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Comparative assessment of four alternative water supply options in arsenic affected areas of Bangladesh

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Abstract

Arsenic contamination in groundwater and its toxic effect on human health is a major public health problem in Bangladesh and it is emphasized in the national level to use alternative water sources for drinking water to mitigate the arsenic problem. To identify reasons of non-functioning and in order to develop a comparative information and better understanding of the options, assessment of alternative water supply options in both technical and social aspects are essential. The study was conducted on 11 Dug wells (DW) of Charghat, Dohar and Gazaria, 9 Deep hand tubewells (DTW) of Dohar and Gournadi, 17 Rain water harvesting systems (RWHS) of Charghat, Gournadi, Pathorghata and Ghior and 6 Pond sand filters (PSF) of Pathorghata and Gournadi. Microbial contamination were found in 95 percent water samples of DW, 7 percent of DTW, 43 percent of RWHS and 77 percent of PSF. None of DW water sampled in this study had an arsenic concentration higher than the Bangladesh drinking water standard (BDS) of 50 µg/L but arsenic concentrations exceeding the WHO guideline value (WHOGV) of 10 µg/L were found in 35 percent of DW water samples. Arsenic concentrations in DTW, RWHS and PSF water samples were found within BDS and WHOGV. Both iron and manganese were present in DW water of Dohar and Gazaria in excess of BDS. Manganese was present in DTW water of Dohar in excess of BDS. The concentrations of nitrate in DW, DTW, PSF and RWHS water samples were within BDS. Water quality of DWs of Charghat in all respects was found better than DWs of Dohar and Gazaria. Users' satisfaction and social acceptability of the DW, DTW, PSF and RWHS were found area specific depending on the quality and availability of water.

Keywords: Arsenic, Alternative water supply options, Dug wells, Deep hand tubewells, Pond sand filters, Rain water harvesting systems

1. Introduction

Arsenic contamination in groundwater and its toxic effect on human health is a major public health problem in Bangladesh (Ahmed, 2002; BGS-DPHE, 2001). Water supply in Bangladesh is primarily based on groundwater sources. The country achieved a remarkable success by providing 97% of the population with access to improved water supply. However, this success is being overshadowed by the presence of arsenic in excess of acceptable levels in the shallow aquifers. Ground water based water supply programs that provide safe drinking water in order to control diseases like diarrhea, dysentery, typhoid, cholera and hepatitis have exposed population to arsenic related health problems. It has been estimated that about 29 million people in Bangladesh are exposed to drinking water with arsenic exceeding Bangladesh standards of 50 µg/L and 49 million people exceeding provisional WHO guideline value of 10 µg/L (GOB, 2002). Thus arsenic contamination has reduced the estimated national population coverage with safe water supply from 97 to 74% (Ahmed, 2002). Blanket screening of shallow tubewells in 270 arsenic affected Upazilas has shown that 29% (or about 1.5 million tubewells) of about 5 million tubewells tested had arsenic concentrations exceeding the Bangladesh standards of 50 µg/L (BAMWASP, 2004). There are 8,540 villages in Bangladesh where more than 80% tubewells used as only source of drinking water are contaminated with arsenic. Total of 38,430 cases of arsenicosis have been identified under national screening program.

In the absence of an alternative source, people in acute arsenic problem areas are drinking arsenic contaminated water without paying much attention to possible consequences. On the other hand, people with arsenic phobia are likely to use unprotected surface water to avoid arsenic poisoning and get sick by water borne/related diseases. Arsenic toxicity has no known effective treatment, but drinking of arsenic free water can help the arsenic affected people to get rid of the symptoms of arsenic toxicity. Hence, provision of arsenic free water is urgently needed to mitigate arsenic toxicity and protect health and well being of rural people living in acute arsenic problem areas of Bangladesh. The options available for water supply in the arsenic affected areas can be brought into two major categories: alternative arsenic-safe water source and treatment of arsenic contaminated water. Groundwater from deep aquifers and dug wells, surface water and rainwater can be potential sources of water supply to avoid arsenic ingestion through shallow tubewell water.

