Bangladesh CTCN-TA Project

Fact-finding report

April 2019

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1. Background

1.1 Global water scarcity

Water scarcity is a phenomenon occurring when the human and ecological demand for water exceeds the available amount during a certain period or when poor quality restricts its use. It is a more inclusive and broader concept. Water scarcity generally involves water stress, water shortage or deficits, and water crisis. Water stress is the difficulty of obtaining sources of fresh water in some period of time; whereas water shortage refers to climate change induced causes; and water crisis is when available water is less than prevailing demand [1]. Water scarcity can result from two mechanisms: Physical or absolute water scarcity results from inadequate natural water resources to supply a region's demand, and economic water scarcity results from poor management of the sufficiently available water resources [2]. Water scarcity already affected every continent and over 2.8 billion people around the world suffer at least one month in a year. Moreover, more than 1.2 billion people lack access to clean drinking water. In general, various indexes has been utilized to express the water stress. For instance, WRI[3] . describes water stress as the ratio of total withdrawals to total renewable supply in a given area and estimated the respective stress index of various countries (see Fig.1). Accordingly, the analysis result finds that 37 countries currently face "extremely high" levels of water stress, meaning that more than 80 percent of the water available to agricultural, domestic, and industrial users is withdrawn annually.

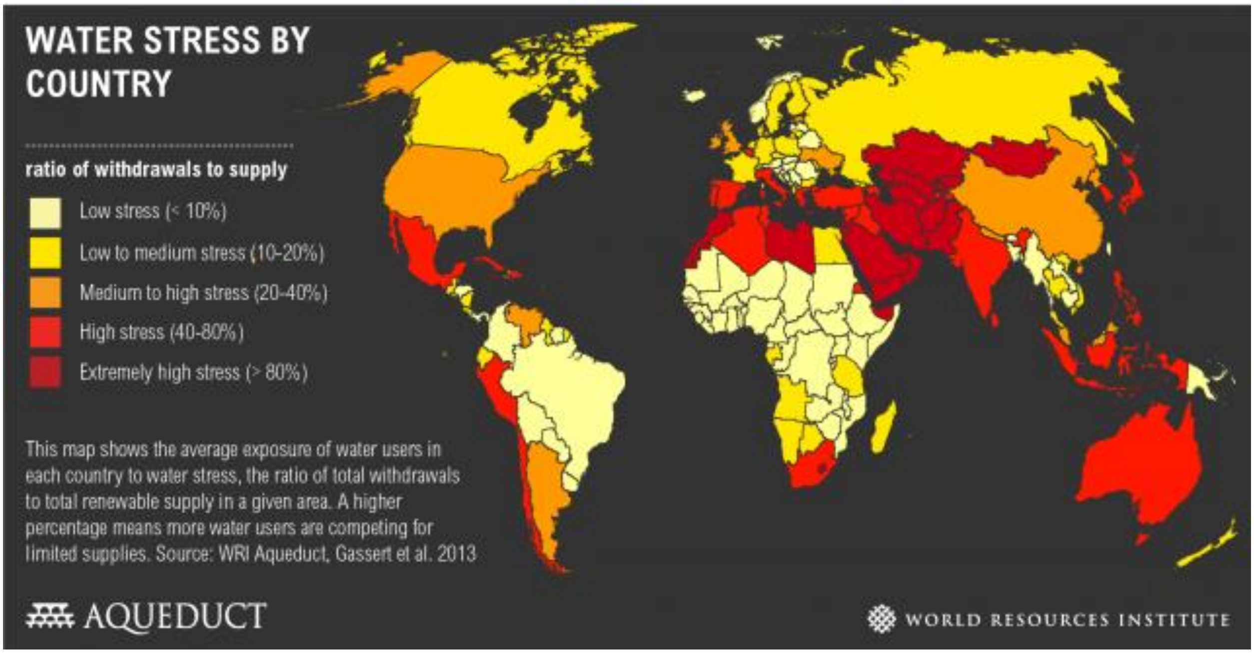

Figure 1. Water stress by countries (Referred from World Resources Institute)

[1] "Water Scarcity," ScienceDaily, accessed February 2, 2019, https://www.sciencedaily.com/terms/water_scarcity.htm.
[2] "Water Scarcity," in *Wikipedia*, January 31, 2019, https://en.wikipedia.org/w/index.php?title=Water_scarcity&oldid=881142879.
[3] "Water Stress by Country | World Resources Institute," accessed February 2, 2019, https://www.wri.org/resources/charts-graphs/water-stress-country.

