

Technology for adaptation: a case study of developing a detailed inventory of drinking water supply technologies along the salinity-affected coastal region of Bangladesh

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ABSTRACT

The south-western coastal zone of Bangladesh is suffering from an acute crisis of freshwater due to salinity intrusion. First, the extent of the problem and its causes in detail were investigated. Climate change along with a few other anthropogenic impacts are the main causes. Exploring technologies for adaptation to climate change is emphasized today to overcome the problem of climate change impact. The coastal community was found to be already adopting technological measures as an adaptation means. This study developed a detailed inventory of all the available indigenous water supply technology options along the region and categorized them. An analysis of the suitability of the technologies was done, focusing on factors like the state of the technology, convenience in operation, quantity and quality of the supplied water, as well as financial viability or management practice. Both qualitative and quantitative approaches to the study were adopted to collect and analyze the data through extensive field visits, laboratory testing, and secondary data analysis. It is found that in most cases, solutions are on an *ad hoc* basis, having a lifetime of less than 5 years. In some places, people are gradually moving towards community-based and long-term hi-tech solutions.

Key words: adaptation, climate change, drinking water supply technologies, freshwater crisis, inventory and comparative analysis

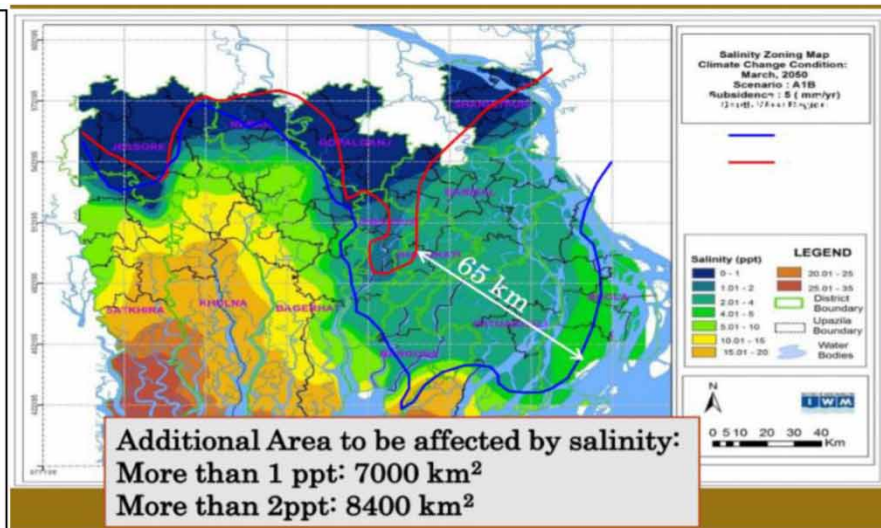
HIGHLIGHTS

- In Bangladesh, such an assessment of adaptation technologies is probably the first of its kind.
- UNFCCC is emphasizing the issue of technological development and nurturing indigenous technologies for adaptation.
- UNFCCC negotiation platform SBSTA and the requirement of Technology Need Assessment (TNA) by member countries are mentioned here.
- In line with the above context, the paper can contribute significantly.

GRAPHICAL ABSTRACT

Graphical Abstract

Technology for adaptation:
Developing an inventory of drinking water supply technologies along the salinity affected coastal region of Bangladesh



1= Sweet water pond, 2= PSF with solar & pipeline supply, 3=Shallow Tube well, 4= Rain water Harvest (Motka) 5= Deen Tube well based Pipeline supply. 6= Catchment. 7= Rainwater Harvest (Tank with UV). 8 =Community Based Rainwater Harvest, 9= PSF (DPHE), 10=MAR, 11= Rainwater Harvest at School, 12= PSF with Solar, 13= Desalination with Bottled water supply, 14= Desalination (Caracol), 15= PSF with BP Treatment 16= Desalination pipeline supply unit, 17= CBWTP, 18= PSF with Solar & UV, 19= Desalination (RO & UV)

INTRODUCTION

Bangladesh, a low-lying deltaic floodplain with a long coastline, which is marginally above the Mean Sea Level (MSL), is considered one of the most vulnerable countries in the world due to the impact of climate change and Sea Level Rise (SLR) (IPCC 2014; Kabir *et al.* 2016). As per the Global Climate Risk Index 2020, Bangladesh ranks third among the countries most hit by disasters and seventh in climate vulnerability (Germanwatch 2020). It has a long coastline of 734 km. Integrated Coastal Zone Management Plan (ICZMP 2004) first explicitly defined the coastal zone of Bangladesh by identifying 19 districts and 147 upazilas as shown in Figure 1, with a land mass of around 47,201 km², i.e. around 32% of the country (Islam 2004). The entire coastal zone is inhabited by around 38.35 million people, which is about 28% of the total population of the country (BBS 2011). It again defined coastal districts under two categories as interior coast and exposed coast, depending on their proximity to the sea and the probability of being affected by coastal processes. Reports from different climate agencies reveal that the south-west coastal zone of Bangladesh is more vulnerable to the effects of climatic changes compared to the rest region (BCCSAP 2009).

The south-western zone has also been severely devastated by frequent cyclonic storm surges in the last few decades, allowing saline water to enter far inland due to its low relief of just around 1 m above MSL. Again, groundwater from both the shallow and deep aquifers along the coast gradually becomes saline, where there is almost no rainfall for around 6 months of the year, and surface water reserves are contaminated due to storm surges (Brammer 2014). Furthermore, anthropogenic impacts like water withdrawal along the major river Ganges by upstream countries, excessive groundwater withdrawal locally, or shrimp farming severely aggravate freshwater availability along this zone (Abedin *et al.* 2014). This zone comprises a population of around 12 million in nine districts, where most of the surface and groundwater sources are contaminated with salinity levels beyond the acceptable limit, leading to a severe crisis of freshwater availability with grave public health hazards as the prevalence of excess salinity related diseases (Ahmed 2006; Khanom & Salehin 2012; Rahman 2015; World Bank 2015). In turn, it becomes a major predicament for the economic development of the region.

