Potable water scarcity: options and issues in the coastal areas of Bangladesh

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ABSTRACT

In the coastal areas of Bangladesh, scarcity of drinking water is acute as freshwater aquifers are not available at suitable depths and surface water is highly saline. Households are mainly dependent on rainwater harvesting, pond sand filters and pond water for drinking purposes. Thus, individuals in these areas often suffer from waterborne diseases. In this paper, water consumption behaviour in two southwestern coastal districts of Bangladesh has been investigated. The data for this study were collected through a survey conducted on 750 rural households in 39 villages of the study area. The sample was selected using a random sampling technique. Households' choice of water source is complex and seasonally dependent. Water sourcing patterns, households' preference of water sourcing options and economic feasibility of options suggest that a combination of household and community-based options could be suitable for year-round water supply. Distance and time required for water collection were found to be difficult for water collection from community-based options. Both household and community-based options need regular maintenance. In addition to installation of water supply facilities, it is necessary to make the residents aware of proper operation and maintenance of the facilities.

Key words | Bangladesh, coastal areas, rural households, water supply

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INTRODUCTION

In Bangladesh, 73% of the population lives in rural areas and tubewell water is the primary source of drinking water for the majority of rural people (WHO & UNICEF 2010). Tubewells have been installed at various depths, depending on availability and the level of groundwater. However, in the coastal areas of Bangladesh, the development of a dependable water supply system is limited because suitable freshwater aquifers are not available at suitable depths (Kamruzzaman & Ahmed 2006; Islam *et al.* 2010). There are certain areas in the coastal districts where both shallow and deep tubewells are not useful due to high salinity in groundwater. In many settlements in these areas, rainwater is preserved in natural or man-made ponds and collection of rainwater is the only source of drinking water (Kamruzzaman & Ahmed 2006; Alam *et al.* 2011).

Rainwater harvesting (RWH) is a promising way to supplement the water supply in areas where surface and groundwater are scarce and the existing water supply system is inadequate to meet demand. Consequently, RWH is becoming very important in the coastal areas of Bangladesh. In these areas, the government is currently promoting household and community-based alternative water supply options, such as household-based rainwater harvesting systems (RWHSs), community-based rainwater harvesting systems (CRWHSs) and pond sand filters (PSFs). In case of RWHSs, the water collection tanks are mainly burnt clay pots (*motkha*), plastic tanks and ferrocement tanks, which are constructed on the surface. Plastic and ferrocement tanks are considered as improved tanks and their capacity mainly ranges from 1,000 to 3,200 L. In case of CRWHSs,

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larger sub-surface reservoirs (ranges from 10,000 to 25,000 L) made of reinforced cement concrete or ferrocement are used for storing rainwater. The PSF is a manually operated treatment unit based on the principle of slow sand filtration. Water is pumped up from the rainfed pond by a hand pump and is poured into a filter chamber filled with sand. So, the treated water quality depends on the efficiency of filtration system and also on the raw water quality of the pond. However, few households have community-based water supply facilities within a short distance. Water scarcity causes great hardship to families, in particular women, who usually spend several hours each day collecting water from distant sources. Substantial queuing time at community water collection points also restricts the collection of safe water (Sullivan *et al.* 2003). So, people generally use rainfed pond water during the dry season because many households do not have a large tank to store sufficient rainwater for the whole year. Previous studies have shown that pond water in Bangladesh is heavily contaminated with faecal coliforms and pathogenic bacteria (Albert *et al.* 2000; Alam *et al.* 2006).