There are also similar global water scarcity maps released by other institutes.

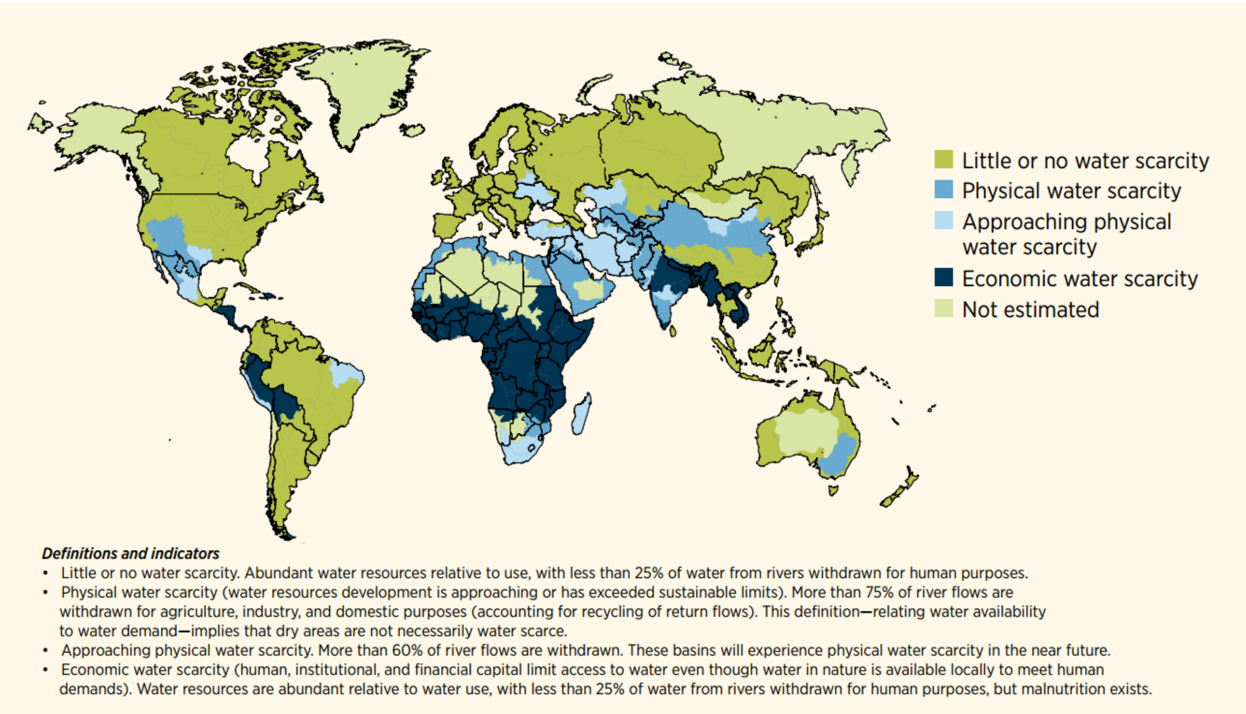

Figure 2. Global water scarcity maps (Source: UN World Water Development Report 4 (2012))