A number of adaptation technologies have been in practice already as an alternative option to supply fresh water during the dry period in the study area (Islam & Mohammad 2013; Islam *et al.* 2014; Rahman *et al.* 2017). It ranges from simple rain-water harvesting to Pond Sand Filter (PSF) up to modern technology like desalination. Different government departments

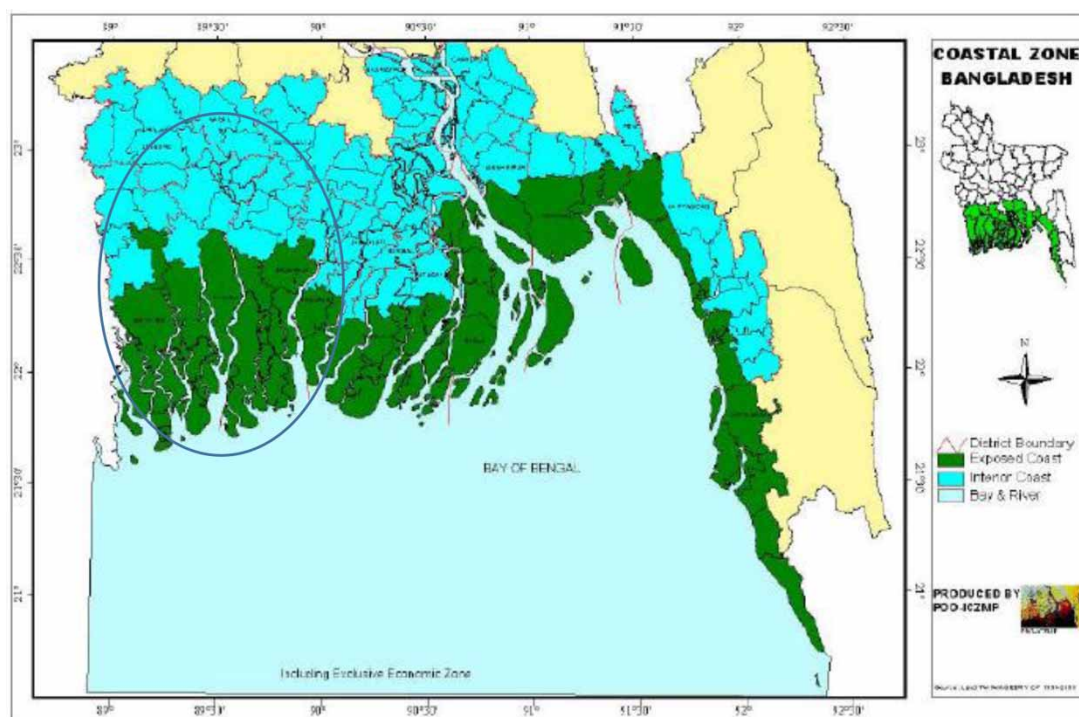


Figure 1 | Coastal zone of Bangladesh, as identified by ICZMP (2004).

and non-governmental organizations (NGOs) are helping the local people adapt to the changing conditions (Minar *et al.* 2013). Day by day, more people are adopting traditional as well as alternative technologies to overcome the crisis, so it is high time to get an overview of all the adaptation technologies, their problems, and prospects.

This study was thus conducted with the main objective of assessing the status of the adaptation technologies in the water supply sector along the coastal region of Bangladesh. As per UNFCCC directives, such proactive analysis is an urgent necessity in almost all sectors in different parts of the world, to ascertain the role of technology to overcome the impact of climate change. Technology Need Assessment (TNA) to address climate change has been asked to submit to UNFCCC for all the member countries in that respect. Bangladesh, being a developing country, is going to be severely affected due to the impact of climate change and is thus required to assess its condition in this regard. This study is going to help the government to this end.

At the first stage of the study, the extent of the problem and major causes are investigated. After then an inventory of technologies adopted by individuals and different agencies has been listed. The technologies are classified under several groups depending on their process, suitability, and complexity level. Management options and community involvement are also investigated. Field visits to the site, laboratory tests of water quality of raw and treated water; questionnaire survey among users, technology providers, government officials, NGOs, and local community leaders' reviews of secondary data were the means to conduct the study. It is expected that the study can provide a detailed overview of the present status of adaptation options and technologies for drinking water supply along the south-western part of Bangladesh.

ADAPTATION TECHNOLOGY: UNFCCC INITIATIVES

Until now, in the climate change regime, technology has been emphasized mostly in the mitigation sector, like reducing emissions through efficiency improvement, greener technology, or shifting from non-renewable to renewable energy sources, etc. No doubt, there were rationales behind this as mitigation is something to reduce emissions and thus retard climate change. Adaptation technology, on the other hand, truly is not less important for some other reasons: first, the warming now being experienced is the result of emissions that took place over many decades and it will continue amid mitigation measures adopted now because of previous emissions; second, after IPCC AR5, it has been confirmed that the impacts of climate change are already evident in the natural systems, so that we cannot avoid it, even with all those mitigation measures; third, development of adaptation technology for climate change will be useful not only for anthropogenic climate change but for any natural variability of climate in future, as well as human impact to the natural system for any reason (IPCC 2014). Under UN Climate Change, the technology issue is discussed in both the negotiating track on technology, i.e. SBSTA, and the one on adaptation, in a variety of contact groups and bodies. In 2001, the Conference of the Parties (COP) of the UNFCCC adopted a technology transfer framework (Decision 4/CP.7). Nairobi Work Program was another milestone here. Since then a number of studies under UN Climate Change, including technical reports, meetings, and programmes have been adopted to emphasize the issue which focuses on a set of activities under key thematic areas, which include: TNAs, technology information, enabling environments, capacity-building, and transfer mechanisms (UNFCCC 2020).

METHODOLOGY OF THE STUDY

The study was conducted along the three most severely affected south-west coastal districts of Bangladesh, as shown in Figure 1. It adopted both qualitative and quantitative approaches to collect and analyze data. Primary data were collected through a questionnaire survey, FGD (Focus Group Discussion), KII (Key Informants Interview), case study, and household interview. Personal observation through field visits was another approach and was probably the most effective one. Laboratory testing of water quality of different technologies to assess the effectiveness of the treatment was also done. The secondary data were collected from government bodies and NGOs to understand the extent of the problem and the present status of the water supply situation through a review of a number of technical and policy studies.

In terms of approach, four steps were adopted to conduct the study. In the first stages, the extent of the problem has been assessed including the level of salinity intrusion, major causes of the problem, and its impact in different sectors. This was done mostly based on secondary data analysis from relevant agencies, literature review, and critical analysis of them. In the second stage, an inventory of technologies adopted at different parts of the study area has been listed and categorized, based on extensive field visits and secondary information. In the third stage, laboratory tests of water quality from a number of major technologies to assess their treatment level and suitability as per Bangladesh standards have been assessed.

In the fourth stage, a detailed investigation of the performance, acceptability, management approach, and user response of the technologies are evaluated based on the gathered information.

