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Drinking Water Supply Options in Arsenic and Salinity Affected Areas of Bangladesh: A Case Study

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Abstract

Widespread groundwater arsenic contamination in south, south-western and north-eastern regions and high salinity in the south-western coastal region are the two major challenges for drinking water supply in Bangladesh. In this study, we assessed various water supply technologies used for mitigating arsenic and salinity in Laksam of Cumilla and Assasuni of Satkhira district. Water samples were analyzed for Arsenic, Iron, Chloride (indicator for salinity) and FC from different water extraction systems (shallow, deep and Tara tubewells), groundwater arsenic treatment units (SIDKO and READ-F), rainwater harvesting systems (RWH), pond sand filters (PSF), and managed aquifer recharge units. Most shallow tubewells, both in Laksam and Assasuni, have been found to produce arsenic contaminated water. But water from deep and Tara tubewells have been found arsenic-free, though high concentration of iron was observed in the wells in Laksam. Rainwater harvesting systems, PSF and MAR units in Assasuni have been found to provide water free from the common chemical contaminants but suffer from high bacterial contamination. Deep tubewell appear to be the most preferred option where a suitable aquifer is available. The community-scale groundwater treatment systems would require strong operation and maintenance support from the service providers to be successful.

Key words: Arsenic, Functionality, Operation and maintenance, Salinity, Social acceptance

Introduction

The widespread arsenic contamination of groundwater in the south, south-west, south-central, and north-eastern regions, the presence of salinity in potable water in many coastal areas, and microbial contamination of water are the significant challenges for water supply in Bangladesh. BGS and DPHE (2001) identified arsenic in 268 Upazilas out of 464 Upazilas in the country in 2001. A comprehensive screening of shallow tubewells in 270 affected Upazilas (sub-District) has shown that about 1.5 million tubewells (29% of all tubewells) had arsenic concentrations exceeding the Bangladesh drinking water standard of 50 ppb (BAMWSP, 2004). In certain areas, the fraction of tubewells contaminated by arsenic is even higher. ICDDRB and BRAC screened more than 13,000 tubewells in Matlab Upazila of Chandpur district, where 65% tubewells were found to have arsenic concentration above 50 ppb (Jakariya *et al*., 2005).

The southwestern coastal regions of Bangladesh have been experiencing an acute shortage of safe drinking water and increased salinity intrusion in surface and groundwater over the past few years. The people in the Satkhira district are still suffering from shortage of drinking water, long after the cyclone Aila in 2009 devastated the major drinking water sources. During the disaster, high tidal surges contaminated all freshwater sources (ponds and shallow tubewells) with polluted saline water (Farhana, 2011). Long term exposure to saline drinking water can cause adverse health effects including hypertension (EPA, 2003). In south-west Bangladesh, high salinity in drinking water has also been linked to relatively high rates of preeclampsia and gestational hypertension, with the latter occurring at higher rates in the dry season than in the wet season (Khan *et al*., 2011). High salinity in irrigation water and soil also decreases crop yields (Ali, 2006). It has been reported that when salinity in irrigation water exceeds 5 ppt, crop yields can decrease by as much as 50% (Clarke *et al*., 2015).

Providing drinking water in salinity and arsenic affected areas is a challenging task. Different water options have been identified, tested, and used in arsenic and salinity affected areas in Bangladesh. Arsenic mitigation technologies include deep and shallow tubewells installed in arsenic-free aquifers, arsenic removal technologies (e.g., SIDKO plant, community-based arsenic iron removal plant, READ-F), and alternative water options (e.g., Pond Sand Filters, rainwater harvesting system). Deep tubewells (DTW) have been found as the most preferred drinking water option mainly because of its acceptable water quality (low arsenic concentration), easier operation and maintenance (Hossain *et al*., 2015). The deep aquifer in most areas of the country is free from arsenic contamination and has moderate iron and salinity (DPHE and JICA, 2010). The BGS and DPHE (2001) survey reported that only about 1% deep tubewells having a depth greater than 150m has arsenic concentration higher than 50 ppb, and 5% deep tubewells has arsenic concentration above 10 ppb. Even in the highly affected area of Matlab Upazila of Chandpur district, deep tubewells having a depth of 67m or more have been found to be mostly free from arsenic (Jakariya *et al*., 2005). The Department of

Public Health Engineering (DPHE) of Bangladesh installed a total of 205,214 DTWs throughout the country in 2007, and the number has now increased to 390,241, of which more than 97% are functioning (DPHE, 2019). However, suitable deep aquifer for extraction of groundwater is not present in many coastal areas.