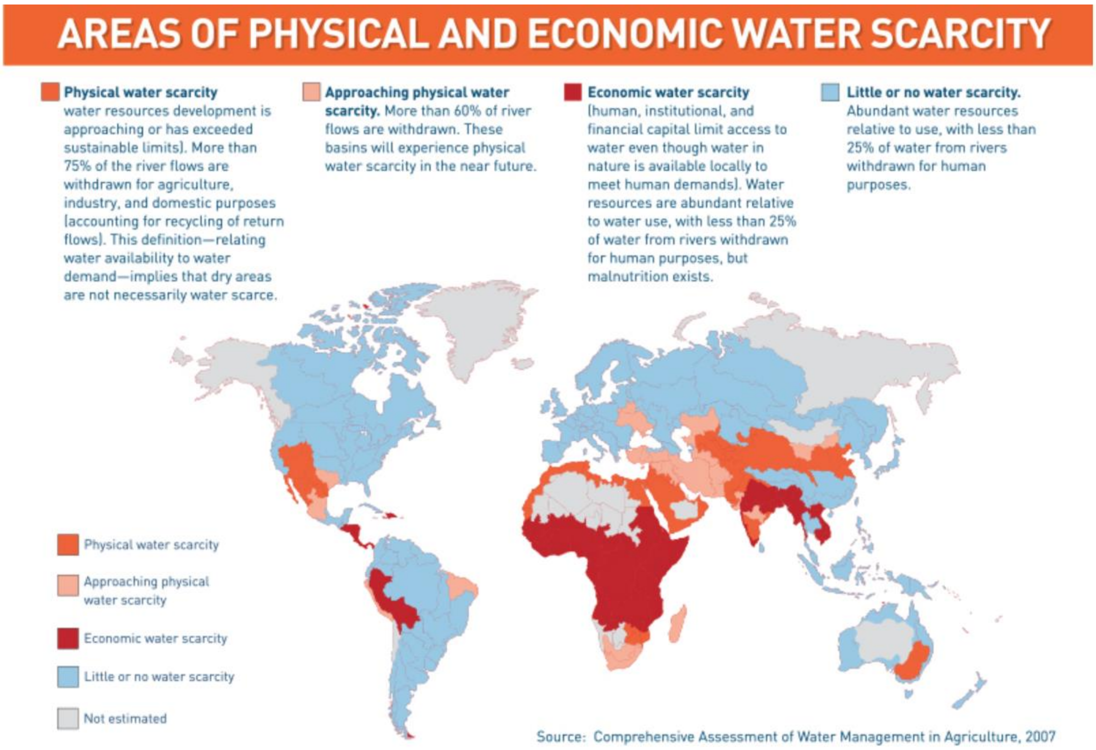

Figure 3. Areas of physical and economic water scarcity

World vision [4] has also recently released important global water crisis facts as follows.

- 844 million people lack basic drinking water access, more than 1 of every 10 people on the planet.
- Women and girls spend an estimated 200 million hours hauling water every day.
- The average woman in rural Africa walks 6 kilometers every day to haul 40 pounds of water.
- Every day, more than 800 children under age 5 die from diarrhea attributed to poor water and sanitation.
- 2.3 billion people live without access to basic sanitation.
- 1 billion people practice open defecation.
- 90 percent of all-natural disasters are water-related.

Causes of global water scarcity

Some of the most dominant causes for water scarcity are as follows [5]:

✓ Water pollution: There are many sources, for example pesticides and fertilizers that wash away from human waste or industrial waste and pollute the ground water.

✓ Inefficient management*:* Agriculture uses 70% of the world's accessible freshwater, however approximately 60% of the used water is wasted. This insufficient use of water is drying out rivers, lakes and underground aquifers.

✓ Population growth*:* The population growth already occurred and will continue at an unpredictable rate. As stated by the LPR 2014, around 200 river basins, home to 2.67 billion people, already experience water scarcity.

1.2 Water scarcity in Bangladesh

Bangladesh has one of the highest population densities in the world, with a population of 160 million living within 57,000 square miles. Of those 160 million people, 4 million lack safe water and 85 million lack improved sanitation. Lack of access to safe water and improved sanitation facilities in rural areas, overcrowded conditions, and a lack of healthy ways of disposing waste in urban centers contribute to the water and sanitation crisis in Bangladesh. The World Health Organization (WHO) estimates that 97 per cent of the people of Bangladesh have access to water and only 40 per cent have proper sanitation. With a staggering 60 per cent of the population that must endure unsafe drinking water, the nation is in danger. The availability of this water greatly fluctuates throughout the year as the warmer season brings massive amounts of water in frequent monsoons and the cooler season brings drought. The infrastructure cannot adequately deal with the barrage of water in monsoon season, so the water is not saved for the drier months. Of the water that is available, over 80 per cent is used for agriculture. Some of the following maps show the drought and water scarcity status of Bangladesh these days (see Fig. 4 and 5)

[4] "Global Water Crisis: Facts, FAQs, and How to Help," *World Vision* (blog), May 18, 2018, https://www.worldvision.org/clean-water-news-stories/global-water-crisis-facts.
[5] "Water Scarcity – The Main Causes," accessed February 2, 2019, https://www.eoi.es/blogs/imsd/water-scarcity-the-main-causes/.