Dug wells (DW), pond sand filters (PSF), rain water harvesting systems (RWHS) and deep hand tube wells (DTW) have been installed by BAMWSP, JICA/AAN, Danida, Unicef and some other organizations as alternative arsenic-safe water source in some selected arsenic affected areas (APSU, 2005). In some areas alternative water supply options are working well but not functioning properly in some other areas. To identify reasons of non-functioning and in order to develop a comparative information and better understanding of the options, assessment of alternative water supply options in both technical and social aspects are essential. The major objectives of this study were:

(i) To assess water quality and sanitary integrity of dug wells, deep hand tubewells, rainwater harvesting systems and pond sand filters in different hydro-geological conditions.
(ii) To investigate the functionality and social acceptability of dug wells, deep hand tubewells, rainwater harvesting systems and pond sand filters in selected arsenic affected areas.

2. Methodology

2.1 Selection of study area

The study areas were selected on the basis of presence alternative options (DW, DTW, PSF, and RWHS) in arsenic affected areas. At least two sites were selected for each of the above-mentioned options in different hydro-geological conditions and different types of communities. Charghat of Rajshahi and Gazaria of Munshiganj were selected for DW initially but all the visited DWs in Gazaria were found in abandoned conditions, for this reason Dohar of Dhaka were selected later for DW study. Dohar of Dhaka and Gournadi of Barishal were selected for DTW study. Gournadi of Barishal and Pathorghata of Barguna were selected for PSF study. Charghat of Rajshahi, Gournadi of Barishal, Pathorghata of Barguna and Ghior of Manikganj were selected for RWHS study. Numbers of water points in each site were selected on the basis of availability alternative options in suitable location. Figure 1 shows the locations of study area with the name of alternative options.

2.2 Selection of water quality parameters

The two important water quality parameters arsenic and bacteriological quality were selected from health risk point of view. Fecal coliforms (FC) were analyzed to represent bacteriological quality of water, as they are the most commonly used indicator bacteria. Other physical and chemical water quality parameters (Turbidity, colour, pH, iron, manganese, nitrate, lead, zinc) that considered important for DTW and DW, RWHS and PSF water were also analysed.

2.3 Collection and analysis of water samples

Samples for bacteriological analysis were collected in sterile bags and transported in ice-box. Fecal coliforms (FC) were analyzed in BUET laboratory by membrane filtration method. Samples for analysis of turbidity, Colour and Nitrate were collected in 500 ml plastic bottles. Turbidity of samples were measured by DR Lange Turbidimeter. Colour, Nitrate, Manganese of samples were determined by Hach DR/4000 UV-Visible Spectrophotometer. Samples for analysis of Arsenic, Iron, Manganese, Lead, and Zinc were collected in the acidified 250ml plastic bottles. Iron of samples was determined by Nesler tube methods respectively. Arsenic, Lead and Zinc were determined by graphite furnace atomic absorption method by AA-6800 Atomic Absorption Spectrometer of SHIMADZU. pH of water samples were measured with pH meter at the field.Water samples have been analyzed in the Environmental Engineering Laboratory of Bangladesh University of Engineering and Technology following standard methods (APHA, 1998). HACH DR4000U UV-VIS Spectrophotometer has been used for analysis of NO_3-N and PO_4. Hanna pocket pH meter, calibrated with pH standards 4.0 and 7.0, has been used for pH measurements. NO_3 and P contents in soil and plant samples have been analyzed at BRRI following methods given by Huq and Alam (2005).

2.4 Sanitary inspection

Sanitary inspection uses observation to assess the sanitary integrity and potential hazards in the environment that may affect water quality, particularly microbiological quality. Its use is well documented in the literature (WHO, 1997; Howard, 2002a; WHO, 2004). It is generally used in conjunction with microbial analysis to understand the potential causes of contamination when it occurs, to assess the potential for contamination in the future and to develop control measures to microbial water quality. Sanitary inspection forms were prepared in the light of WHO Guidelines for Drinking-Water Quality Volume 3 (WHO, 1997) and adapted for DWs (with and without hand pumps), DTWs, PSFs and RWHSs for use in the study.