Different community-based water treatment options have been installed to mitigate arsenic contamination in arsenic-affected areas. These include SIDKO, READ-F and arsenic-iron removal plants (AIRPs), and household filters (e.g., Sono filter). ITN-Bangladesh (2004) evaluated the effectiveness of 40 (forty) SIDKO Arsenic Removal Plants installed in Pabna, Manikganj and Chandpur districts and found that 100 percent of these plants produced safe drinking water (i.e., arsenic concentration in treated water was below Bangladesh standard), but required a high initial investment and regular maintenance. The arsenic-iron removal plants (AIRPs) remove arsenic utilizing naturally occurring iron in groundwater. Assessment of some community AIRPs installed by different Non-Government Organizations (NGOs) (e.g., NGO Forum, SEDA, ISDCM, and BRAC) shows that the AIRPs are capable of effectively reducing arsenic concentration below the Bangladesh standard when the arsenic concentration in the raw water is less than 100 ppb (Hoque, 2006). Household level alum-based arsenic removal filter units were found to be useful in reducing arsenic concentration below 50 ppb for water with arsenic concentration ranging between 157-518 ppb, high iron, and low phosphate concentration (ITN-BUET, 2007). Besides treatment technologies, some alternative water supply options, including household rainwater harvesting (RWH) system and community-based pond sand filter (PSF), have also been installed in arsenic-contaminated areas of Bangladesh (Jakariya *et al*., 2005).

For areas with salinity problems, the government and different NGOs have installed Managed Aquifer Recharge (MAR), and desalination systems (RO plant, solar desalination system) to provide safe drinking water. Water Aid Bangladesh (2016) assessed the performance of 640 water options, including PSF, RWH systems, tubewells, ring wells, and RO plant in Shyamnagar and Assasuni upazilas of Satkhira and Koyra upazila of Khulna district. They recommended PSF as the most viable option for safe drinking water supply in the salinity prone areas.

There is growing evidence that aquifers in the Bengal basin are vulnerable to fecal contamination. ITN-Bangladesh, and APSU (2005) first conducted a systematic study of fecal contamination in various drinking water options in rural Bangladesh. The study detected low TTC (thermo-tolerant coliform) in water from DTW (mean 1 cfu/100 ml during the dry season, and 11 cfu/100 ml during the wet season). Recent studies have enhanced our understanding of microbial contamination of tubewell water, and it is now well understood that the problem of fecal contamination is not only specific to Bangladesh but also throughout the Bengal Basin (Luby *et al*., 2008; Leber *et al*., 2010; van Geen *et al*., 2011). Fecal contamination of shallow tubewells (in Matlab and Araihazar) has been reported to be inversely related to arsenic, higher during the wet season, and proportional to the population density around the well (van Geen *et al*., 2011). Leaching from nearby latrine pits and contaminated ponds were identified as the primary sources of fecal coliform in shallow tubewell water. Bacteriological contamination is a significant concern for traditional PSF water, rainwater harvesting, and MAR systems (ITN-BUET, 2015).

Although many technologies are adopted to mitigate arsenic and salinity problems in such challenging areas in Bangladesh, there is a lack of understanding regarding their functionality, social acceptance, operation, and maintenance issues, all of which affect sustainability. A good understanding of these issues is also vital for planning future interventions aimed at improving water supply in these affected areas.

Here, we have conducted a case study to assess the functionality and social acceptance of a range of water supply options in two arsenic and salinity affected areas. We have chosen Laksam, Cumilla as an arsenic prone area, and Assasuni, Satkhira, as a salinity problem area. We collected water samples from different water options in the study areas and analyzed the water quality parameters. We conducted a questionnaire survey among users to get their feedback, and key informant interview (KII) with technology providers and key stakeholders to gather their views on the functionality and user acceptance of technologies.