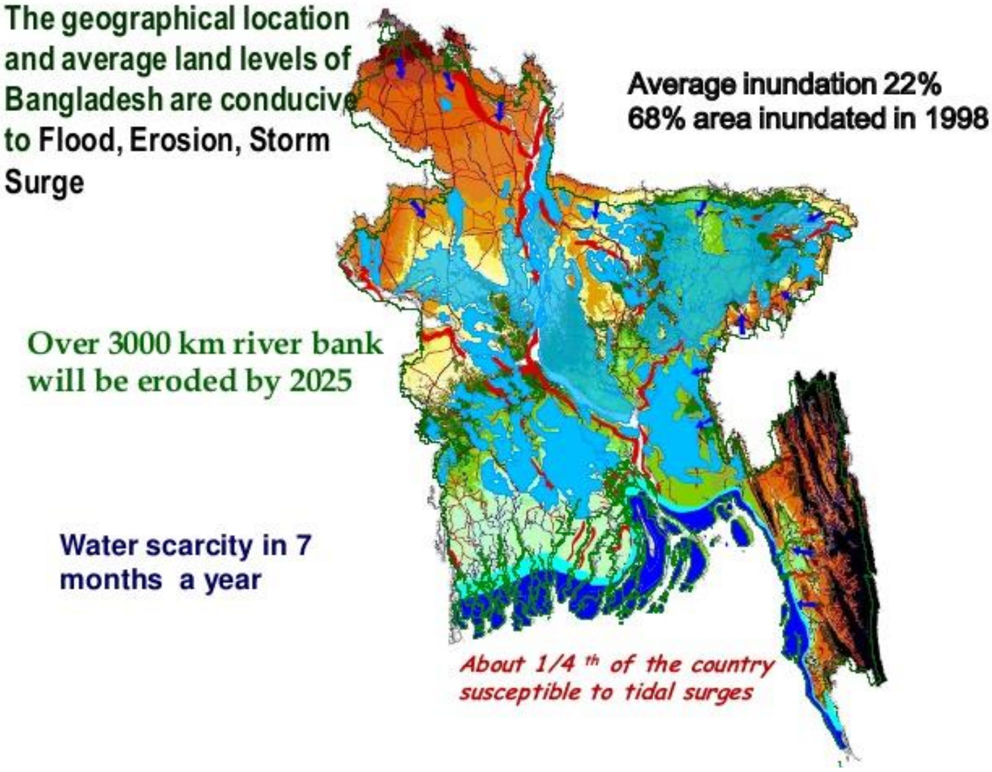

Figure 4. Water status in Bangladesh

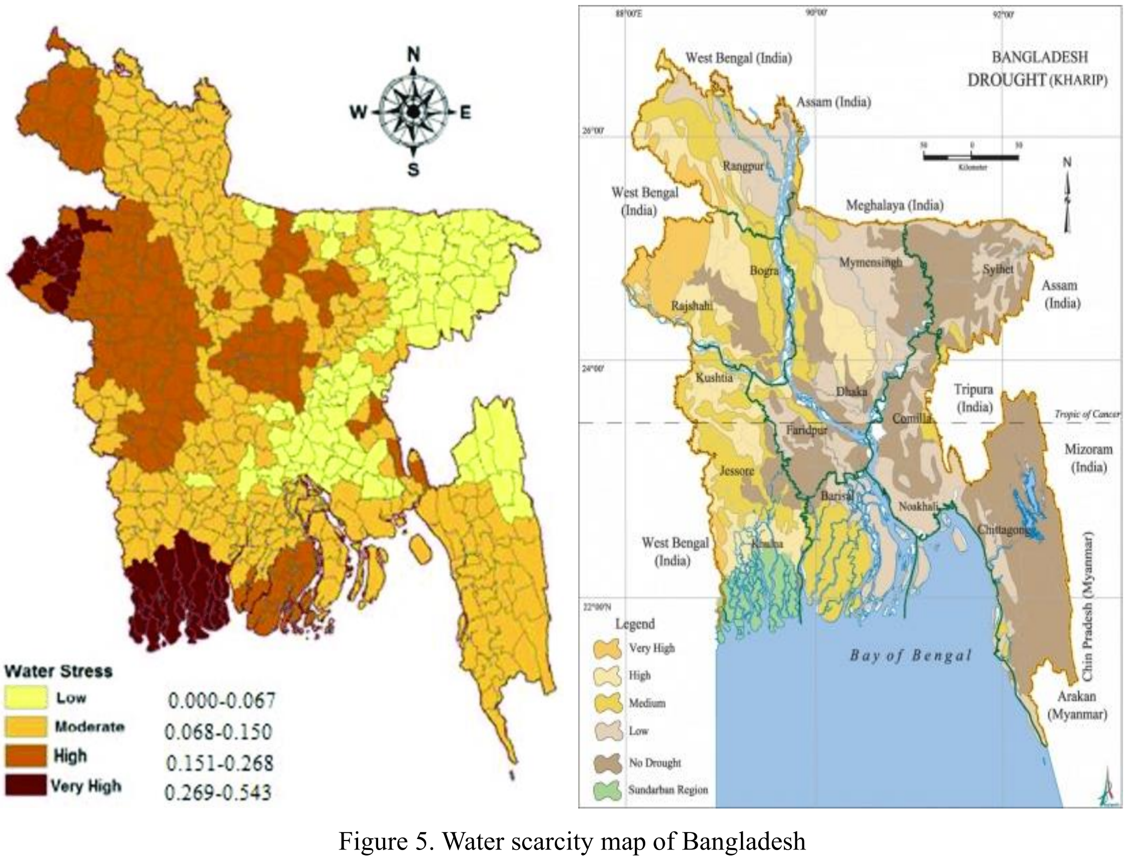

Figure 5. Water scarcity map of Bangladesh

Causes of water scarcity in Bangladesh

Several aspects like change in climatic condition, irrigation practice and drainage characteristics of major rivers are the prime factors for water scarcity. In addition, arsenic, salinity, drought, natural hazards (i.e. flood, cyclone) and decreasing water table are also very important components. The great rivers (see Fig 6) (Brahmaputra, Meghna, and Ganges) originate from other countries and the amount of water that eventually gets to Bangladesh is greatly limited by the booming populations of China and India. Only 7 per cent of the total land that creates the watersheds for these rivers is in Bangladesh. Therefore, the Bengalis have very little control over how much water they receive from these sources.