Over the years, the local people of the southwestern coastal areas of Bangladesh have adapted their water consumption behaviour because of varying levels of water availability. To ensure safe sources of water is one of the most important issues for human health and sustainable socio-economic development in these areas. Planning for effective water supply in the rural coastal Bangladesh requires understanding of the existing water consumption patterns. The volume of water consumed is an essential element in quantitative microbial risk assessment (QMRA). In the WHO *Guidelines for Drinking-water Quality* (WHO 2004), the Water Safety Plan is the central approach to safeguarding the health of the drinking water consumer. Within a Water Safety Plan, QMRA can be used to assess the microbial safety of drinking water. QMRA has been suggested by various authors as the scientific basis for assessing risks of pathogen exposure (Teunis *et al.* 1997; Haas *et al.* 1999; Medema *et al.* 2003). When assessing the exposure to pathogens through drinking water, both the concentration of pathogens in drinking water and the volume of drinking water consumed are important parameters. Therefore, the main objectives of this study were: (i) to identify water consumption behaviour of a rural salinity-affected population; and (ii) to make suggestions for their future safe water supply. The findings of the present study may help in planning and implementation of improved water supply facilities not only for the coastal areas in Bangladesh, but also for other coastal areas with a similar hydro-geological situation.

METHODOLOGY

The study was conducted in the southwest coastal areas of Bangladesh, particularly Mongla and Dacope upazilas (sub-districts) of Bagerhat and Khulna districts, respectively. These areas were selected because: (i) neither shallow or deep tubewells are useful in these areas due to salinity; (ii) most of the communities depend on multiple sources of drinking water; and (iii) convenient transportation for collecting data. A questionnaire survey was administered to gather detailed information on the water consumption behaviour of the coastal people. The data included: socio-demographic information on the respondents; their water collection and consumption behaviour; information on maintenance of water sources; and the preference of water collection options. The draft questionnaire was pre-tested in villages of the two districts covered in the study. The questionnaire was revised after two rounds of pre-testing. The target population of this study was individual households. The household was considered as a unit of analysis because water supply issues were concerns of the entire household. Households were selected from 39 villages in the study area by using systematic random sampling technique. Respondents were selected from the list of residents from each village obtained from Union Parishad office. Ten per cent of the households in each village were selected randomly. From each selected household, one woman was selected as the sample. Only the female participants were selected because they are mainly responsible for collecting drinking water in the household. In Bangladesh, 90% of the women are responsible for the collection of water while men, girls and boys comprise 5, 4 and 1% of the water collectors, respectively, when drinking water is not available on their own premises (WHO & UNICEF 2008). In the reconnaissance survey, we also found that women are primarily responsible for the collection of household drinking water in the study area. When any household

member refused to participate, the nearest house was considered. The total number of samples in this study was 750.

To quantify the daily water consumption by direct drinking, a method similar to the Cup Method (Watanabe *et al.* 2004) was used, in which direct water consumption is estimated by asking the respondent how many cups of water are consumed in a day. The water consumption data of the respondent herself and the members of her respective household were collected. In the study area, all the individuals have been found to have their own cup with which they drink water. However, in some cases, a single cup was shared by two or more members of the same family. The cup used for drinking water was identified for each individual and the capacity of the cup was measured using a standard-sized glass of 250 ml. The number of cups marked was multiplied by the capacity of that person's cup to estimate the water consumption rate.

Secondary data on the economic cost of the water supply options were obtained from the Department of Public Health Engineering (DPHE) office. The DPHE is responsible for water supply in the rural areas of Bangladesh. The construction and maintenance cost of RWHSs and PSFs were collected to calculate the economic cost of the systems.

The questionnaire was administered face-to-face by the first author and eight trained surveyors (graduate students of Environmental Science Discipline at Khulna University, Bangladesh) who are fluent in the local language. The data were collected during March 2009 and March 2010. Analyses were done using Statistical Package for Social Sciences (SPSS) version 16.0.

RESULTS

Socio-economic and demographic profile of the study population

The socio-economic and demographic characteristics of the respondents are shown in Table 1. The mean age of the respondents was 37 years. The mean family size was 4.67 persons in a household. Nearly 33% of the respondents had no formal education. A large percentage of the households' income source was agriculture (37%); others owned small businesses (23%), were daily labourers (30%) or in paid employment (10%). Approximately 53% of the participants reported monthly family income of less than Tk. 3,000 (approximately USD 39).