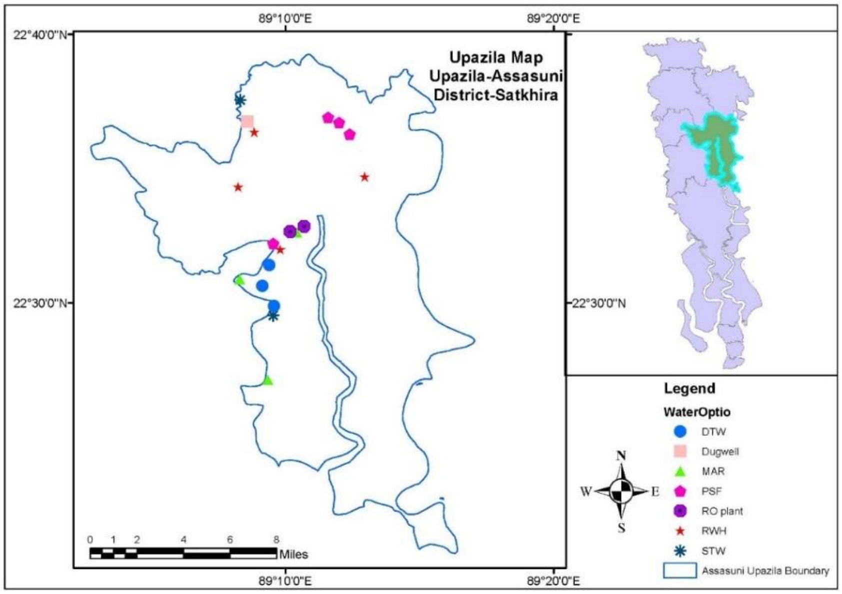
Materials and Methods

Study area

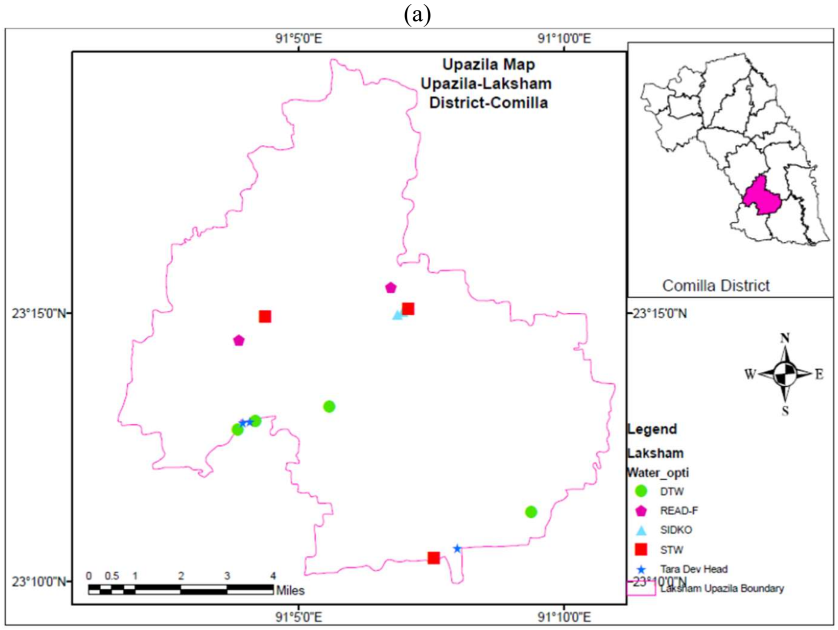
The study was conducted in Laksam upazila of Cumilla district and Assasuni upazila of Satkhira district. These two upazilas have been selected to represent arsenic and salinity problem areas, respectively. Laksam upazila consists of 7 Unions and 1 Paurashava (Municipality) with a land area of 152.06 sq km, having a total population of 294,719 (BBS, 2011). Assasuni upazila of Satkhira consists of 11 Unions with a total land area of 367 sq. km and a total population of 268,754 (BBS, 2011). Groundwater is the primary source of drinking water in Laksam, and the dominant water supply technologies are shallow and deep tubewells; groundwater arsenic removal treatment technologies SIDKO and READ-F are also used here. Both groundwater and surface water are used as drinking water sources in Assasuni, where shallow and deep tubewells, Pond Sand Filter (PSF) and Rainwater Harvesting (RWH) are the widely used water technologies.