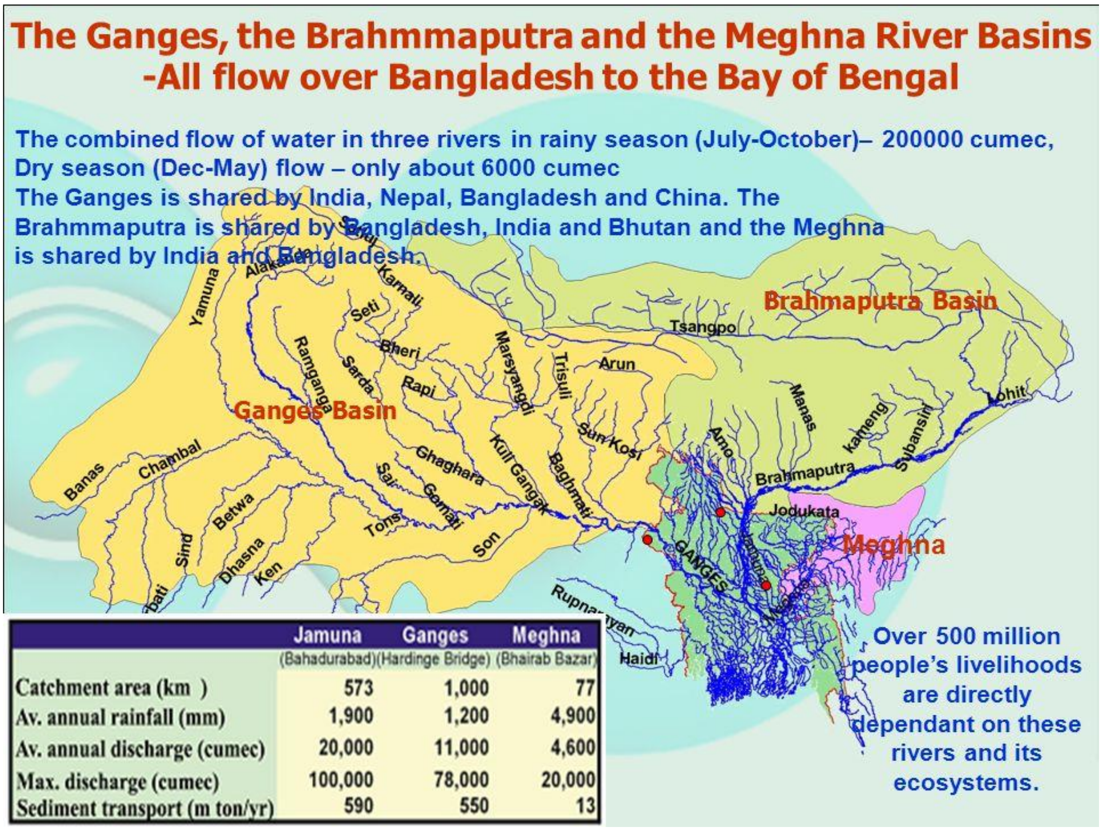

Figure 6. Basins in Bangladesh

Fifty-seven transboundary rivers feed into Bangladesh, carrying a peak water flow of an estimated 1.5 million cumecs (m^3 per second)[6]. These rivers effectively create the world's second largest riverine drainage basin, the Ganges–Brahmaputra–Meghna (GBM) Basin. Since time immemorial, this river system has supported and maintained the agrarian societies of the basin. However, riverine environmental stress is now a challenge to these societies, with long-term consequences for food security, health and development in the region. Bangladesh is dependent on river water for human consumption, crop irrigation, fisheries, transportation and conservation of biodiversity. With rapid industrialization and population growth in the region, agrarian demand for water is also competing with hydropower and industrial demand. In parts of the GBM Basin there are disturbing signs of decreasing dry-season river flows with serious consequences for agricultural yields and groundwater replenishment (see Fig above)

[6] Åshild Kolås, "Water Scarcity in Bangladesh. Transboundary Rivers, Conflict and Cooperation," Report number: 1/2013; PRIO Report Project: India in the World: Emerging Perspectives on Global Challenges (INDWORLD), accessed March 21, 2019, PRIO Report.