Table 1 | Respondents' socio-demographic characteristics

Characteristics	Descriptive	$n = 750$	Percentage
Age	<30	205	27.3
	30–40	302	40.3
	>40	243	32.4
Education	No education	245	32.7
	Primary	217	28.9
	Secondary	273	36.4
	College	15	2.0
Family size	1–4 people	404	53.9
	≥5	346	46.1
Main occupation (*missing* = 3)	Agricultural	277	37.1
	Small businesses/trade	175	23.4
	Daily labourer	224	30.0
	Employment/teacher	71	9.5
Average monthly income (Tk.)	<3,000	398	53.1
	3,000–5,000	227	30.2
	>5,000	125	16.7

Note: Tk., Bangladesh Taka, 1 USD = Approximately 78 Tk.

Drinking water sources and pattern of water use

Drinking water sources available in the study area are presented in Table 2. The RWHS is the only household-based water supply option available in the study area. Water sourcing patterns of the households are presented in Table 3. The survey

Table 2 | Drinking water sources available in the study area

Drinking water source	Source of original water	Level of option
Household-based rainwater harvesting system	Rainwater	Household based
Community-based rainwater harvesting system	Rainwater	Community based
Pond sand filter	Rainwater	Community based
Sharing of functional tubewells	Groundwater	Neighbourhood
Pond water	Rainwater	Neighbourhood

Table 3 | Drinking water sourcing patterns

Dependency on source	Source type	Number of households	% of households
One source	RWHS	41	5.5
	CRWHS	12	1.6
	Tubewell	6	0.8
	Pond	5	0.7
	Buy water	1	0.1
Two sources	RWHS + PSF	81	10.8
	RWHS + Pond	391	52.1
	CRWHS + Pond	11	1.5
	RWHS + Tubewell	23	3.1
	RWHS + Buy water	16	2.1
Three sources	RWHS + PSF + Pond	109	14.5
	RWHS + CRWHS + Pond	33	4.4
	RWHS + Tubewell + Pond	13	1.7
	RWHS + CRWHS + Buy water	8	1.1
Total		750	100.00

Note: RWHS, household-based rain water harvesting system; CRWHS, community-based rain water harvesting system; PSF, pond sand filter.

results reveal a complex water sourcing pattern. Out of the total households, about 91% reported that they rely on two sources to obtain drinking water. More than half of the households were found to use a RWHS and pond water for drinking purposes. About 11% of the households reported using RWHS and PSF water, while about 15% used RWHS, PSF and pond water as their drinking water sources. Only about 9% used a single source for drinking purposes.

The principal drinking water sources of the households during dry and wet seasons are presented in Table 4. Households' choice of water sources is seasonally dependent. In the dry season, ponds were found to be the most common source of drinking water, followed by PSFs, with the use of other sources being limited. About 69 and 18%, respectively, of the households reported using pond and PSF water during the dry season. However, in the wet season, the majority of the households (91%) reported using RWHS water. While only about 4 and 3%, respectively, of the households chose to use PSF and CRWHS water.

The duration of water use for different drinking water sources are presented in Table 5. Households reported using PSF, tubewell and pond water for about 8, 9 and 8 months, respectively. In the case of harvested rainwater, use of CRWHS water was higher than RWHS water. Households were found to use RWHS water for only about 4 months.

Table 6 shows averages, standard deviations and the 50th and 75th percentile of the daily water consumption by the coastal population according to sex and age groups. The average daily water consumption was about 3.35 L/d without gender difference. Significant difference was observed

Table 4 | Principal water sources by season

Principal water sources	Percentage of households	
	Dry season	Wet season
RWHS	5.87	91.1
CRWHS	2.13	2.8
PSF	17.73	4.3
Tubewell	4.80	0.8
Buy water	0.13	0.1
Pond	69.34	0.9
Total	100.00	100.0

Table 5 | Duration of water use

Drinking water sources	Most frequent response in months
RWHS	4 months (Jun–Sep)
CRWHS	6 months (Jun–Nov)
PSF	8 months (Oct–May)
Tubewell	9 months (Oct–Jun)
Pond	8 months (Oct–May)