Water quality analysis

Several water quality parameters were tested from 18 water options in Assasuni (3 DTWs, 2 STWs, 1 DW, 5 PSFs, 4 RWH systems, and 3 MAR units), and 17 water options in Laksam (10 tubewells, 7 community arsenic treatment units). The sampling locations for both Assasuni and Laksam are shown in Figure 1 (a) and (b). The water samples were tested for arsenic (As) using HACH EZ Arsenic Test Kit (Cat. No. 28228-00), Iron (Fe) using a spectrophotometer (HACH, DR/2010), Chloride (as Cl^-) using a HACH Test Kit (Model 8-P, Cat. No. 1440-01) and pH using a pH tester (Hanna). Wagtech Potakit (Wag-WE 10030 Potakit) was used for testing bacteriological quality (Fecal Coliform) of the water samples. Water quality data of the study area were also collected from secondary sources.



(a)



(b)

Fig. 1. Location of water options visited, and water samples collected in (a) Assasuni, Satkhira, and (b) Laksam, Cumilla

Feedback on water options

Feedback from the users on various water options in the study area was gathered through a questionnaire survey. Feedback and opinion on different water options were also gathered from Key Informant Interviews (KIIs), and meeting with the technology providers. The key informants interviewed in this study included Mr. Shorif Hossain Khan, Assistant

Engineer, DPHE Laksam; Rabin Barai, Health Program Organizer, Laksam ADP-World Vision Bangladesh; Md. Wahidur Rahman, Branch Manager, Holudia Mohila Unnayan Songstha, Cumilla; Mr. Rezaul Karim, Tubewell Mechanic of DPHE, Assasuni; Md. Mamtaz Uddin, Engineer, Rupantar, Assasuni; Salim Ahmed, Centre Manager, Uttaran, Assasuni; Manik Halder, Program Officer, Assasuni ADP-World Vision Bangladesh; Md. Rabiul Islam, Upazila Manager, Rupantar, Assasuni and Nadim Mahmud, Supervisor, Sushilan, Assasuni. The technology providers we interviewed included DPHE, World Vision Bangladesh, Rupantar, Uttaran, Sushilan, Qatar Charity, and Holudia Mohila Unnayan Songstha.

Results and Discussion

In this study, we have assessed five different water supply options/technologies widely used in the arsenic and salinity affected areas in Bangladesh. These include: (a) tubewell water (i.e. groundwater extracted through tubewells without treatment); (b) Groundwater treatment technologies (READ-F, SIDKO); (c) Managed aquifer recharge (MAR) technology; (d) Pond sand filter (PSF); and (e) Rainwater harvesting. An assessment of each of these technologies is provided below.

Groundwater extracted through tubewells

In Laksam, Cumilla, groundwater samples were collected from 4 deep tubewells (DTWs), 3 shallow tubewells (STWs), and 3 Tara pumps; and in Assasuni, Satkhira, groundwater samples were collected from 3 DTWs and 2 STWs. Table 1shows that the shallow aquifers in Laksam and Assasuni are contaminated with high concentrations of arsenic. Water samples from all three shallow tubewells (STW) in Laksam (depth 45 to 60 ft) contain high concentrations of arsenic (varying from 103 ppb to 500 ppb), which exceeds the national drinking water standards (50 ppb) by a factor of 2 to 10. The STWs (depth 135 ft and 192 ft) in Assasuni, though contain a lower concentration of arsenic (88 to 90 ppb) compared to those in Laksam, also exceed the national drinking water standard (50 ppb) by a factor of about 2. The groundwater extracted from deeper aquifer through DTW and Tara pump contains relatively low concentrations of arsenic (5 to 27 ppb) both in Laksam and Assasuni, as shown in Table 1. Water quality data collected from secondary sources (Table 2 and Table 3) also confirms this observation.

Table 1 and Table 2 show that all 18 wells extracting groundwater from the deeper aquifer (500 to 800 ft) in Laksam, and all 27 groundwater samples from the deeper aquifer (≥ 400 ft) in Assasuni contain low concentrations of arsenic (3 to 20 ppb). Thus, the deeper aquifers (> 400 ft) in Laksam and Assasuni appear to be safe from arsenic contamination. Jakariya *et al.* (2005) reported that in the arsenic affected Matlab upazila of Chandpur district, 95% of the shallow tubewells (with depth ranging from 17 to 67 m) have arsenic concentration more than 50 ppb, while almost 100% of deeper wells (with depth greater than 67 m) have arsenic concentration less than 50 ppb.