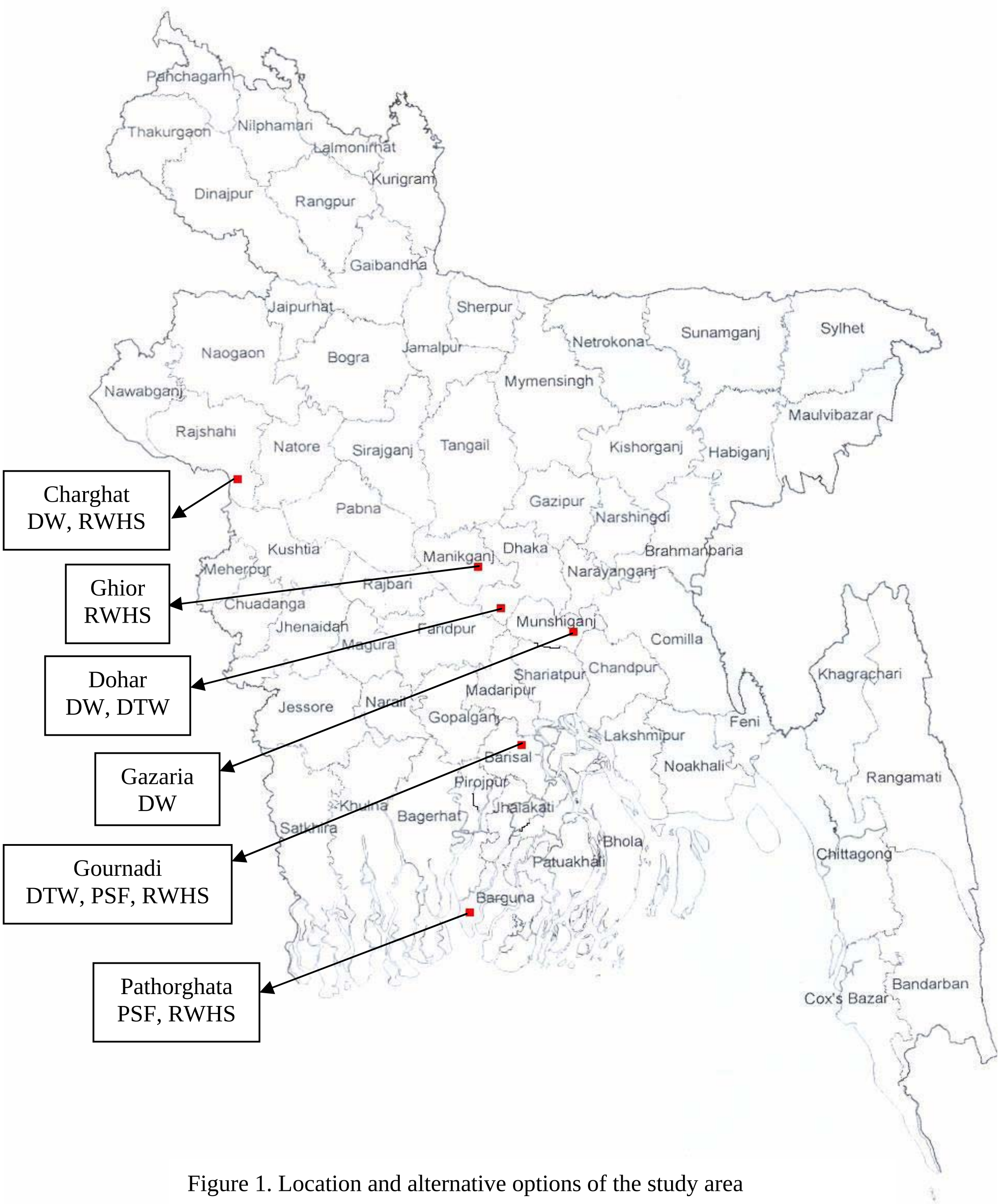

Figure 1. Location and alternative options of the study area

2.4 Social assessment

The questionnaires were designed to elicit answers on the key questions like awareness about arsenic, water use pattern, users' attitude towards mitigation options, acceptability/non-acceptability of the option by the users (with reason), users' comment on water quality, operation and maintenance etc. The DW, DTW and PSF are community facilities serving a number of households while RWHS is primarily a household option. Therefore, separate questionnaires for community and household units were developed.