STUDY AREA AND THE EXTENT OF THE PROBLEM

Study area

The coastal zone of Bangladesh has been divided into three sub-regions – Western, Central, and Eastern regions. The digital elevation map shows that along the regions, 62% of the land has an elevation of less than 3 m and 86% less than 5 m (Miyan 2009; Rahman 2010; Sarker & Ahmed 2015). As shown in Figure 2, out of these three coastal regions, salinity intrusion along the south-western part is extended the most towards inland due to its low relief from the MSL. This research aims to study this south-western part of the coast, i.e. the most affected region. (ADB 2010; DPHE 2011; BMD 2014). Three districts and the Upazilas (sub-districts) selected under the study are as follows:

District	Upazila
Bagerhat	Rampal and Mangla
Khulna	Dacope
Satkhira	Shamnogor, Ashashuni

Specifically, the south-western part is also known as the Ganges Dependent Area (GDA), because numerous tributaries originating from the Ganges river flow through the region. Freshwater availability of those rivers fully depends on water availability in the Ganges, which has been reduced significantly in the last few decades due to water withdrawal upstream (Mirza 1998).

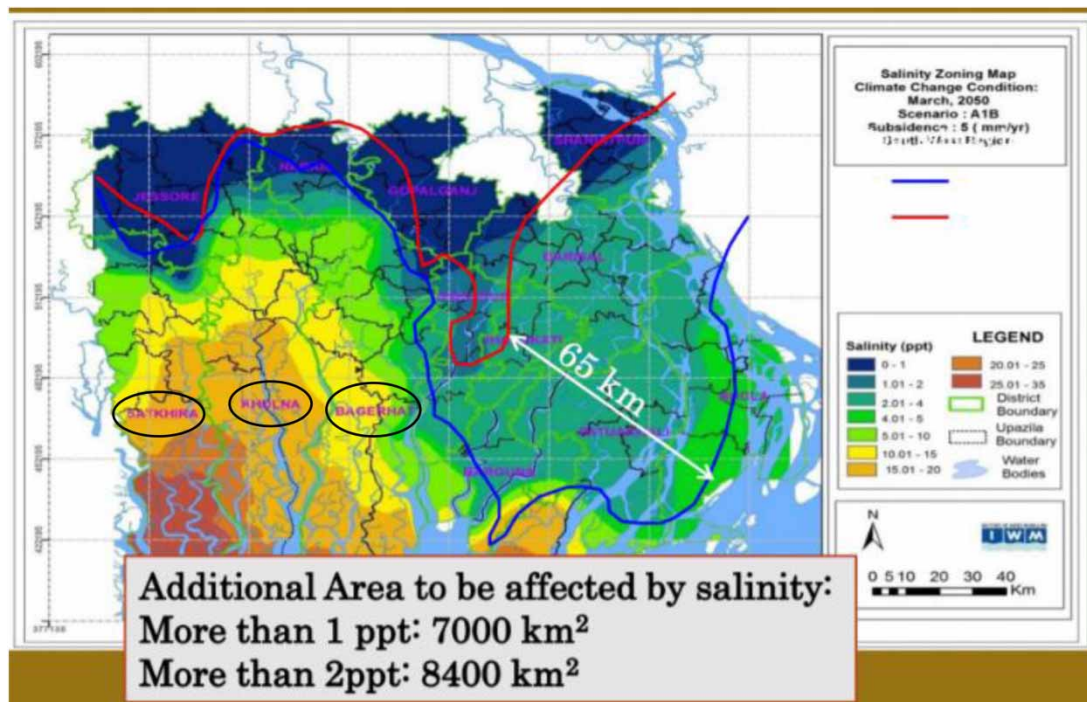


Figure 2 | The problem of salinity intrusion and future projection under the climate change scenario for March 2050 (IWM 2020). Circle indicates the three most affected districts as the study area.

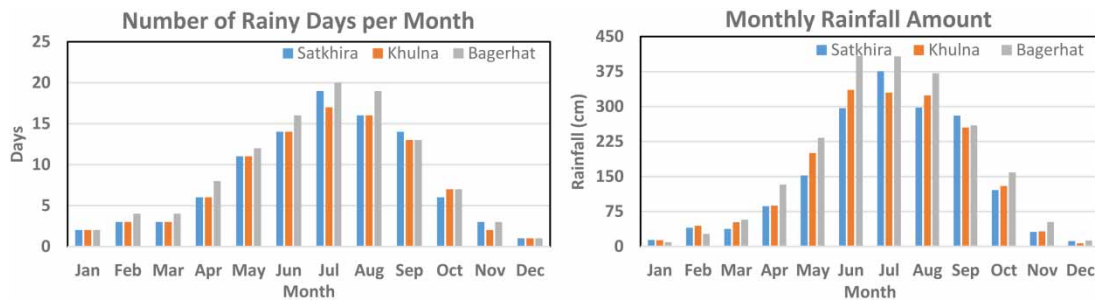


Figure 3 | Distribution of rainy days and total rainfall amount over months at three districts in the study areas (BMD 2014).

Rainfall characteristics

Strong seasonality is observed along the three districts Satkhira, Khulna, and Bagerhat on rainy days, and the total amount of rainfall variation over the year, as shown in Figure 3. Five months, namely November, December, January, February, and March, are crucial in terms of freshwater availability along the region. Due to the shortage of freshwater flow in the rivers, saline water intrudes further inland during the period. Groundwater level also declines or is contaminated gradually due to the lack of freshwater at that time (Mirza 1998).

Causes of salinity

In the last 50 years, salinity level along coastal Bangladesh has increased significantly, specifically south-western parts. A long dry spell of around 3–4 months almost without precipitation actually aggravates the effects, while at the same time, the freshwater flow in the river declines significantly for both natural and manmade reasons. The cause of salinity intrusion in the south-west coastal belt of Bangladesh can be related to a number of issues as shown in the following.

U/S water withdrawal

The annual discharge of the Ganges river flow decreased significantly due to water withdrawal along the river Ganges, specifically at the point of Farakka Barrage. Apart from this, the Ganges passes through the most densely populated region of India so water withdrawal from this river is increasing day by day. A notable change in the hydrology of the Ganges during the post-Farakka period has been observed too. It is estimated that water flow has been dropped to a minimum of $150 \text{ m}^3/\text{s}$ at the Hardinge bridge point in 1995 from $20,000 \text{ m}^3/\text{s}$, which was the average minimum flow of the Ganges during the pre-Farakka period (Mirza 1998). Eventually, most of the tributaries pass through the GDA and almost become dry. Saline tidal water then gets minimum resistance from the upstream freshwater flow, and thus intrudes further inland (Islam & Gnauck 2011). Figure 4(b) shows the salinity intrusion before and after Farakaka.