Table 1. Characteristics of groundwater collected from tubewells in the study areas

Upazila	Sample Location	Type of Tubewell	Depth (ft)	Water Quality				
				As (ppb)	Fe (mg/l)	Cl^- (mg/l)	pH	FC (cfu/100ml)
Laksam	Kandirpar	DTW	800	< 10	6.44	1350	7.1	4
	Mudafarganj	DTW	790	< 10	2.80	40	7.1	400
	Ajgara	DTW	710	5	1.82	35	7.4	50
	Kandirpar	DTW	650	< 10	3.16	60	7.1	Nil
	Kandirpar	Tara	700	< 10	2.71	40	7.2	Nil
	Kandirpar	Tara	700	< 10	2.22	40	7.1	Nil
	Uttardah	Tara	700	27	0.05	420	7.8	Nil
	Uttardah	STW	60	393	2.72	140	8.1	8
	Paurashava	STW	45	103	2.25	85	7.5	--
	Mudafarganj	STW	45	500	2.89	460	7.8	--
Assasuni	Assasuni	DTW	480	6	0.42	140	10.5	80
	Assasuni	DTW	470	<10	0.14	140	8.4	Nil
	Assasuni	DTW	470	10	0.09	100	8.3	52
	Kulla	STW	192	88	5.60	80	7.3	20
	Assasuni	STW	135	90	5.72	820	7.2	220

The two STWs in Assasuni contains high levels of iron (> 5 mg/l), and one of them contains high concentration of Cl^- (820 mg/l), possibly indicating salinity intrusion (Table 2). Some groundwater samples from the deeper aquifer in Laksam and Assasuni contain relatively higher concentrations of Fe (up to 6.44 mg/l). In Laksam, Iron (Fe) concentrations of all groundwater samples from shallow and deeper aquifers (except one) exceed the Bangladesh drinking water standard of 1.0 mg/l. Data collected from secondary sources (see Table 2) also show a similar trend.

The deeper aquifer of Assasuni Upazila appears to contain relatively low levels of Iron (Fe); only three groundwater samples (out of 34 reported in Table 1 and Table 3) have Fe concentration exceeding Bangladesh drinking water standard. On the other hand, six groundwater samples out of the 32 (Table 1 and Table 3) from the deeper aquifer in Assasuni have Cl^- concentration exceeding Bangladesh standard of 600 mg/l. Thus, the deeper aquifer (> 400 ft) in Assasuni appears to contain relatively low levels of Fe and Cl^-. In Laksam, among the 21 groundwater samples (Table 1 and Table 2) from the deeper aquifer (> 500 ft), only three have Cl^- concentration exceeding Bangladesh drinking water standard of 600 mg/l; all three samples are from the same Union (Kandirpar). However, more data are needed to delineate the spatial variation of salinity in Laksam. Water from these tubewells (i.e., with low As and higher Fe/Salinity) may be considered for potable use if local people accept this (considering the taste and aesthetic considerations).

Table 1 shows the presence of fecal coliform (FC) in groundwater samples from 3 DTW out of 4 in Laksam and 1 DTW out of 3 in Assasuni. Fecal contamination is found in almost all STW samples. Groundwater is typically considered microbiologically safe due to natural pathogen removal and inactivation by percolation through soil (Gadgil, 1998). Tubewells in rural Bangladesh are often located close to latrines and ponds. Possible mechanisms for tubewell contamination with fecal pathogens include infiltration into the groundwater aquifers from nearby latrines, septic tanks, and ponds (Knappett *et al*., 2011a,b), and short-circuiting of contaminated surface water into the wells through unsealed or broken tubewell platforms (Knappett *et al*., 2012). In this study, groundwater from Tara pumps were found to be free from FC. The possible reasons for this could be the provision of a protective cover fitted over the tubewell head, good quality tubewell platform, and proper wastewater drainage provision.