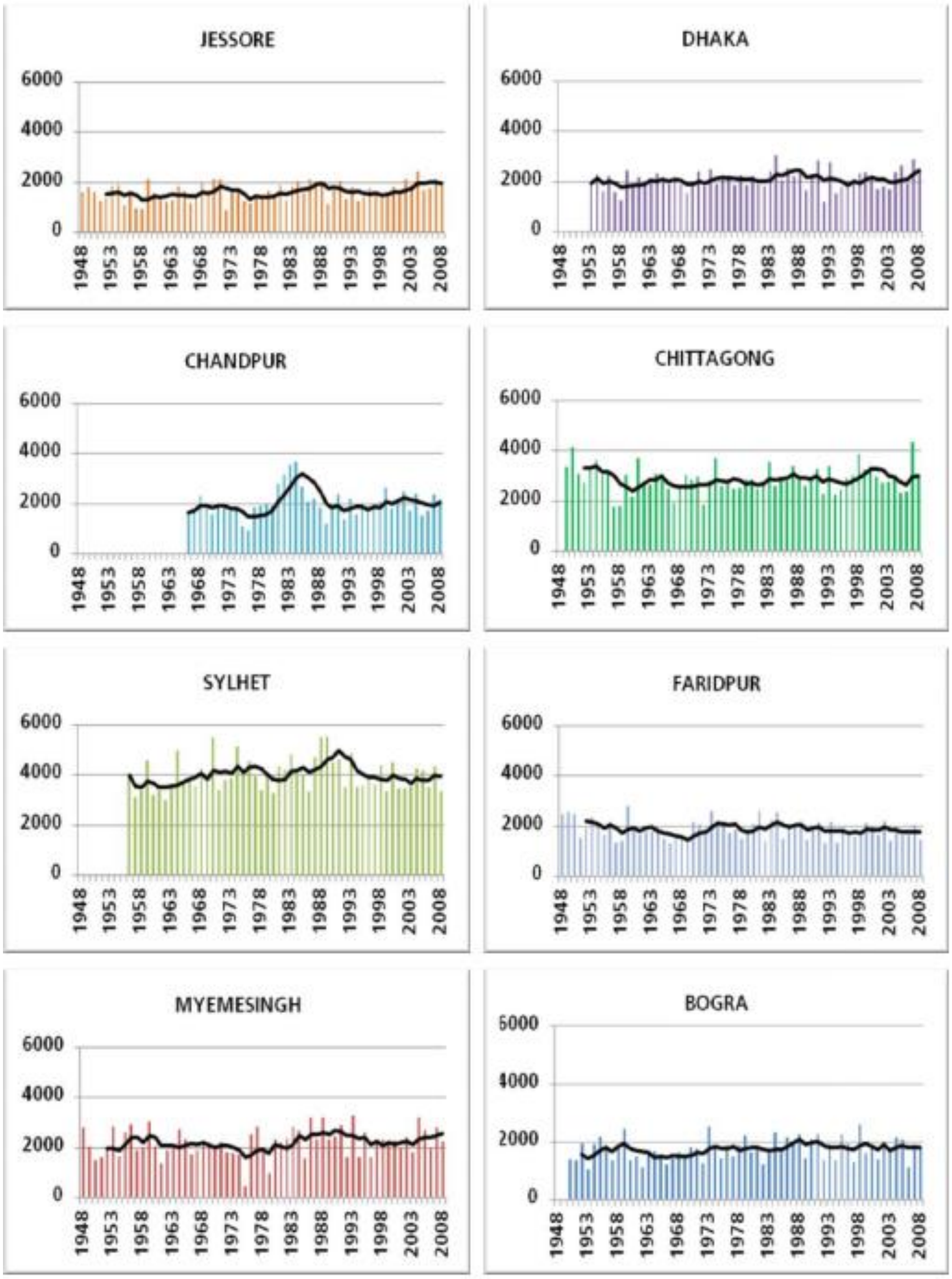

Figure 7. Long-term annual rainfall totals (mm) for eight districts in Bangladesh

Common water challenges in Bangladesh

Water salinity rise/ Lack of sweet water: In Bangladesh, the salinity of surface and groundwater is determined by a combination of factors, including river flow, tidal surges, rainfall and groundwater extraction, as well as the influence of sea-level rise and other climatic variables. Due to sea-level rise, saline water intrusion in the coastal areas increased. One of these factors is the construction of the Farraka Barrage, a structure in India that diverts water from the Ganges to irrigate Indian soil. This decreases the flow of the Ganges thereby causing the salinity to be increased. Salinity is also rising due to shrimp farms in various bodies of fresh water whereby salt water is deliberately retained in ponds to cultivate shrimp. This has contributed to increased groundwater salinity, soil degradation, and a lower yield and acreage of rice. Climate change has also caused rising sea levels which are claiming precious water from freshwater river deltas. This increase in salinity affects the soil and the quality of the ground water. The IPCC 2007 study showed that the global sea level rose at an average rate of 1.8 mm/year between 1961 and 2003 and this rate is being accelerated from 1993 to 2003 to about 3.1 mm/year. This sea-level rise during the last 22 years for Bangladesh is shown to be 4, 6 and 7.8 mm/year for three coastal stations (Hiron Point, Char Changa, and Cox's Bazaar) , which is higher than the global sea-level rise over 100 years.