Table 6 | Daily water consumption by coastal populations

	N	Mean (SD) L/d	Range (L/d)	Percentiles	
				50th	75th
Total	2,654	3.35 (0.98)	1.00–6.25	3.00	3.50
Gender ($p = 0.001$)					
Male	1,237	3.52 (1.04)	1.00–6.25	3.50	3.75
Female	1,417	3.19 (0.89)	1.00–6.25	3.00	3.25
Age group (years) ($p = 0.158$)					
15–24	606	3.25 (1.09)	1.25–6.25	3.00	3.25
25–34	642	3.36 (0.95)	1.00–5.75	3.00	3.50
35–44	547	3.56 (0.97)	1.25–6.25	3.25	3.50
≥ 45	859	3.26 (0.90)	1.00–5.75	3.00	3.50

between male and female consumption. However, no significant differences were observed between the different age groups. The 35–44-year-olds had the highest average and median consumption, while the 15–24-year-olds consumed the least of the all age groups. It is noteworthy that a substantial individual difference was evident and some individuals consumed as much as 6.25 L/d.

Among households who were found to use harvested rainwater only about 3% reported using any in-house method to purify their drinking water (Table 7), whereas about 13% of the PSF water users treat their water in their home. In case of pond water users, about 53% reported using alum to treat the water. Approximately 37% of the households who boiled their pond water also use alum for additional treatment.

Operation and maintenance of RWHSs, CRWHSs and PSFs

Table 8 shows the features of the RWHSs operation and maintenance schedule for the households surveyed. More than one-third (34%) of the households reported that they do not clean the roof annually. About 42% reported that they clean the roof once a year. A majority reported that the first flushing time was less than 10 min. It is important to note that about 14% reported that they do not first flush before rainwater collection. The majority of the households (63%) reported that they clean the rainwater tanks several times a year. Manual abstraction of water from the tank was common amongst the households; only about 6% of the rainwater tanks had a tap for water collection. In case of CRWHSs and PSFs, the majority of the respondents said that there is no community-based management for operation and maintenance.

Table 7 | Treatment of drinking water prior to consumption

Treatment method	Number of households	Percentage
Harvested rainwater ($n = 738$)		
Alum (Chemical)	6	0.8
Boiling + alum	11	1.5
Boiling	1	0.1
Filtering (home filter)	3	0.4
Total		2.8
PSF water ($n = 190$)		
Alum (chemical)	11	5.8
Boiling + alum	11	5.8
Boiling	2	1.1
Total		12.6
Pond water ($n = 562$)		
Alum (chemical)	294	52.3
Boiling + alum	206	36.7
Boiling	16	2.8
Boiling + bleaching powder	2	0.4
Filtering (home filter)	15	2.7
Others	4	0.7
Total		95.5

Table 8 | Operation and maintenance schedules of RWHS reported by household surveyed

Operation and maintenance	Tanks surveyed ($n = 715$)	Percentage
Roof cleaning		
No cleaning	241	33.7
1 time/year	303	42.4
2 times/year	77	10.7
3 times/year	19	2.7
Many times	75	10.5
First flush time after dry period (missing = 4)		
No first flush	101	14.2
<10 min	431	60.6
10–20 min	118	16.6
≥30 min	61	8.6
Tank cleaning (missing = 5)		
No cleaning	5	0.7
1 time/year	113	15.9
2 times/year	97	13.7
3 times/year	45	6.3
Many times	450	63.4
Water collection from the tank		
Manually	672	94.0
From tap	40	5.6
Other means	3	0.4

Effects of distance and time on PSFs and CRWHSs water collection

The distance that the respondents need to travel and also the time required for water collection from PSFs and CRWHSs

are presented in Tables 9 and 10, respectively. In the case of PSFs, about 30% of the total households had PSFs within 400 m of their houses (see Table 9), while about 46% of the households had no PSF within 2 km. Time required for water collection from the PSF was more than 2 hours for 55% of the households. In response to a question on why people use pond water instead of PSF water, about 68% of the respondents replied that 'PSF is not available within a short distance', and 79% of them said that 'water collection from the PSF is time consuming'. In addition, about 42% said 'PSF does not function properly year-round'. Only about 6% of the households had a CRWHS within 400 m of their houses, while about 81% had no CRWHS within 2 km of their houses (see Table 10). Time required for water collection from CRWHSs was more than 2 hours for about 83% of the households.