The questionnaire survey was administered to a 10% sample of households using the mitigation options provided to communities. Assuming an average of 50 households using one DW, DTW and PSF, 5 households per mitigation option were interviewed. The first household for interview was selected at random; the subsequent households were picked at an interval of 10 households in a systematic order. Since RWHS is a household option, all households having an operational RWHS among the selected samples were interviewed.

Adult women respondents were selected by preference as the principal household water manager, but men and child over the age of 15 were also accepted. Should no adult or child over 15 be available in a selected household or be unwilling to respond the next household was picked. Women as respondent were given preference and more than 50% of the respondents were women.

3. Results and discussions

3.1 Water quality of alternative water supply options

3.1.1 Microbiological quality

Distribution of FC concentrations among alternative options is shown in Fig. 2. Microbial contamination of DW water was very common, as high as 95% water samples of DWs were found contaminated with fecal coliforms. Low levels of microbial contamination were found in 7% of DTWs (i.e. only one sample of DTW of Gournadi). Poor sanitary conditions and priming of the wells with contaminated surface waters are the likely causes of microbial contamination of DTWs.

Microbial contamination of PSF water was high. About 77% PSFs water samples were found contaminated in both the seasons with higher level of FC in the wet season compared to dry season. High level of contamination of pond water, inadequate filter depth and poor maintenance of PSF are the main reasons for high microbial contamination of PSF water

43% water samples of RWHS were found contaminated with fecal coliforms. Contamination was generally lower than PSF and DW but higher than DTW. Contamination appears to occur from contaminated roof top catchment, in-sanitary surroundings and poor handling of water in RWHS practiced in Bangladesh.

3.1.2 Chemical quality

Distribution of arsenic concentration among alternative options is shown in Fig. 3. None of DWs sampled in this study had an arsenic concentration higher than the BDS of 50 μg/L but 35% of DWs samples exceeding the WHOGV of 10 μg/L. None of DTWs sampled in this study had an arsenic concentration higher than the BDS and WHOGV. Arsenic was found at very low levels in both PSF and RWHS waters. Arsenic in most samples from RWHS and PSF were found below detection level (< 1μg/L).

Distribution of iron concentration among alternative options is shown in Fig. 4. 15% of DWs samples exceeding the BDS of 1 mg/L (GoB, 1997) but none of the samples of DTW, PSF and RWHS exceeding the BDS.