River water source depletion: Brahmaputra, Meghna, and the Ganges are the biggest rivers in the country and all starts in other neighbour countries and a limited amount of water eventually arrive at Bangladesh as the increasing population in the neighbouring India and China also explores the same source from the upper catchment. Consequently, Bangladesh community has got only 7% of the total watershed of this river in the country so that extremely limited control and usage over this river is possible. Declination of fresh water flow from tributaries resulted in the salt saturated land. In saline areas, this has led to an increased burden on people, in particular women and children of poor households to collect fresh water. Women in coastal areas need to go miles to collect a pitcher of safe drinking water. Worsening weather extremes that bring floods, storm surges and cyclones are contributing to increases in water salinity and other problems accessing clean water. The World Bank study confirms surface water sources have already dried up in many parts of the country, which will have a heavy impact on access to drinking water, sanitation, and ecosystems.

Depletion in ground water replenishment: In coastal areas, about 82% drinking water is collected from ground water. However, groundwater levels in the city are falling drastically as a result of excessive extraction to meet its growing needs. For instance, Dhaka's underground aquifers are usually recharged with water that percolates underground in nearby districts, but the levels of underground fresh water in those districts have dropped, allowing seawater to start seeping into the aquifers. If this continues drinking water from such ground water sources could become increasingly undrinkable. In the northern Bangladesh, drought-prone Barind area, one has to dig more than 350 meters to get safe drinking water and this situation is expected to even worsen owing to reduced underground replenishment from the unusually low rainfall in the area. The other factors hindering the potable use of ground water sources are arsenic, dissolved iron, and bacterial contamination,