Households' preferred option

In response to the query regarding the preference for the household (RWHS) and community-based (CRWHS or PSF) option or options after explaining all the technologies in detail, such as initial cost and running cost, quality of water, convenience of use and health risks, about 78% of the respondents preferred the RWHS and about 22% opted for community-based options. Of respondents who preferred the RWHS, about 95% reported harvesting rainwater in the wet season. However, only about 19% were found to have improved rainwater tanks (tank size ≥1,000 L) for household rainwater collection.

DISCUSSION

The study shows that coastal households are mainly dependent on multiple sources for drinking purposes. The use of pond water in the dry season by the majority of respondents as a principal source of water supply reflects the lack of PSFs and CRWHSs in the study area. In the wet season (May to October), it is possible to harvest rainwater at the household level. However, the majority of respondents said that they do not have tanks large enough for storing rainwater for long periods. In the case of RWH, plastic and ferrocement tanks are considered as improved tanks. According to the survey results, only about 23% of the households reported having improved rainwater tanks for household rainwater collection. Many of the respondents said that even in the wet season if there is a long dry

Table 9 | Distance and time required for water collection from PSF

	Drink PSF water		Do not drink PSF water		Overall % of total households
	Number of households	% of total households	Number of households	% of total households	
Distance of PSF					
<400 m	91	47.9	137	24.5	30.4
400–1,000 m	74	39.0	77	13.8	20.1
>1,000–2,000 m	8	4.2	21	3.8	3.9
>2,000 m	17	9.0	325	58.0	45.6
Total	190	100.00	560	100.0	100.00
Time required for water collection[a]					
<20 min	27	14.2	36	6.4	8.4
20–60 min	55	29.0	55	9.8	14.7
>60–120 min	92	48.4	71	12.7	21.7
>120 min	16	8.4	398	71.1	55.2
Total	190	100.00	560	100.0	100.0

[a]Total collection time (in minutes), which includes roundtrip travel time from the house to the source and filling and queuing time.

Table 10 | Distance and time required for water collection from CRWHS

	Drink CRWHS water		Do not drink CRWHS water		Overall % of total households
	Number of households	% of total households	Number of households	% of total households	
Distance of CRWHS					
<400 m	41	64.1	1	0.1	5.6
400–1,000 m	19	29.7	15	2.2	4.5
>1,000–2,000 m	4	6.3	60	8.8	8.5
>2,000 m	0	0	610	88.9	81.3
Total	64	100.0	686	100.00	100.0
Time required for water collection[a]					
<20 min	39	61.0	1	0.1	5.3
20–60 min	23	35.9	8	1.2	4.1
>60–120 min	2	3.1	57	8.3	7.9
>120 min	0	0	620	90.4	82.6
Total	64	100.0	686	100.00	100.00

[a]Total collection time (in minutes), which includes roundtrip travel time from the house to the source and filling and queuing time.

period, they need to collect water from other sources. The overall use of ponds suggests that they are very important sources of drinking water for rural households. The duration of tubewell water use was the highest among the sources. However, tubewells are useful in very few places. Only 6% of the households were found to use tubewell water for drinking purposes. In addition, households using tubewell water complained about high iron and salinity in the water.

Economic feasibility of RWHSs, CRWHSs and PSFs

Economic feasibility of RWHSs, CRWHSs and PSFs are shown in Table 11. Rainfed ponds were not considered in the economic analysis since ponds are natural or man-made reservoirs rather than a technological option. The analysis was done considering that a family of five members would consume 25 L of water per day for drinking and cooking. This analysis will not be effective if water is used for other purposes. Storage capacity for RWHSs and CRWHSs was considered to be 5,000 L (one household) and 25,000 L (five households), respectively, which will ensure water storage for at least 180 d. Since rainfall is available for about 6 months, the storage capacity will ensure a year-round water supply. For water consumption by a family, considering that economic life span of a ferrocement tank is 15 years, the unit cost of PSF water is estimated to be Tk. 0.013/L, whereas for RWHS the cost is Tk. 0.232/L and for CRWHS, Tk. 0.225/L. It is apparent that water collected by PSF is the cheapest option. In case of RWH, a CRWHS would be little cheaper than a RWHS.