Table 2. Groundwater quality at Laksam, Cumilla (DPHE and JICA, 2010)

Sl. No.	Sample Location	Type of Tubewell	Depth (ft)	Water Quality		
				As(ppb)	Fe(mg/l)	Cl^-(mg/l)
1	Ajgara	DTW	500	10	2.5	220
2	Ajgara	DTW	540	20	3	240
3	Bakai	DTW	560	4	2.7	180
4	Gobindapur	DTW	600	10	4.5	120
5	Uttardah	DTW	630	20	2.4	280
6	Uttardah	DTW	650	10	3.2	200
7	Mudafarganj	DTW	700	1	2.5	200
8	Kandirpar	DTW	700	20	1.7	1600
9	Kandirpar	DTW	710	10	3	55
10	Bakai	DTW	750	3	3	210
11	Kandirpar	DTW	750	10	2.2	1400
12	Gobindapur	DTW	750	10	4.5	12
13	Gobindapur	DTW	750	20	2	285
14	Mudafarganj	DTW	780	20	2.6	180

Table 0. Groundwater quality at Assasuni, Satkhira (DPHE and JICA, 2010)

Sl. No.	Sample Location	Type of Tubewell	Depth (ft)	Water Quality		
				As (ppb)	Fe (mg/l)	Cl^- (mg/l)
1	Sreeula	DTW	370	2	0.11	340
2	Anulia	DTW	400	1	4.82	952
3	Anulia	DTW	400	1	0.48	126
4	Sreeula	DTW	431	1	0.25	210
5	Assasuni	DTW	445	4	0.03	230
6	Assasuni	DTW	445	3	0.02	250
7	Assasuni	DTW	455	5	0.03	230
8	Anulia	DTW	460	4	2.25	728
9	Anulia	DTW	465	1	1.44	977
10	Pratap Nagar	DTW	476	1	0.16	180
11	Pratap Nagar	DTW	483	1	0.4	340
12	Anulia	DTW	488	18	0.18	223
13	Pratap Nagar	DTW	494	1	0.11	530
14	Pratap Nagar	DTW	495	2	0.23	640
15	Sobhnali	DTW	510	1	0.55	430

Sl. No.	Sample Location	Type of Tubewell	Depth (ft)	Water Quality		
				As (ppb)	Fe (mg/l)	Cl^- (mg/l)
16	Sreeula	DTW	549	1	0.7	80
17	Sreeula	DTW	551	1	0.32	320
18	Sobhnali	DTW	585	3	0.54	300
19	Sobhnali	DTW	590	2	0.43	130
20	Sobhnali	DTW	610	1	0.09	310
21	Sobhnali	DTW	625	2	0.1	80
22	Sobhnali	DTW	625	1	0.22	200
23	Sobhnali	DTW	625	4	0.14	640
24	Sobhnali	DTW	632	1	0.22	640
25	Anulia	DTW	510	0	0.5	120
26	Sobhnali	DTW	510	<10	0.5	190
27	Pratap Nagar	DTW	520	2	0.37	126
28	Pratap Nagar	DTW	540	<10	0.5	190
29	Sreeula	DTW	540	0	0.5	180

Groundwater treatment technologies

Table 4 shows the results of analysis of the water samples collected from 3 SIDKO units and 4 READ-F units in Laksam; these technologies treat groundwater extracted from the shallow aquifer. Among the 3 SIDKO units, two units appear to be performing well in reducing As concentration to an acceptable level. These two units also effectively reduce Fe. However, one SIDKO unit in Mudafarganj, Laksam was not working well and produced visibly turbid water with relatively high As and Fe concentrations. This unit was reported to be performing well after installation and was being used by 200-250 families. However, after about three months of installation, it began to produce turbid water, and the service provider failed to rectify the problem. Currently, only about 10-15 families are using this unit.

The arsenic concentration in the treated water by the four READ-F units varied from less than 10ppb to 213ppb. Depending on the arsenic concentration of raw water and use, the filter media of READ-F units need to be changed periodically. However, the users of the units reported that the filter media have not been changed in the last 3-4 years since installation. The frequency of filter replacement needs to be shorter for higher raw water As concentration and higher water demand. The varied and often poor performance of the READ-F units appears to be due to improper operation and maintenance and lack of support service (e.g., periodic replacement of filter media) from the technology provider. The Fe concentration in the units is mostly within the acceptable range. Among 7 units of SIDKO and READ-F, FC was detected in 3 units, and the possible cause could be the fecal contamination of groundwater used as source water for the units.