Climate change and resulting SLR

It is already evident from some of the studies that the coast of Bangladesh is experiencing a trend in SLR (Sarwar 2005; Baten *et al.* 2015). As per the National Adaptation Programme of Action (NAPA 2005), the trend is 4.0 mm/year at Hiron Point (Western coast), 6.0 mm/year at Char Changa (Central coast), and 7.8 mm/year at Cox's Bazar (Eastern coast). Future projections are also made by several research organizations like SAARC Meteorological Center (SMRC 2005) as well as from the IPCC TAR (IPCC 2001). Summarizing all these predictions, NAPA predicted the future trend in SLR as 14 cm in 2030, 32 cm in 2050, and 88 cm in 2100.

Natural hazards

The Bay of Bengal is a hotspot for cyclones and resulting storm surges. The frequency and intensity of cyclones and storm surges have increased manifold over the last few decades along the region in the warmer climate (BCCSAP 2009). A large part of coastal areas in Bangladesh is protected by polders. However, the dilapidated condition of the polders due to their age, faulty management (Baten *et al.* 2015), and repeated attacks by cyclones and storm surges, breaches are there in many places which allows the saline water to enter the inland easily, especially during a cyclone and subsequent storm surge and remain trapped for a long time (Haque 2021; BWDB 2022).

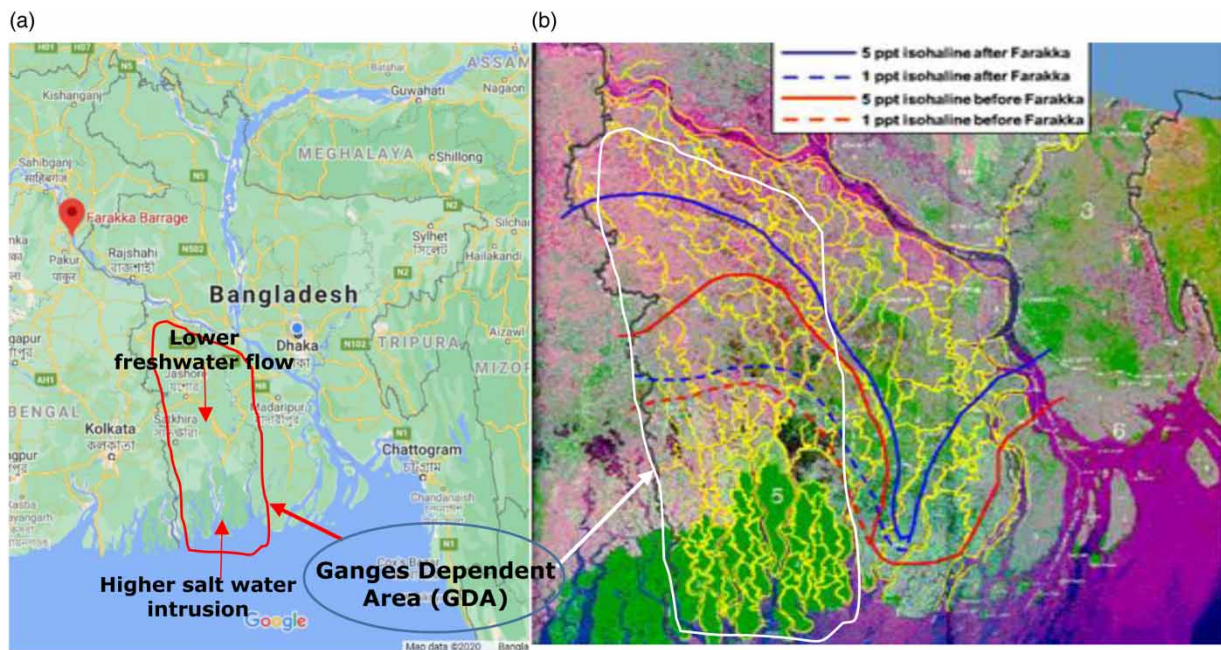


Figure 4 | (a) Location of Farakka barrage and (b) salinity map as observed before and after construction of the Farakka barrage (Source: Google map and IWM, Bangladesh; 2021).

Other anthropogenic impacts

Excess withdrawal of groundwater for drinking and irrigation purposes further allows salinity intrusion into the aquifer. Commercial cultivation of brackish water shrimp is also liable here. According to a study by Mahalder *et al.* (2018), the saline area due to shrimp farming along the three districts Khulna, Satkhira, and Bagerhat has increased from 3,74,370 ha in 1973 to 4,57,127 ha in 2015, i.e. by around 22.1%. Ultimately it causes saline water to contaminate both the surface and groundwater.

DEVELOPING INVENTORY OF WATER SUPPLY TECHNOLOGIES

Identification of technology types

Considering severe water scarcity along the study area, already a wide range of drinking water supply options are being practised by local communities. The study team prepared the inventory of these technologies through the following

- Extensive field visits along the three districts of Satkhira, Khulna, and Bagerhat at some selected locations to cover different types of technologies. The list of sites is shown in Table 1. Before field visits, information was collected from different secondary sources like academic research papers, NGOs, international development agencies, and government bodies about the types of technologies and prospective locations to visit them.

Table 1 | Number of water technologies studied

Study area	Number of water options studied	Ground water-based technology	Surface water-based technology	Both surface and groundwater	Rainwater-based technology
Dacop	21	6	5	5	5
Assasuni	17	4	6	3	4
Shyamnagar	26	7	7	6	6
Mongla	21	4	7	5	5
Rampal	18	4	7	3	4

- Questionnaire survey, FGD (Focus Group Discussions), and an adequate number of KII (Key Informant Interviews) were also conducted at the field visit sites.
- After a detailed investigation, the study team found a large variety of different drinking water supply technologies, which were later classified under 13 major categories that are prevalent along the region as listed in Table 2.

Figure 5 also showed some real pictures of some of the water supply facilities taken during the field visit by the study team. A further division of technology options is shown there in a tree diagram. Three major sources of freshwater were considered: surface water, groundwater, and rainwater. In some cases, both surface and groundwater were the sources.

Coastal Bangladesh is mostly rural so domestic and agricultural water demands dominate. However, this study specifically concentrated on potable water use, so domestic water uses are further classified under the categories as drinking, cooking, bathing, washing clothes, washing vegetables, and washing utensils. Technological options through which the above forms of domestic water supply are met in the study areas are listed in Table 3.