Feasible combination of options

RWH for the coastal communities that experience a minimum of 6 months rainfall duration is indeed a worthwhile strategy. The average yearly rainfall in Bangladesh varies from 2,200 to 2,800 mm. Several studies (Ferdausi & Bolkland 2000; Islam *et al.* 2010) have shown that household RWH is a feasible alternative water supply option for coastal areas of Bangladesh. In the study area, the majority of households prefer the household-based option (RWHS). In addition, inconvenience of use and maintenance requirements are also low for RWHSs. The main advantage of the RWHS is provision of water right at the household, thus avoiding the burden of having to walk a long distance to fetch water. However, a water supply system completely based on harvested rainwater requires large storage reservoirs (Table 11). Since the

Table 11 | Economic feasibility of RWHS, CRWHS and PSF

RWHS	CRWHS	PSF
	Cost for 5 households • Construction cost (include first flush and gutter system) Tk. 1,40,260 (storage capacity 25,000 L) • Maintenance cost Tk. 1,000/year (including cleaning by chlorine and repairing if any leakage detected)	Cost for 60 households • Total construction cost Tk. 66,000 • Maintenance cost Tk. 3,000/year (including cleaning by chlorine and repairing if any leakage detected)
Cost per household • Cost of construction (include first flush and gutter system) Tk. 29,000 (Storage capacity 5,000 L) • Maintenance cost Tk. 200/year (including cleaning by chlorine and repairing if any leakage detected)	Cost per household • Total construction cost Tk. 28,052 • Maintenance cost Tk. 200/year	Cost per household • Total construction cost Tk. 1100 • Maintenance cost Tk. 50/year
Economic life = 15 years Therefore, total cost = [29,000 + (200 × 14)] = Tk. 31,800	Economic life = 15 years Therefore, total cost = [28,052 + (200 × 14)] = Tk. 30,852	Economic life = 15 years Therefore, total cost = [1,100 + (50 × 14)] = Tk. 1,800
Annual payment = (31,800/15) = Tk. 2,120	Annual payment = (30,852/15) = Tk. 2,057	Annual payment = (1,800/15) = Tk. 120
Cost/L = [31,800/(25 L × 365 d × 15 years)] = Tk 0.23/L	Cost/L = [30,852/(25 L × 365 d × 15 years)] = Tk 0.21/L	Cost/L = [1,800/(25 L × 365 d × 15 years)] = Tk 0.013/L
Cost/L = Tk. 0.232	**Cost/L = Tk. 0.225**	**Cost/L = Tk. 0.013 (Cheapest)**

Note: Construction costs of the systems are according to DPHE (Department of Public Health Engineering) Bangladesh. 1 US$ = 78 Tk. (Bangladesh Taka).

financial base in the rural area is very weak, a RWHS for year-round water supply would not be easily affordable. In the coastal areas, there is no plan to supply piped water in the near future. For households who cannot use a RWHS all year, a combination of options will be useful. According to economic feasibility, preference of option, a combination of the RWHS and PSF need proper consideration for providing safe drinking water to the rural coastal population.

Issues concerning RWHS

Cost is an important issue for introducing RWHSs in rural Bangladesh. In the study areas, about 53% of the respondents reported that their annual income is less than Tk. 36,000 (US$462/year). Clearly, up front payment in cash would be a major problem for lower income groups. In recent years, several programmes (Water Supply and Sanitation Coastal Belt Project; Village Water Supply and Sanitation Projects in Coastal Belts; Water Supply and Environmental Sanitation Project at Mongla Pourashava; Water Supply in Coastal Belts Project; WASH intervention for SIDR cyclone) have been undertaken by government organizations and non-governmental organizations (NGOs) to promote RWHSs; however, the study shows that the coverage is very poor. So, subsidies or payment in instalments should be given due consideration for a safe supply of drinking water to the poor.