Table 4. Characteristics of treated water samples collected from SIDKO and READ-F units

Sl. No.	Sample Location	Type of treatment technology	Water Quality				
			As (ppb)	Fe (mg/l)	Cl^- (mg/l)	pH	FC (cfu/100 ml)
1	Kandirpar	SIDKO	33	< 0.02	45	7.5	6
2	Paurashava	SIDKO	36	0.08	75	7.5	Nil
3	Mudafarganj	SIDKO	64[a]	2.11	140	7.8	14
4	Paurashava	READ-F	82[a]	< 0.02	80	7.7	2
5	Kandirpar	READ-F	< 10	< 0.02	60	7.7	Nil
6	Mudafarganj	READ-F	213	0.15	60	8.0	Nil
7	Laksam	READ-F	68	< 0.02	55	8.0	--

[a] Arsenic concentration of raw water (from an STW) is 250-500 ppb

Managed Aquifer Recharge (MAR)

The Managed Aquifer Recharge (MAR) systems in Assasuni involves recharging aquifer with pond water, after passing through slow sand filters (SSFs). The chemical contaminants in the aquifer (e.g., As, Cl^-) get reduced due to dilution with pond water. Oxygenated pond water may also reduce As, Fe, and Mn by promoting their oxidation and retention in the subsurface. Table 5 shows that the water from the MAR systems in Assasuni contains low concentrations of As and Cl^- and satisfy the Bangladesh drinking water standard. However, Fe concentrations in two water samples exceed the Fe standard of 1.0 mg/l. Since groundwater characteristics before their recharge by MAR systems are not known, it was not possible to assess the effectiveness of the MAR systems in reducing the chemical contaminants (As, Fe, and Cl^-). The water samples from the MAR systems contain fecal coliform (FC) ranging from 20 to 76 cfu/100 ml. It should be noted that Doza *et al.* (2018) reported fecal coliform in the range of 1-10 MPN or more in water samples from 40% MAR units studied (in Satkhira, Khulna and Bagerhat), compared to 99% in the source pond water. There was no latrine pit within 30 feet around the MAR recharge wells in our study area. So, pond water could be the source of fecal coliform for the MAR water samples.

Table 5. Characteristics of water samples collected from MAR, PSF and RWH systems

Sl. No.	Sample Location	Technology	Water Quality				
			As (ppb)	Fe (mg/l)	Cl^- (mg/l)	pH	FC (cfu/100 ml)
1	Assasuni	MAR	10	1.35	400	7.5	20
2	Sreeula	MAR	7	0.70	240	7.3	76
3	Assasuni	MAR	25	2.61	140	7.4	60
1	Assasuni	PSF	<10	< 0.02	240	7.4	3,840
2	Kadakati	PSF	< 10	< 0.02	280	8.0	40
3	Kadakati	PSF	< 10	< 0.02	450	8.0	40
4	Assasuni	PSF	< 10	0.20	200	9.3	240
5	Budhata	PSF	< 10	0.09	300	8.5	3,000
1	Assasuni	RWH	< 1	< 0.02	15	7.5	64
2	Budhata	RWH	< 1	< 0.02	20	7.4	140
3	Budhata	RWH	< 1	< 0.02	15	7.0	12
4	Kadakati	RWH	< 1	< 0.02	15	6.5	880

Pond Sand Filter (PSF)

PSFs are widely used in many salinity-affected coastal areas where freshwater ponds are available. In this study, water samples were collected from 5 PSFs; two of these were fitted with solar-powered pumps for lifting pond water into the filter system, while for the other three, water has to be carried from pond to the PSF using No.6 hand pump. None of the PSFs were fitted with any disinfection system. Table 5 shows that the quality of water from the PSFs was acceptable with respect to the selected chemical impurities (As, Fe, Cl); however, the concentration of these parameters may change with season (e.g., likely to increase during the dry season when there is no rainfall and less dilution). The presence of a relatively higher concentration of Cl^- in pond water could be the intrusion of saline water from the shallow aquifer. All water samples from the PSFs contain fecal coliform (FC), and their concentration is as high as 3,840 cfu/100 ml. The introduction of a disinfection system could significantly improve the bacteriological quality of PSF treated water.

