.
D = design effect (to take into account that clustering can reduce the random component of the survey design).
e2 = acceptable precision expressed as a proportion.

In applying the equations, the sample sizes were determined based on the microbiological quality of water, as this is the most likely parameter to show contamination and would be the principal hazard that would substitute for arsenic. Overall, this would provide the greatest health risk. The number of water points was found to be 72 for a design effect of 2, a precision of 0.1 and for values of P equal to 0.9 for DW and 0.1 for DTW. The samples were selected from 12 clusters all over the country. The sampling interval is determined for each technology type by dividing the cumulated total of supplies for that technology (given in the proportional weighting tables) by the number of clusters for that technology. The random numbers were obtained by drawing numbers (digit by digit) from numbers written on paper.

Water quality analysis

The two water quality parameters considered most important for health risk are arsenic and microbial quality. Water quality parameters were measured in the field by field test kits and in the laboratory by standard analytical methods. Thermotolerant coliforms (TTC) in water were measured as an indicator microorganism to represent the bacteriological quality of water. Some 20-30 percent of selected sub-samples were tested for E. coli and some 24 samples were tested for coliphage as a surrogate for viruses. Additional 12 physical and chemical water quality parameters, considered important for DTW and DW water were also analyzed in the field and laboratory. Analysis of all water quality parameters was also undertaken for 24 STW (2 STW from each cluster). Proper quality assurance and control was adopted in the laboratory analysis of all water quality parameters. Sanitary inspection was also conducted at each site. The water quality parameters were assessed by technology type in relation to both Bangladesh Water Quality Standards (ECR, 1997) and WHO Guidelines for Drinking-water Quality (WHO 1993).

Results and discussion

The range, mean and median values of all physical, chemical and microbial parameters analyzed for assessment of water quality are presented in Table 1. It may be observed that the median and mean values differ widely in cases of almost all water quality parameters indicating an unequal distribution of frequency of variations within the ranges of maximum and minimum values. In case of bacteriological quality, the mean values of TTC of DW, STW and DTW water samples were 163, 23 and 1.13 cfu/100mL respectively. It indicates that microbial contamination decreases with the increase in the depth of wells.

The mean values of arsenic for STW, DW and DTW waters were 172, 7.92 and 1.05 respectively. The results also support that water in the shallow aquifers are more contaminated with arsenic, while groundwater in both the very shallow and deep aquifers is less contaminated. The percentages of samples of DW, DTW and STW water that exceeded the Bangladesh Standards (BDS) and WHO Guideline values (WHO GVs) for the major water quality parameters are presented in Table 2.

Physical parameters

The temperature of water at the water points ranged between 17°C to 25°C. Although the mean and median values of turbidity were well within the acceptable value of 10 NTU, 28% of DW water and 4% of STW water exceeded the acceptable value. Water samples from all sources often failed to meet BDS and WHO GV for colour. The total dissolved solids (TDS) of some samples of DW, STW and DTW ex-

Table 1 : The Maximum, Median, Mean and Minimum Values of the Water Quality Parameters Tested for Water Quality Assessment

Water Quality Parameters		Dug Well (DW)			Deep Tubewell (DTW)			Shallow Tubewell (STW)		
		Range	Median	Mean	Range	Median	Mean	Range	Median	Mean
Microbial	TTC (cfu/100 ml)	0-TNTC	48	163	0-27	0	1.13	0.0-438	0	23
	E-coli (cfu/100 ml)	0-600	0	138	0-2	0	0.17	-	-	-
	Coliphage	0 -0	0	0	0-0	0	0	-	-	-
Physical	TDS (mg/L)	373-2293	900	968	153-9167	317	615	340-2027	563	707
	Turbidity (NTU)	0.22-52	3.05	8.39	0.19-3.01	0.52	0.75	0.21-11.10	1.56	3.14
	Colour, TCU	0-107	11	21	0-163	22	36	0-55	35	30
Chemical	pH	6.9-8.2	7.1	7.14	6.6-8.1	7.1	7.21	6.6-7.6	7.2	7.2
	Nitrate-N (mg/L)	<1.0-15	1.22	5.4	<1.0-0.5	0.52	0.83	0-1.20	0.50	0.58
	Ammonia (mg/L)	<1.10	0.466	1.16	<1.0-8	0.52	0.83	0.18-12.35	3.53	4.39
	Phosphate (mg/L)	0.06-5.0	0.48	0.74	0.15-1.47	0.73	0.72	0.10-13.30	2.03	3.67
	Silica (mg/L)	13.1-48.3	21.1	25.56	20.3-63.9	47.9	44	14.0-51.6	27.1	29.1
	Iron (mg/L)	0-2.7	0.46	0.68	0.05-21.7	1.12	1.66	0.24-15.40	3.83	4.96
	Manganese (mg/L)	0.02-1.41	0.17	0.35	0.01-0.53	0.03	0.074	0.02-2.15	0.25	0.49
	Arsenic (ppb)	0.0 - 108	0.74	7.92	0.0-9.0	0.41	1.05	0.0-824	151	172
	Chromium (mg/L)	0.0-0.01	0.01	0.01	-	-	-	-	-	-
	Boron (mg/L)	-	-	-	0.0-0.2	0.1	0.1	-	-	-

#TNTC- Too numerous to count

Table 2 : Dug Well Water Exceeding BDS and WHOGV

Parameters	% Dug Wells Exceeding		% Deep TWs Exceeding		% Shallow TWs Exceeding	
	WHO GV	BDS	WHO GV	BDS	WHO GV	BDS
Arsenic	25	3	0	0	87	87
FC/TTC	94	94	8	8	29	29
Iron	61	22	83	58	92	87
Manganese	75	75	19	19	100	79
Ammonia-N	11	50	6	53	67	79
Nitrate-N	4	4	0	0	0	0
Turbidity	39	28	0	0	17	4
Color	44	44	56	56	69	69
TDS	28	28	3	3	17	17

ceeded the acceptable level. The physical quality of water has no known direct effect on health but is important from an aesthetic point of view.