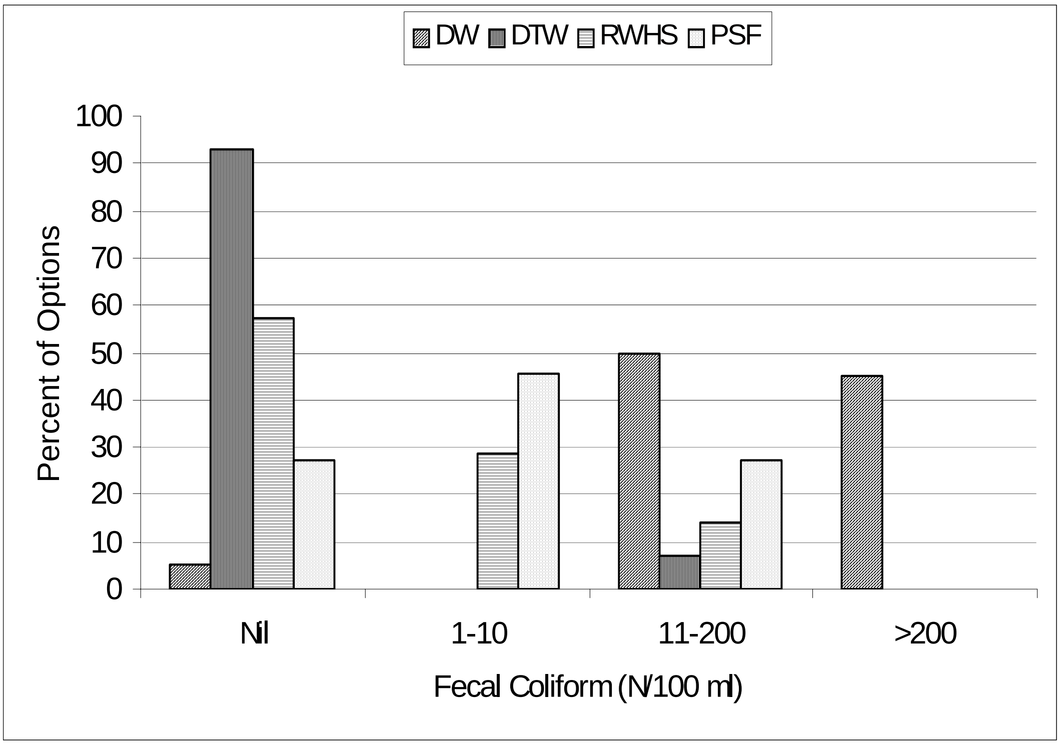

Figure 2. Distribution of FC concentrations in DW, DTW, RWHS and PSF

The concentrations of nitrate in DW (0.5 to 3.8 mg/L), DTW (0.3 to 2.8 mg/L), PSF (1.4 to 2.7 mg/L) and RWHS (1.5 to 1.6 mg/L) waters were within BDS.

Distribution of pH value among alternative options is shown in Table 1. High pH values were observed in most of the water samples collected from RWHS. High pH values were also observed in most of the water samples collected from newly build PSFs. 85.71% of RWHSs samples and 45.45% of PSFs samples exceeding the BDS of 8.5. The possible reason of such high pH value is leaching of calcium oxide from cement used for the construction of rainwater storage tank. The pH levels of water from DW and DTW were close to neutral.

The presence of zinc and lead was considered to be important in RWHS from the metallic roofs used as catchment for rainwater harvesting. The concentrations of these two heavy metals in water from RWHS were within acceptable levels for drinking water.

3.1.2 Physical quality

Distribution of turbidity among alternative options is shown in Table 2. DTW, RWHS and PSF water was found clear with turbidity well within acceptable levels of BDS (10 NTU) while 40 percent of DW water exceeded. Distribution of colour among alternative options is shown in Table 2. 35% of DW water samples, 43% of RWHS samples and

45% of PSF samples exceeded the BDS of 15 pt-co unit for colour. None of the samples of DTW exceeded BDS.