WATER QUALITY TEST

One of the major challenges of this water supply technology is to ensure the standard quality of water required for potable purposes. Water samples were collected from each of the representative technologies and tested in the laboratory – both raw

Table 2 | Broad classification of water supply technologies

Sl. No.	Broad class of technology	Technology in the field
1	Shallow tube well (STW)	STW at a number of places with sweet water pockets.
2	Deep tube well (DTW)	DTW at a number of places with sweet water pockets.
3	Managed aquifer recharge (MAR)	MAR by the University of Dhaka in one place. It was mainly for research purposes, but later continued to serve people.
4	Pond sand filter (PSF)	Mostly available all along the coastal region, especially rural areas, with community-based management approach under different categories as: a) PSF b) PSF with Solar c) PSF with UV + Solar d) PSF Chlorine-treated e) PSF bleaching powder-treated f) PSF-based school water supply
5	Pipeline water supply	A few of them available along the small town or business centers with government support under different categories as: a) Pipeline (DTW-based) b) Pipeline (PSF + solar) c) Pipeline (Desalination, RO), d) Pipeline
6	Desalination	Mostly available along the Upazila (Sub-district), small town or business centers or at some discrete point either with the support of government, NGO or Charity organizations like Ahsania Mission under different categories as: (a) DESAL-RO, Municipal (b) DESAL-RO, Commercial (c) DESAL, RO (d) DESAL, RO + UV (e) DESAL, carocel (f) DESAL, Basin Type
7	Bottled water	Bottled water supply commercially, also in big jars.
8	Community-Based Water Treatment Plant (CBWTP)	Available in some areas where there is a pocket of surface water reserve. Sometimes surface water is treated with chemicals to improve its quality using this treatment plant and distributed.
9	Dug well	Dug well at some places depending on the aquifer level
10	Catchment storage	Planned storage of water pond, channel or conserving in catchment.
11	Surface Water Treatment Plant (SWTP)	a) Surface water treatment b) Commercial chemical treatment
12	Rainwater harvesting (RWH)	a) RWHS -HH (motka) b) RWHS -HH (Tank) c) RWHS-HH (Tank with UV) d) RWHS-School-Based e) RWHS-HH (Tank + Bleaching Powder-Treated) f) RWHS-CBA g) RWHS-Commercial h) PSF-Based RWHS-School i) UV-Treated RWHS-CBA j) Bleaching Powder-Treated RWHS-CBA k) Modified RWHS-HH
13	Sweet water pond	Sweet water pond conserved and direct use of that water after boiling

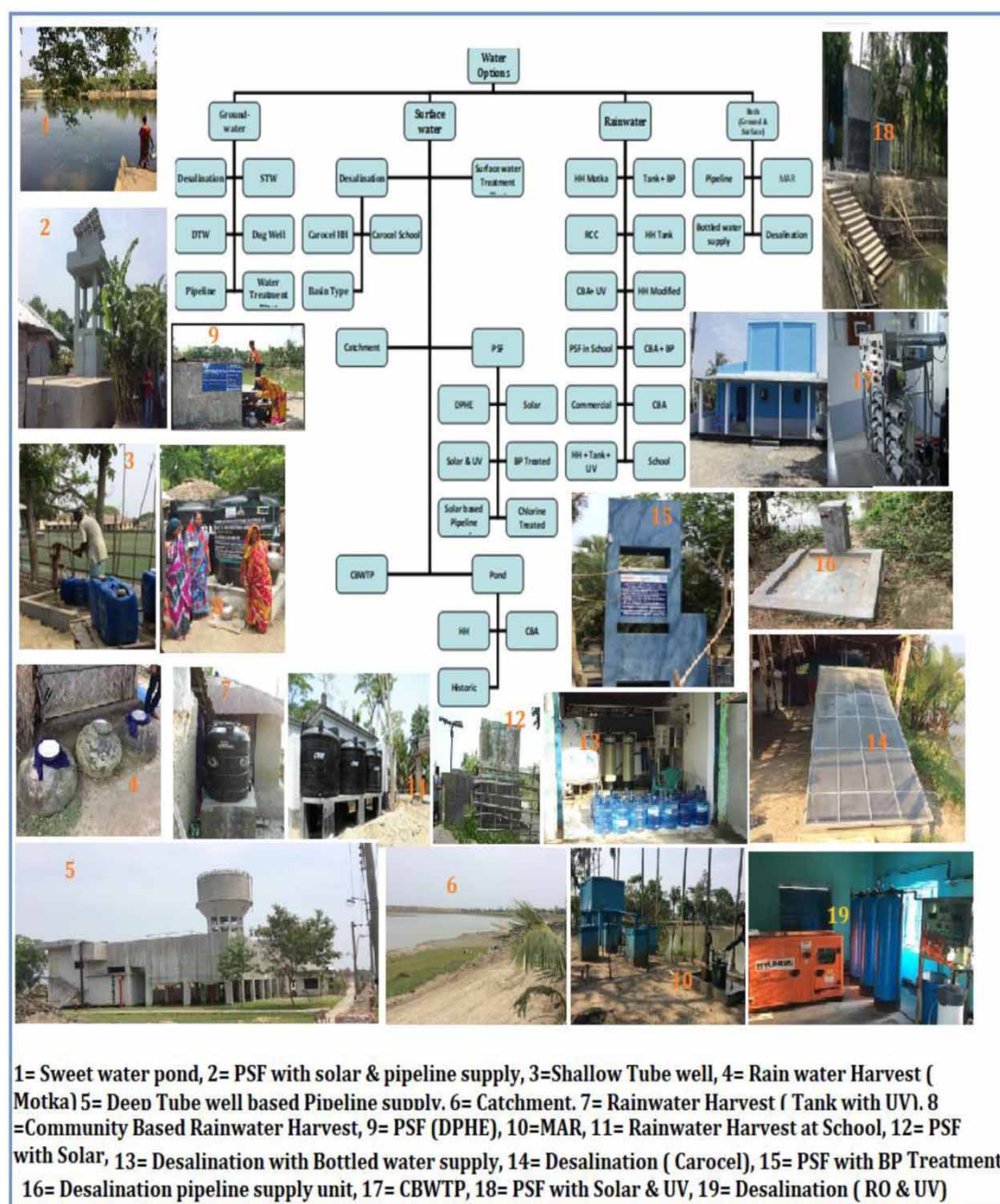


Figure 5 | Classification and pictorial display of water supply technologies based on the source of water.

water before the treatment and the treated water afterward. The parameters tested were pH, salinity (EC), TDS, DO, and faecal coliform. The test results show that the treated water mostly meets the water quality standard of Bangladesh and WHO, with the exception of MAR. The following findings can be summarized from the analysis of the water samples tested:

- No FC/*E. coli* was found in the treated water. In most of the cases, disinfectants were used, at least chlorine.
- pH: All the samples were within the acceptable limit.
- TDS: As a source of water, groundwater and rainwater contain minimum TDS. Most of the methods were quite effective in removing TDS.
- DO: DO level always improved due to the removal of TDS and organic contents.