Poor operation and maintenance of RWHSs was found in the study area. Islam *et al.* (2011b) found that knowledge of safe drinking water is currently not sufficient among south-west coastal communities of Bangladesh. The lack of knowledge and poor maintenance behaviour influence harvested rainwater quality (Bagmura *et al.* 2010). Therefore, while the use of roof-collected rainwater can contribute to increasing available water, it might at the same time introduce new health threats due to waterborne diseases (Leder *et al.* 2002). Risks of rooftop runoff contamination appear to be limited to those rainwater systems that do not have proper design, proper materials or adequate disinfection procedures (Lye 2009; Ward *et al.* 2010). Islam *et al.* (2011a) showed that contamination of harvested rainwater is associated with lack of first flushing, water collection from the tank manually, unclean inside of the storage tank and a

dirty gutter or blockage in the path the water takes from the roof to the storage tank.

In the study area, the majority of the households do not have first flushing devices and they abstract water manually. These may cause risk of microbial contamination of harvested water. For instance, it is common for funding agencies to subsidize tank-building while leaving construction of gutter and flushing devices to the householder's discretion (Thomas & Martinson 2007). Karim (2010) surveyed 1,000 RWHSs in arsenic-affected and coastal areas of Bangladesh and found that about 24% RWH systems have no gutter and down pipe. In such cases, there is no definite rainwater collection and conveyance system to the storage reservoir and people mainly do it manually. It is thus necessary not only to install RWHSs, but also to increase public knowledge of the physical and non-physical features of these systems, as well as of measures to safeguard the quality of the water collected in the tanks. So, the sustainability of the RWHS requires close cooperation between the government organizations and NGOs, and the rural households (Figure 1). A sustainable RWHS is one that is implemented after considering the physical and non-physical attributes, and the socio-economic attributes in its design. Guidelines on the operation and maintenance of RWHS should be written and disseminated to rural communities. The experience gained from the RWHS pilot programme will be very valuable in incorporating local experience in the guidelines. Increasing awareness through the dissemination of relevant information may help individuals lower their health risk.

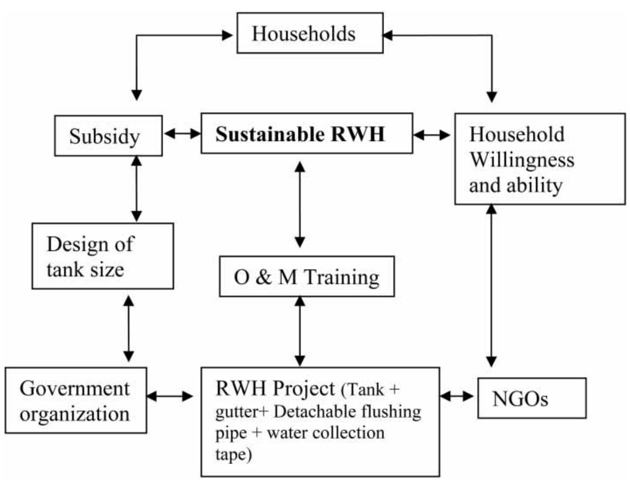

Figure 1 | Sustainable household RWH scheme for rural households.

Issues concerning PSF

In the study area, PSFs have been installed randomly based on the availability of rainfed ponds. PSFs are located in distant locations in a scattered manner. The effect is that a considerable number of rural residents must travel a long distance to fetch water from PSFs (see Table 7). In coastal areas of Bangladesh, PSF is the only suitable option for year-round water supply (Kamruzzaman & Ahmed 2006). The PSF is a low-cost technology with very high efficiency in turbidity and bacterial removal. It is preferred as an alternative water supply system in the coastal areas of Bangladesh. The availability of PSFs within a short distance of the households will reduce the use of pond water. The study showed that about 18% of the households had PSFs within 400 m of the households but they do not drink PSF water. The time required for water collection from PSFs, their non-functioning and lack of awareness about health risks may have been the reasons for not using PSF water. Health impacts of water are related to both the quality of water and its availability within a reasonable distance. In addition, substantial queuing time at community water collection points may restrict the collection of safe water.