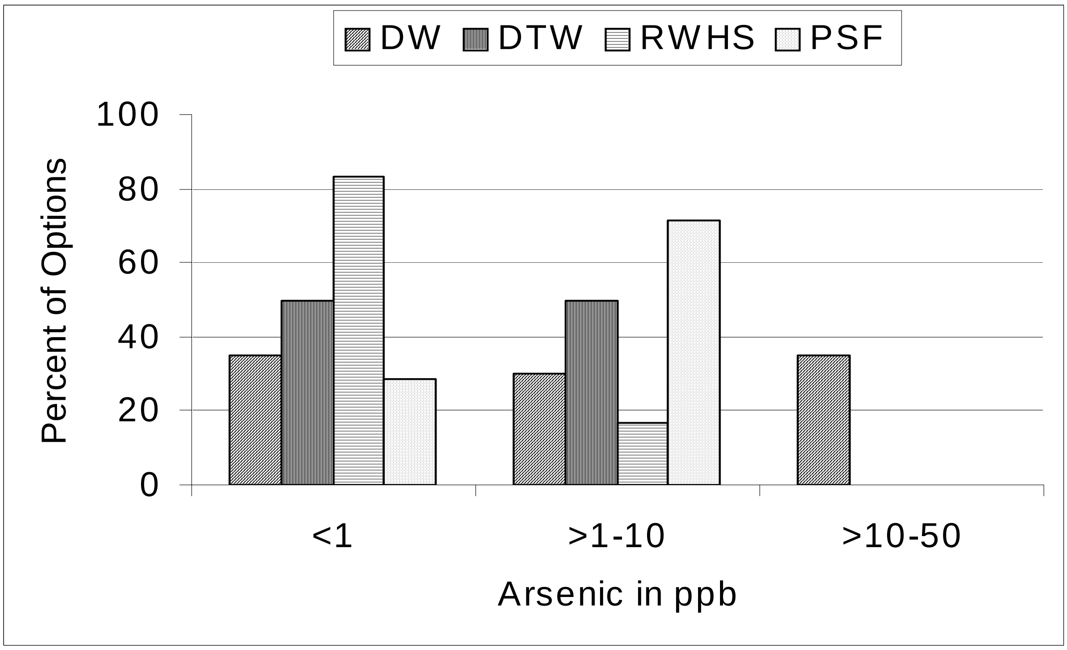

Figure 3. Distribution of arsenic concentration in DW, DTW, RWHS and PSF

Distribution of Manganese concentrations among alternative options is shown in Table 1. 85% of DWs samples and 71.43% of DTWs samples exceeding the BDS of 0.1 mg/L.

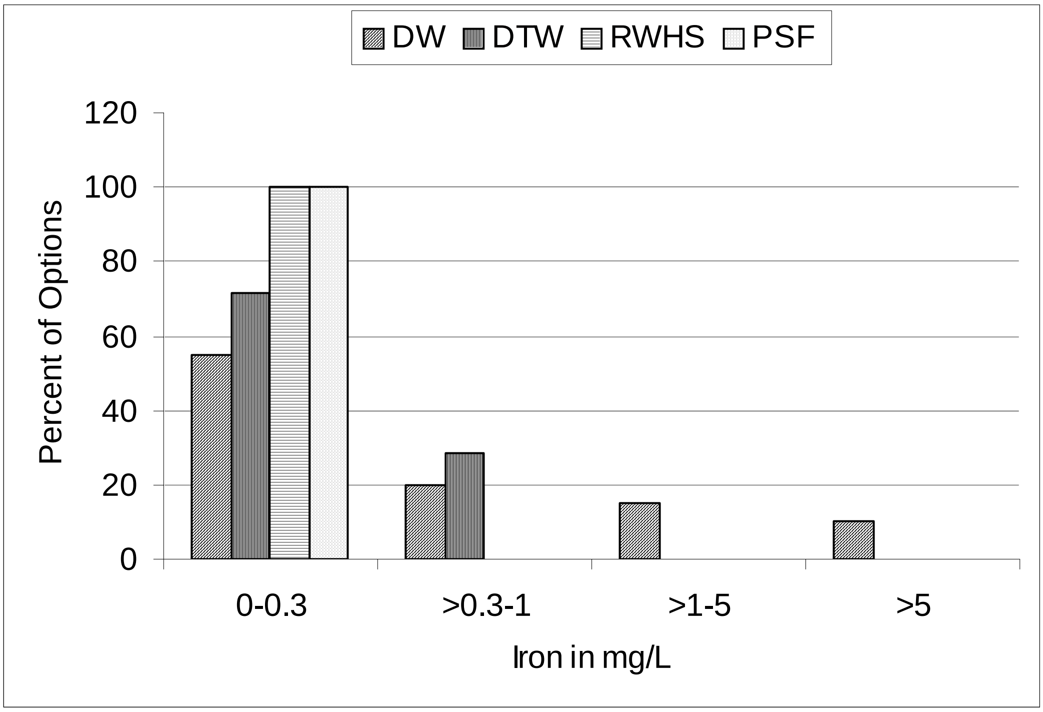

Figure 4. Distribution of iron concentration in DW, DTW, RWHS and PSF

Manganese concentrations in water samples of both DWs and DTWs of Dohar were found higher than other area of study.