Table 3 | Information regarding the sources of water for various purposes in the study area

Use of water	Water supply technology (% use)							
	PSF	STW	DTW	DESAL	RWHS	Pipeline	Pond	Others
<i>Drinking</i>	50.4	2.1	3.5	2.0	40.3	0.8	0.1	0.8
<i>Cooking</i>	18.5	1.8	2.3	0.7	1.0	0.2	74.4	1.1
<i>Bathing</i>	0.0	1.2	0.0	0.0	0.0	0.0	97.7	1.1
<i>Washing clothes</i>	0.0	0.0	0.0	0.0	0.0	0.0	99.8	0.2
<i>Washing vegetables</i>	2.8	1.1	1.4	0.0	0.0	0.3	93.8	0.6
<i>Utensils washing</i>	2.6	1.3	1.4	0.0	0.0	0.2	94.1	0.4

- EC: Raw water contains an excessive amount of salinity in the region. Specifically, while using STW and DTW with the source as groundwater. Rain water contains the least amount of salinity, as well as sweet water ponds. Desalination was the best for removing salinity from any source of water. Most of the other technologies thus relied on sweet water sources.
- All the test results were compared with the standard parameters used by BD Guidelines. [Table 4](#) shows a summary of all the parameters tested and their test results for both raw and treated water.

Table 4 | Water quality test result

Sl. No.	Source	Water type	pH	EC (µS/cm)	TDS (ppm)	DO (mg /L)	FC/E. coli (count)
1	WHO standard	For drinking water	6.5–8.5	400	500–1,000	4–6	Undetectable/100mL
	Bangladesh standard	For potable water	6.5–8.5	150–600	1,000	6	0
	DESAL-RO	Raw	7.55	1,472	736	7.51	–
		Treated	7.83	58.9	29.4	7.97	NIL
2	PSF DPH	Raw	7.82	1,300	654	3.76	–
		Treated	7.4	665	332	5.54	NIL
3	DESAL-RO + UV	Raw	7.57	4,550	2,260	7.06	–
		Treated	7.92	101.5	50.8	7.55	NIL
4	Desalination (Carocel)	Raw	6.8	30,600	15,100	4.2	–
		Treated	7.88	128.7	64.3	8.04	NIL
5	Desalination	Raw	7.29	7,090	3,500	2.79	–
		Treated	7.54	235	117.9	6.48	NIL
6	MAR	Raw	7.54	7,972	1,445	9.38	–
		Treated	8.32	5,730	–	5.07	NIL
7	PSF With UV	Raw	7.69	2,323	666	9.08	–
		Treated	8.22	1,323	–	5.01	NIL
8	PSF UV Solar	Raw	8.49	1,160	383	11.73	–
		Treated	8.18	875	–	5.15	NIL
9	MAR	Raw	8.36	2,068	1,033	12.17	–
		Treated	7.87	1,949	–	5.15	NIL
10	Chlorine Supply	Raw	8.02	1,112	406	9.49	–
		Treated	8.23	929	–	5.1	NIL
11	PSF Pipeline	Raw	9.08	344	172	12.29	–
		Treated	7.5	337	–	4.69	NIL
12	RWH (Tank)	Raw	8.01	62.8	31.3	11.11	–
		UV-Treated	7.19	47	–	5.17	NIL
13	Supply Water system	Raw (Pond)	7.81	1,012	406	9.31	–
		Treated	8.24	884	–	5.05	–

ANALYSIS OF FGD, KII, AND OTHER INTERVIEW RESULTS

Analysis of the result obtained from the FGD, semi-structured interview, household survey, and KII, as mentioned in Table 5, revealed the following findings:

- Availability of safe drinking water is a burning issue and a major daily problem across the whole study area. It has been clearly evident from all respondents' responses and also during physical visits to the affected areas.
- The situation is aggravated after the occurrence of natural calamities like cyclones, storm surges, or tidal flooding. Saline water further aggravates those surface water sources during such calamities and takes years to flush out.
- As a result, many people have no option but to drink saline or impure water from tube wells or other surface water sources. Consequently, they are suffering from salinity effects as well as water-borne diseases such as hypertension, allergy, skin diseases, cholera, and diarrhoea.
- Water supply systems in the study areas are mainly controlled and monitored by the government organization DPHE, which mostly provides water supply facilities up to the local town or municipality levels. Even though some NGOs and donor agencies installed facilities at a number of places, these attempts are visibly insufficient compared to the demand. Many of the facilities are malfunctioning due to a lack of maintenance. Installed by donors, the maintenance cost later is usually borne by the locality.
- Most of the households depend largely on community-level sources, as well as household rainwater harvesting methods for drinking water. Collecting water still results in extra costs, labor, and hardship for the people.
- Poorer households, being unable to spend money, use the traditional method of rainwater harvesting in earthen pots. But storing drinking water in earthen pots is also risky in terms of quality and taste when stored for a longer period.
- Women and girls, who are generally responsible for household water collection, now have to travel long distances to fetch pure drinking water. The study reveals that now women and girls in some of the affected areas have to spend an additional 1–2 h every day collecting drinking water from nearby localities. Many of the school-going girls are affected and had to stop studying for this reason.
- Among the technologies, PSF has been a major means of water supply, but in many cases found to be malfunctioning with poorer quality of water. The situation is worse during the dry season.
- People in the study area prefer the supply of water by using advanced technology such as desalination through reverse osmosis. However, it is too expensive. Some philanthropic organizations, and in one place local administration, provided it free of charge. Commercial supply of water is also evident and gradually getting to market. However, only the richer part of the community can afford it.
- A ray of hope is that safe drinking water technologies and facilities are increasing day by day, as the demand is rising. Advancement in technology is also trending. Within the last 5 years, most of the technologies blended the solar power concept for their operation. There is ample scope for commercialization of low-cost drinking water supply in the region.