In Bangladesh, one of the major problems of the existing PSFs is poor operation and maintenance (Alam *et al.* 2011). During the field survey, some of the PSFs were found to be non-functioning. Performance of a PSF depends mainly on its operation and maintenance. Sand washing is the main component of operation and maintenance. Users are found to be reluctant to wash the sand bed, which results in reduction of filtration rate and increase in fetching time. Sometimes people collect water from PSF source ponds to avoid the long fetching time to collect water from PSFs. In the study area, outlet taps of the PSFs were found to be absent in some cases and people were using sticks in the outlet pipe to control outflow of water. These sticks may be responsible for secondary sources of contamination of the treated water from PSFs. A large number of PSF source water ponds were found unprotected (no suitable embankment to control surface runoff), which allows a high pollution load to enter the pond. High bacteriological contamination in PSF source pond water was found by Islam *et al.* (2011a).

It will not be simple to have PSFs accepted on a permanent basis. If people are to be encouraged to adopt PSFs, there are a number of critical issues to be addressed. PSFs will require regular maintenance and will generally be shared by a number of households. This raises the issue of ownership, who will pay, and how the payment, access and responsibility for maintenance will be shared. Therefore, villagers should be involved in both the financing and operation and maintenance of PSFs. Community participation can generate the commitment for maintenance because they are involved. User groups may be formed among the beneficiaries to conduct regular monitoring and maintenance.

Daily water consumption

Estimates of drinking water consumption are necessary in risk assessment on microbial hazards in drinking water. The daily water consumption of the coastal population estimated in the present study was not so far from the previous estimates of the rural arsenic-affected areas of Bangladesh (see Table 12) but higher than the standard of 2 L/d used by WHO and some regulatory agencies (Levallois *et al.* 1998). Nevertheless, the findings of a previous study (Shafiquzzaman *et al.* 2009) show very high water consumption. According to that study, the average daily water consumption was 5–7 L/d. This difference may partly be due to difference in the calculation of the amount of per capita water consumption as the total household water amount was divided by the total number of household members, while the other studies reported here obtained water consumption data directly from the participants. The findings of this study show that the water consumption rate of 2 L/d generally used for health risk assessment may not always be adequate, especially in tropical countries like Bangladesh. The impact of seasonal variation on water consumption in this coastal population has not been examined yet.

Table 12 | Reported daily water consumption in the rural arsenic-affected areas of Bangladesh

Average per person daily consumption L/d	Maximum L/d	Number of participants	Reference
3.00	6.00	38	Watanabe *et al.* (2004)
3.53	–	640	Milton *et al.* (2006)
5–7	–	428	Shafiquzzaman *et al.* (2009)
3.00	5.70	65	Ohno *et al.* (2007)

CONCLUSIONS

Use of multiple sources for drinking purposes is noted as being common amongst the rural coastal population. Households are mainly dependent on pond and RWHS water during the dry and wet seasons, respectively. In the dry season, due to lack of suitable water sources, a large number of people drink pond water. Distance and time required for water collection were found to make it difficult to collect water from both PSF and CRWHS sources. Water consumption patterns and households' preference of option suggests that a combination of RWHS and PSF could be suitable for year-round water supply. Subsidies or payment in instalments for improved RWHSs should be given due consideration. In addition, concerted efforts must be directed towards increasing availability of PSF within a short distance. Both RWHSs and PSFs need regular maintenance. In addition to installation of water supply facilities, it is necessary to make the residents aware about proper operation and maintenance. For PSFs, a community-based maintenance system may ensure regular monitoring and maintenance. Moreover, Water Safety Plans have been developed for small-scale water supply systems including RWHSs (Mahmud *et al.* 2007). So, implementation of Water Safety Plans will support safe potable water supply in the water-scarce coastal communities in Bangladesh.

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