Table 1
Distribution of pH and Mn concentration in DW, DTW, RWHS and PSF

Options		pH		Manganese (mg/L)			
	Range	6.5-8.5	>8.5	0-0.1	>0.1-0.5	>0.5-1	>1
DW	Count	20	0	3	7	3	7
	Percent	100	0	15	35	15	35
DTW	Count	14	0	4	8	2	0
	Percent	100	0	28.57	57.14	14.29	0
RWHS	Count	3	18	-	-	-	-
	Percent	14.29	85.71	-	-	-	-
PSF	Count	6	5	-	-	-	-
	Percent	54.55	45.45	-	-	-	-

Table 2
Distribution of turbidity and colour in DW, DTW, RWHS and PSF

Options		Turbidity (NTU)			Colour(pt-co unit)		
	Range	0-5	>5-10	>10	0-5	>5-15	>15
DW	Count	10	2	8	4	9	7
	Percent	50	10	40	20	45	35
DTW	Count	10	4	0	4	10	0
	Percent	71.43	28.57	0	28.57	71.43	0
RWHS	Count	20	1	0	3	9	9
	Percent	95.24	4.76	0	14.28	42.86	42.86
PSF	Count	9	2	0	0	6	5
	Percent	81.82	18.18	0	0	54.54	45.45

The physical quality of water from both PSF and RWHS measured by turbidity and total dissolved solid content was found to be within acceptable limit. The water from RWHS was of much superior quality in respect of physical quality as compared to DW and PSF waters. Water quality of DWs of Charghat in all respects was found better than DWs of Dohar and Gazaria.

3.2 Sanitary Integrity

Sanitary inspection uses observation to assess the sanitary integrity and potential hazards in the environment that may affect water quality, particularly microbiological quality. Sanitary inspection provides an assessment of the existing sanitary conditions of the water point and quantifies the risk on a scale of 0 (no risk) to 10 (very high risk). The distribution of sanitary risk scores for dug wells, deep tube wells, rain water harvesting systems and pond sand filters shown in Table 3 indicate that overall sanitary conditions of DWs and PSFs are very poor than that of other options. The water points with higher sanitary risk scores are likely to show high microbial counts, although this would usually be seen in the monsoon season. The data suggest that sanitary risk factors can be controlled through compliance with construction protocols, improved training of communities, raising awareness within the community, behavioral changes within the community and ensuring community participation in planning and implementation.

Table 3
Distribution of SI scores for DW, DTW, RWH and PSF

Risk Score	Risk Category	% DW n = 11	%DTW n = 9	%RWH n = 17	%PSF n = 8
0	No Risk	0	11.11	11.77	0
1-3	Low Risk	63.64	77.78	82.35	62.5
4-6	Intermediate to high Risk	27.27	11.11	5.88	37.5
7-10	Very high Risk	9.09	0	0	0

For DWs it is also likely that control of microbial water quality requires disinfection, as discussed by DASCOH (2004). The much better microbial quality of the DTWs despite a similar level of sanitary risk indicates that this technology is more robust with regard to microbial contamination. And microbial contamination should be very limited provided construction of well head is properly done. This is a finding that is supported from studies in other countries, for instance in Uganda boreholes with handpumps were found to be of good quality in most areas despite obvious risks (Howard, 2002b).

The reduction in sanitary risks and maintenance of water quality require action by the water supply operators. This is most critical for DWs and PSF where even slight deterioration in operation and maintenance performance leads to increasing contamination. The high number of sanitary risks and poor microbial quality suggests that agencies providing DWs and PSF need to do more to support communities in maintaining their DWs and PSFs, if these are to provide safe water in the long-term.

3.3 Functionality of alternative water supply options

All of the visited DTWs and PSFs were functioning properly in this study but from previous studies it was found that some PSFs were abandoned or not functioning properly due to lack of maintenance. Out of 25 surveyed RWHS only 2 in Charghat and 1 in Ghior were found temporarily non-functioning due to lack of maintenance. Gutter pipe and collection tap were found in broken condition.