Rainwater Harvesting (RWH) systems

Table 5 shows the chemical and microbiological quality of water samples collected from 4 RWH systems in Assasuni. Among the four systems, two did not have essential components such as gutters, downpipes, and cover of the storage tank. The chemical quality of the water samples from the systems in terms of As, Fe, and Cl is acceptable. However, all water samples contain fecal coliform (FC). ITN-BUET (2015) also reported fecal coliforms in the rainwater storage systems that are not fitted with a disinfection system. The study also reported that solar-powered UV disinfection system removes FC effectively.

Community feedback on water supply options

In Laksam, a DTW or a Tara pumps typically serves 2 to 16 households. Unlike Laksam, the DTWs in Assasuni are mostly community-scale, and each serve over 100 households. On the other hand, STWs are mostly family-scale installations and serve single to a maximum of 10 households. While most users (71%) of these technologies are satisfied with the quality (taste, color, smell) of water, users of some DTWs in Laksam reported smell and color. These DTWs have been recently constructed and are without platforms. It is not clear whether these issues contribute to the reported smell or color. Users of different types of tubewells did not report any specific operation and maintenance issues; the community accepts these technologies very well, and local technicians can take care of the routine operation and maintenance.

The community arsenic removal plants (SIDKO and READ-F) at Laksam typically serve many families; each SIDKO unit serves up to 200 families, while each READ-F unit serves up to 120 families. These arsenic removal plants appear to be suffering from significant maintenance related problems. The filter media of READ-F and SIDKO units evaluated in this study have never been replaced (since their installation during 2009-2012), and there is no monitoring of water quality by the service provider. Users of these units deposit BDT 20 to 50 per month for keeping the system operational and routine maintenance, but they do not get support from the supplier. Community-scale arsenic removal plants (SIDKO and READ-F) appear to be well-accepted by people.

The community-scale Managed Aquifer Recharge (MAR) systems at Assasuni serve about 50 to 80 families. The systems are still being maintained and monitored by the technology provider (NGOs). The users are currently not responsible for operation and maintenance (O&M) of the systems, and the users did not report any O&M related problems. Users of MAR systems appear to be satisfied with the quality (taste, color, smell) of water. However, users of one out of three MAR systems reported an unpleasant smell in water.

The PSFs at Assasuni are also community-scale installations, and each PSF fitted with pumps serves up to 170 families. Users of PSFs appear to be satisfied with the quality (taste, color, smell) of water. Some PSFs are fitted with pumps for drawing water from pond to the filter, while others are filled with pond water manually. Users reported difficulty in carrying water manually up to the PSFs. Other than this, no specific O&M related problems were reported by the users. As discussed earlier, a relatively high concentration of FC in treated water from PSFs is a concern. Household scale RWHS unit serves 1 to 3 families during the wet months of the year. The RWH units provided by the DPHE appears to be properly designed and constructed (e.g., with gutters, filtration system). Users of RWH systems appear to be satisfied with the quality (taste, color, smell) of water from the system.

Conclusions

We have assessed various drinking water options in Laksam and Assasuni, representing arsenic and salinity-affected areas, respectively in Bangladesh. The major findings are:

- The shallow aquifer at Laksam and Assasuni appears to be contaminated with arsenic and is not a viable source of safe drinking water. The deeper aquifer (≥ 400 ft) appears to be free from arsenic contamination but has higher iron and salinity at some locations of Laksam.
- The community-based arsenic treatment system SIDKO appears to be a promising option for arsenic-free water supply if strong support is provided for operation and maintenance.
- Both Pond Sand Filter (PSF) and Rainwater harvesting system appear to have good user acceptance and provide water with good chemical quality. However, water from these systems has high concentration of fecal coliform and therefore disinfection before drinking is necessary. The pump operated PSF is more popular and can serve large communities.
- Managed Aquifer Recharge (MAR) is a relatively new technology and is still at the pilot stage. The bacteriological quality of water from MAR systems is unsatisfactory, and disinfection before drinking is necessary. However, the water quality from MAR units, to some extent, is dependent on the water quality of both the source i.e., pond and aquifer water.
- A single water supply option cannot be recommended for any area. Deep tubewell is the most preferred option where a suitable aquifer is available. Alternative sources (rainwater harvesting and PSF) or treatment technologies (with proper operation and maintenance) could also provide good quality water; however, in most cases disinfection is required to remove fecal contamination of water.

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