Table 5 | The fieldwork and data collection

Survey types	Sample design			Target group
Questionnaire survey	115 households surveyed			User of the water supply facilities. On an average around 10 persons per technology.
Focused Group Discussion (FGD)	FGD Nos. 02 02 02 02 02	Upazila Sample Rampal Dacope Mongla Shyamnagar Assasuni	Total FGD 10	FGD composition of personnel – Female HHH-2 persons – Male HHH-2 persons – Teachers-2 persons – NGOs personnel-2 persons – UP members-4 persons – Ward members (Male)-4 persons – Ward members (Female)-4 persons
Key Informant Interview (KII)	No. of person 4	No. Upazila covered 5	Total persons 20	Community leaders and experts

DETAILED ANALYSIS OF TECHNOLOGIES

Geographical variation

Geographical variation of adopting technology was based on the quality of water, funding support, and financial ability of the consumers. The areas which are urban or semi-urban were using reverse osmosis, rainwater harvesting with UV, and pipe water supply by the municipal authority. In rural areas, PSF and rainwater harvesting without any treatment are common. Again the choice of option relates to the severity of the problem in the zone, too. Areas closer to the coast with higher salinity levels were found to adopt desalination plants at higher density, either supported by local administration or by donor agencies and NGOs.

Adaptation trend

As mentioned earlier, the severity of the salinity problem along the three districts was aggravated mostly after the construction of the Farakka barrage. Along with other anthropogenic factors like shrimp cultivation, the further impact of climate change and the resulting consequences like increased frequency of cyclones and storm surges aggravated it. History shows that since the late 1980s, the situation has become unbearable and indigenous technology for water supply PSF was introduced in many parts of the region. Rainwater harvesting has also become popular at an individual level. For the last two decades, advanced technology like desalination is getting popular as the condition worsens further and large-scale production of drinking water was indispensable. Many NGOs contributed there and in 2007 they started to work under a common umbrella as HYSAWA (Hygiene, Sanitation and Water Supply), i.e. a consortium of all NGOs working in the field of water supply and sanitation along the coastal zone of Bangladesh.

Acceptance

Each of the water technologies has its own merits and demerits to compromise between economy and quality. Few of the technologies have proven their potential to serve good quality potable water but a few old technologies are struggling to maintain its quality. All (100%) respondents preferred water through a desalination process like reverse osmosis. Acceptance of other technologies is PSF with UV (60%), Deep Tube well (DTW) (40%), and normal PSF (25%), respectively.

Water price

Water price varies from technology to technology, area to area, or even season to season. Although most of the expensive technologies have been installed by the DPHE, NGOs, and donor agencies, for maintenance purposes a token contribution is taken from the users. Among all the technologies, the water price for *Desalination* through *Reverse Osmosis* is the maximum. Still, a large mass of people nowadays is ready to pay for it because of its quality. As a result, some organizations commercially installed reverse osmosis plants in the Dacope and Shyamnagar areas. Water costs resulting from other low-cost technologies varies, but are much lower than desalination.

Implementing organizations

Government organizations, donor agencies, NGOs, community organizations, research institutions, and some corporate bodies are the implementers of the technologies. In most cases, they provide water free of cost or at a subsidized price. About 10% of the technologies were from the personal level, 35% from the government, 40% from NGO and donor agencies, and 15% from the community. Names of a few organizations are BRAC, DPHE, NGO Forum, Water Aid, Practical Action, Rupantor, Sushilon, GIZ, Cafod, Friendship, Bachte Shekha, ITN BUET, RDA, Municipal, Ad-Din, CARITAS, World Vision, UNNAYAN ONNESHON, Nobolok, Catholic Mission, Prodiapon, CBA, OXFAM, HSBC, and personal initiatives.

Design life

Depending on the materials used to develop the technology, chemical used, and operation methods, etc. the design life of technologies varies. Most of the technologies sustain an average design life of 5–10 years. Ironically, some sophisticated technologies like Carocel-based desalination, chlorine-treated PSF, etc. were found to have a shorter design life, because of poor maintenance. Maintenance of these advanced technologies is a bit costly so local people later could not continue them unless fully supported by the donors. Actually, proper management and maintenance processes can extend the design life of a technology. Some low-cost mediocre technologies like PSF or RWH were found to continue operation for a longer period, because of low maintenance costs.

Technology type and challenges

There are some age-old indigenous technologies, which have existed for a long time, such as PSF or RWH. Advanced technologies like desalination are rather newer. Every technology has some challenges in terms of the source of raw water, raw materials used, operation and maintenance, etc. Table 6 lists some of those challenges.

Energy/operation options

The operational options of the available technologies are not the same. Some of them can be operated manually, some are based on electricity, some are solar, and some have dual options like solar/electricity, solar/diesel, and electricity/solar. Day by day, newer installations are trying to use renewable energy sources like solar energy.

Management options

Most of the technologies are managed by the community together. However, a 5- to 8-member team is usually formed for overall management including the collection of monthly charges, troubleshooting during failure, regular maintenance, chemical management, and other related issues. NGO-driven and commercial plants are managed by their own people if they are not handed over to the community. Water technologies set up and run by the government are managed by the DPHE mostly, sometimes by the local administration. Involving local people in the maintenance process is always found to be effective.

OVERALL SUITABILITY OF TECHNOLOGIES

In view of the discussion above, Table 7 summarizes different technologies managed by different organizations and a qualitative assessment of suitability and problems associated with them. Apart from the discussion, the approach followed by UNFCCC to classify technology has also been incorporated here. As mentioned already, technology for adaptation has been increasingly emphasized among climate experts, policymakers, and UN climate change negotiations. A number of

Table 6 | Drinking water supply technologies by price

Water price	Technology
Free	STW, DTW, PSF, DESAL(RO), Municipal, Bleaching Powder-based PSF, RWHS-HH(MOTKA), RWHS-HH(Tank), RWHS-School , PSF-Based RWHS-School , PSF-Based School Water Supply, Sweet water pond, Catchment
30–50 Tk./Family/ Month	DTW, MAR, PSF, Pipeline (Solar PSF), DESAL(RO&UV), Chlorine-Treated PSF, CBWTP, Surface Water Treatment Plant , RWHS-CBA, UV-treated RWHS-CBA , PSF(Solar) , Pipeline(DTW-Based)
100 Tk./Family/Month	PSF With UV and Solar
110–150 Tk./Family/ Month	Desal (RO), Desal (RO + UV)
150–200 Tk./Family/ Month	Bottled Water Supply, Commercial Chemical-Treated WTP, DESAL(RO)