In Charghat upazilla of Rajshahi out of 5 dug wells surveyed 4 dug wells were functioning properly and only 1 dug well was found in abandoned conditions due to lack of water for insufficient depth. This dug well could not be constructed properly for sand boiling. In Dohar upazilla of Dhaka out of 11 dug wells surveyed only 5 were found functioning with poor performance in 2004 but only 3 were found functioning with poor performance in 2005. It is to be mentioned that dug wells of Dohar were constructed from 2002 to 2004 by BAMWSP. In Gazaria Upazilla of Munshiganj 100% of dug wells were found in abandoned conditions that were installed in 2002 by BAMWSP.

Poor construction, operation and maintenance, bad odor and taste of water, excessive iron and manganese in water and availability of other source of water like deep tube well are identified as the reasons of non-functioning/ abandonment of dug wells in Dohar and Gazaria.

3.4 Users' perception and attitude towards alternative water supply options

- The users' perception and attitude about the DW, DTW, PSF and RWHS as permanent solution to the arsenic problem were found area specific depending on the quality and availability of water.

- About 90% of the users of Charghat considered DW as a permanent solution to arsenic problem. But reverse situation was observed in Dohar and Gazaria, Users of Dohar and Gazaria did not like DWs and very much annoyed about installed DWs by BAMWSP. All of the visited DWs of Gazaria were found in abandoned conditions. Some users of DWs of Dohar were using DW water after installation but gradually they were shifted to DTW lefting DW in abandoned conditions. They considered DTW as a permanent solution to arsenic problem instead of DW. Water quality of DWs of Charghat in all respects was found better than DWs of Dohar and Gazaria.

- Almost all of the users of Pathorghata considered PSF as a permanent solution to their drinking water problem. They also used rainwater in rainy season. DTW were not success in these areas due to high salinity in ground water. Ground water in deep aquifer is also highly contaminated with saline water.

- The users of RWHS have reported that the rainwater at the initial stage was tasteless like tannin, bitter, etc. But after using a few months they gradually changed their habit and found taste of rainwater like tubewell water. About 70% of the respondents drink rainwater regularly and the rest 30% drink rainwater and arsenic free tubewell water. It has been also reported that the food cooked by rainwater is very testy. Moreover, when rice is cooked by rainwater it becomes fresh and white. Most of the respondents reported that the preserved rainwater is insufficient. It does not cover the demand for whole year. Usually, it covers 8-10 months where the family size is small.

- The respondents provided with a DW, DTW, PSF and RWHS were generally satisfied with the quality of the water but greater satisfaction was expressed in favour of DTW, RWHS and PSF waters as compared to DW water. There was little difference across the income groups regarding their satisfaction with arsenic mitigation options with respect to quality of water.

4. Conclusion

The following conclusions are drawn on the basis of results obtained from the technical and social assessment of alternative water supply options in arsenic affected areas.

- Suitability of alternative water supply options is area specific.
- Social acceptability of alternative water supply options depends on water quality, water availability throughout the year, costs of installation, ease of operation and maintenance.
- Caretakers' training and community participation is essential for sustainability of the water supply options.

For instance, dug wells are functioning properly in Charghat of Rajshahi as water quality is good and water is available throughout the year. Some contribution money was taken from users by installing authority which stimulates them to become owner of their mitigation options like other properties. Caretakers' training was also arranged by a local

NGO. On the other hand, dug wells are not functioning properly and were found in abandoned conditions in Dohar of Dhaka and Gazaria of Munshiganj due to bad water quality, lack of community participation and caretakers' training and availability of better sources like deep tubewells. Almost all of the users of Pathorghata considered pond sand filters as a permanent solution to their drinking water problem. They also used rainwater in rainy season. Deep tubewells were not success in these areas due to high salinity in ground water. Ground water in deep aquifer is also highly contaminated with saline water. Most of the respondents reported that the preserved rainwater is insufficient. It does not cover the demand for whole year. Usually, it covers 8-10 months where the family size is small. High cost of installation and operation of rainwater harvesting system at household level also restricts the use of rainwater in the poor families of rural areas.

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