Chemical parameters

The arsenic contents of DW, STW and DTW were compared in Table 2. It may be observed that percentages of DW water exceeded BDS and WHO GV for arsenic were 3 and 25 respectively. Arsenic content of DW water is much lower than that of STW but higher than the arsenic content of DTW. Arsenic content of all samples of DTW was below WHO GV of 10 µg/L. In previous works, arsenic contamination exceeding the BDS of 50 µg/L was reported in 1% of DTWs all over Bangladesh by BGS and DPHE (2001) and in 10% of DTWs in Sharsha Upazila (sub-district) by JICA/AAN (2004a).

The distributions of arsenic contamination of DW water are presented in Figure 1. Arsenic contamination of DW water found in this study was relatively low and compares well with the contamination level reported by DASCOH (2003) and DCH (2004), but was lower than that found by JICA/AAN (2004b) and NIPSOM (2003). This study along with other studies conducted on arsenic contamination of DW confirms that DW water, previously believed to be arsenic-free, may contain exceeding BDS and WHO GV for arsenic in some cases.

The pH value of all DW, STW and DTW water remained within the BDS. The median value was 7.1, which is very close to neutral water. The water quality analysis showed that the concentrations of NO3-N-- in about 96% of the DW water and 100% of DTW and STW waters were within BDS of 10 mg/l for nitrate-N. The main sources of nitrate in shallow aquifers are leachate from agricultural land and decomposing organic matter buried in soil or from pit latrines. Ammonia in more than 50% of DW, STW and DTW water samples exceeded the BDS for ammonia-N. The presence of ammonia indicates the presence of decomposing organic matter, ammonia is converted to nitrate on oxidation.

The concentrations of iron and manganese in DW, DTW and STW were in excess of acceptable levels in most of

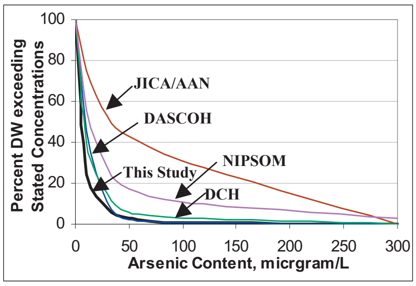

Figure 1. Arsenic contamination of DW water

the samples. Iron has no known major effect on health, but adversely affects aesthetic quality and other domestic uses of water. The concentrations phosphate in both DW and DTW waters were within BDS acceptable limit of 6 mg/L in drinking water but the phosphate content of 8% of STW water marginally exceeded BDS for phosphate. Analysis for chromium in selected DW water and boron in DTW water in the coastal area showed that concentrations were within the BDS acceptable limits of 0.05 mg/L for chromium and 1 mg/L for boron.

Microbiological quality

The presence of TTC was found in 94% of the DW water, with 10% samples exceeding 500 cfu/100mL. The possible reason for very high TTC count for some DW water samples as identified from social survey data was that the water was raised from those DWs either by rope pumps or by rope and bucket. These methods are more prone to contamination by users. The bacteriological quality of DW water found in this study is compared with the level of contamination reported by other organizations and presented in Figure 2. It may be observed that the all the studies reported the presence of high level of bacterial contamination of DW water and most studies found only about 5-25 percent DW water free from microbial contamination.

In case of tubewells, microbial contamination was found in about 8% of the DTWs and 29% of STWs. The possible reasons for contamination of TWs as indicated in the social survey data could be poor sanitary condition at the tubewell site and use of contaminated water for priming of the tubewell pump.

E. coli was detected in DWs having high TTC counts, the

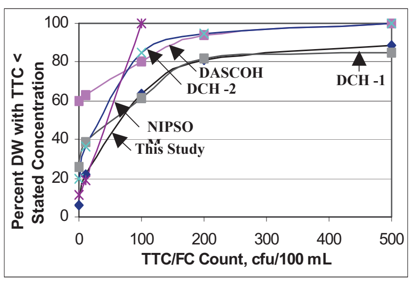

Figure 2. Microbial contamiation found in DW water

ratio of mean E-coli to mean TTC was calculated as 0.84. Analysis of some samples was carried out for coliphage as an index of potential viral breakthrough but no coliphage was detected. This is likely to reflect rapid adsorption of coliphage on intermediate clay minerals with charged sites.

Conclusions

Microbial contamination was detected in few deep and shallow tubewells but most (94%) of the dug wells showed low to very high TTC counts. About 84% of TTC were confirmed as E. coli in DW water but no coliphage was found. Contamination in few shallow and deep tubewells probably resulted from use of contaminated water for priming of the tubewell pump, while contamination of dug wells could be attributed to poor sanitary conditions, unhygienic practices and ingress of contaminated surface water.

DW water is not completely free from arsenic contamination but the level of contamination found was very low, with few DWs exceeding the BDS and WHO GV. A shift from STW to DW for water supply can greatly reduce arsenic ingestion but expose people to higher levels of microbial contamination. DTW based water supply can reduce ingestion of both arsenic and pathogen. People's participation in maintaining improved hygienic conditions, sanitary protection and disinfection of dug well water are requirements for development of dug well based safe water supply in arsenic affected areas.

Iron, manganese, colour, TDS and ammonia were found in many samples of DW, STW and DTW water in concentrations exceeding BDS and WHO GV. These parameters are important for aesthetic reason but have low or no health significance.

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