Table 7 | Drinking water supply technologies and challenges

Challenges	Technology
Not suitable for all household	STW, DTW, MAR, Chlorine-based PSF, CBWTP
Raw materials availability problem	DTW, MAR, Solar-based PSF, Desal (RO), Desal (RO + UV), Chlorine-based PSF, BP-Treated PSF, CBWTP, Bottled water plant, Surface water treatment plant, RWHS (UV, Solar), Pipeline (DTW-based)
Possibility of bacterial attack	PSF, RWHS (Tank, Motka), RWHS-CBA, Dugwell
Cleaning difficulty	PSF, Solar PSF, RWHS (Tank), RWHS-CBA, PSF-Based RWHS-School
Possibility of contamination from external source	Catchment, Sweet water pond, Dugwell
Raw fresh water shortage	Pipeline, Surface water treatment plant, DTW, STW

Table 8 | Suitability of technologies

Sl. No.	Class of technology	Tech. type	Management approach	Acceptance	Water price in (BDT/ Family/ Month)	Design life (in yrs)	Reason for production variation	Suitability	Enabler	Barrier
1	STW	Old	Personal, NGO, GO	Good	Free	5–10	Drop of water table	No treatment required, quick installation	Proper location, pump cost subsidy	GW Table, seasonal variability
2	DTW	Old	CBO, GO, NGO	Good	Free, 30–50	>10	Drop of water table	No treatment, Longer availability	Proper location, Cost subsidy and technical support	Depth of aquifer, salinity intrusion
3	MAR	New	NGO	Neutral	30–50	5–10	Electricity	Natural, no chemical use, and aquifer recharge	Further study and technical support	Technical complexity, and quality issues
4	PSF	Old	NGO, GO,	Neutral	Free	<5	Raw water	Indigenous technology, cheap and manageable	Further improvement, disinfection	Seasonal effect, quality issues, maintenance
	PSF (modified with Solar/UV)	New	NGO	Good	Free	5–10	Raw water, equipment's	Better quality, availability, but still cheap	Trained manpower, cost subsidy	Maintenance, production rate, installation cost
5	Pipeline Water Supply (PWS)	Old	GO	Good	30–50	>10	Electricity	Better coverage and readily available	Government support for policy and technology	Source of freshwater, treatment plant
	PWS (with Solar/ Desalination)	New	GO	Good	50–100	>10	Cloudy weather	Better coverage and the better quality	Government subsidy, commercialization	Cost and technology, maintenance
6	Desalination (Desal)	New	NGO, GO, Commercial	Best	110–150	<5	Electricity, chemicals, cost	Best quality community-based water supply	Technical and Policy support for commercialization	Cost and technology, maintenance
7	Bottled Water Supply	New	Commercial	Best	150–200	>10	Electricity, chemicals, cost	Best quality potable water possible	Policy support and market study for commercialization	High cost, market quality assurance
8	CBWTP	New	CBO	Good	Free	>10	Source dependent seasonality	Greater engagement of the community	Cost reduction through greater participation	Space, source of water and maintenance

(Continued.)

Table 8 | Continued

Sl. No.	Class of technology	Tech. type	Management approach	Acceptance	Water price in (BDT/ Family/ Month)	Design life (in yrs)	Reason for production variation	Suitability	Enabler	Barrier
9	Dug Well (DW)	Old	Personal	Neutral	Free	5–10	Seasonal change of GWT	Ingenious technology at household level	Further research and improvement, location survey	Water quality, and GWT lowering
10	Surface Water Catchment	Old	GO	Neutral	Free	>10	Shortage of rainfall	Natural storage of water, GWT recharge	Land for storage, policy support for long term	Contamination chance, lack of space
11	Surface Water Treatment Plant (SWTP)	Old	GO	Good	30–50	>10	Space, electricity and chemicals	Cost effective and can serve many people	Cost effective with moderate water quality	High installation cost, operation and maintenance
12	RWH (traditional)	Old	Personal, NGO, CBO	Neutral	Free	<5	Short of rainfall, contamination	Low-cost indigenous technology	Further research for customization to need	Seasonality, quality issues, storage
	RWH (Modified with disinfection)	New	NGO	Good	30–50	5–10	Seasonality in rainfall	Improved and longer period of storage	Technology support, further research	Chemical and storage cost, seasonality
13	Sweet Water Pond (SWP)	Old	Personal, GO	Neutral	Free	>10	Short of rainfall	Age-old indigenous technique	Improvement: seepage and evaporation issues	Varied use and Contamination, seasonality

UNFCC documents as UNFCC (2010), UNFCC/ TP (2006), UNFCC/SBSTA (2007), and the Technology Executive Committee (TEC 2017) have identified a few criteria to evaluate an adaptation technology. Three major criteria they adopted are the suitability of the technology, enablers and barriers. Following the above guideline, a further evaluation of the 13 most available technologies is done and presented in Table 8.

CONCLUSION

Salinity intrusion along the interior coast of the south-western part of Bangladesh is significantly evident, which ultimately is limiting the freshwater availability of people living there, posing a serious threat to public health. Alternate water supply technologies are already in practice to adapt to the problem. A detailed study of the freshwater options, evaluation of their technical effectiveness, and analysis of water quality has been done to assess the present status of the technology.

In the past, most people were highly dependent on pond water for their daily work other than drinking. People then gradually adopted low-tech or indigenous technologies such as shallow tube well (STW), DTW, rainwater harvesting (RWH), and PSF. However, nowadays advanced technologies such as reverse osmosis, UV-treated or bleaching-treated pipeline supply water, and bottled water are becoming popular.

A number of philanthropic organizations, NGOs, donor agencies, and the government are also trying to support people during this ever-looming calamity. However, the main weaknesses identified are the lack of proper coordination mechanisms among these agencies, a detailed inventory of technologies, and proper research to identify the suitable technologies appropriate for a particular region. It is noteworthy that there is ample scope to flourish indigenous as well as advanced technologies, but at low cost.

Unfortunately, most of the technologies adopted by different organizations are being implemented on an *ad hoc* basis, with a lifetime of less than 5 years. In most cases, after installation, while handing over to the community, because of lack of funding and technical know-how, maintenance becomes difficult and life span is thus reduced. In terms of treatment effectiveness (raw and supply water quality), desalination is shown to be the best. PSF, though widely used, cannot maintain quality up to the standard. UV-treated solar PSF and Desalination with RO and UV can be sustainable drinking options if some appropriate commercial models for them are in practice. A questionnaire survey revealed that people have the willingness to pay for better-quality drinking water. Still, for the poor and marginalized groups, government subsidies and support from NGOs are direly needed. Among the management options, the community-based approach may work better.

Further study on the improvement of technologies of some conventional techniques like PSF and RWH, or an economically viable commercial model of advanced technology like desalination, needs to be explored. Bangladesh received a large amount of precipitation during monsoon. How to store this monsoon water and utilize it during the dry season is another prospective field of research in the future.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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