Rainfall variability: rainfall across Bangladesh has halved and become more unpredictable over the past five years. That has led to problems including growing salinity in groundwater. Some recent study revealed that winter rainfall has the maximum rainfall variability even more than 100 % while monsoon has the minimum around 30 %. The seasonality index also shows that rainfall in Bangladesh is characterized by markedly seasonal with a long dry season. There are also studies indicated a significant increase in the average annual and pre-monsoon rainfall of Bangladesh. The number of wet months is found to increase and the dry months to decrease in most parts of the country. Seasonal analysis of wet and dry months shows a significant decrease of dry months in monsoon and pre-monsoon

Arsenic problem: The groundwater, which is used by nearly 90% of the population, is also contaminated with arsenic. According to the WHO, the levels of arsenic have contributed to the largest mass poisoning in history, affecting an estimated 30-35 million people in Bangladesh. Exposure to arsenic can cause cancer and severely damage many integral systems in the human body. Arsenic has been shown to be the cause of death for 1 out of every 5 people in Bangladesh (see Fig 8). In addition to the health impact of arsenic, there is also a significant amount of sanitation problem linked to the expansion of slum dwelling.

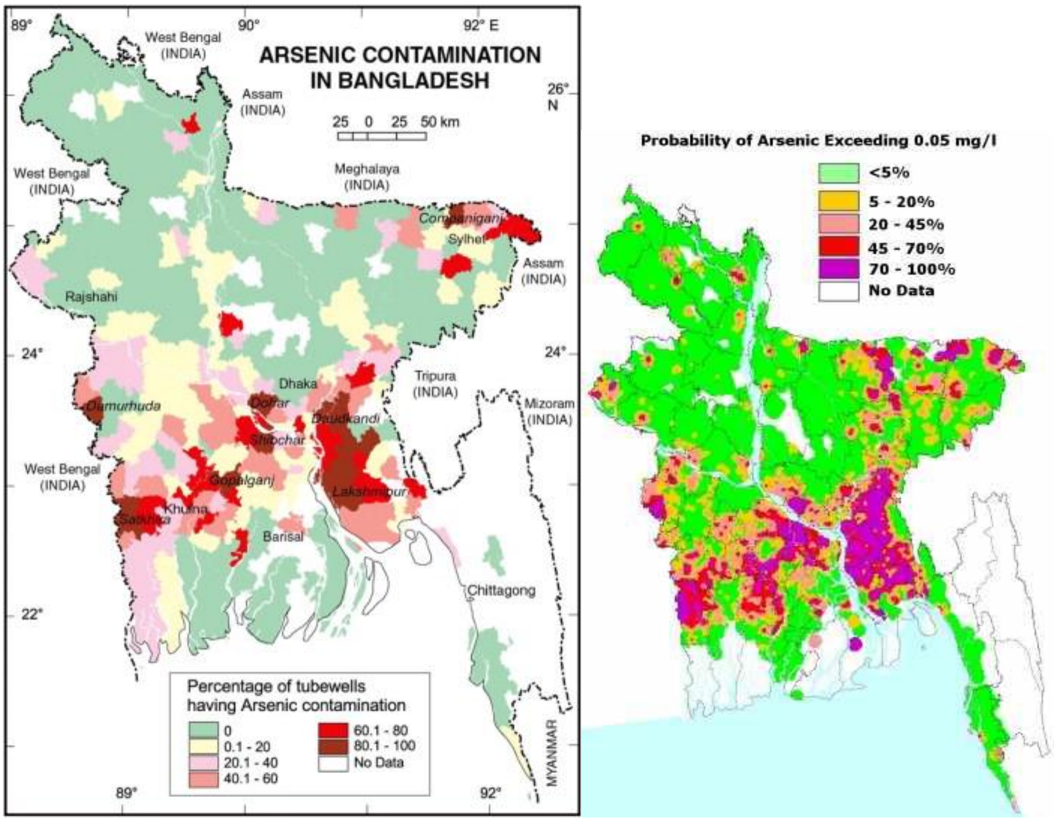

Figure 8. Arsenic contamination and probability of arsenic in Bangladesh

Water related health hazard

Salinity in the water of coastal areas reached over 20 parts per thousand, but the human body can only tolerate five parts per thousand. Different epidemiological studies have shown an association between dietary salt intake and high blood pressure with strong evidence and reported that a sodium intake of higher than 1.8 g/day caused a rise in systolic and diastolic blood pressure of approximately 3–6/0–3 mmHg. Raised blood pressure throughout the range seen in developed countries is the major cause of cardiovascular disease, responsible for 62% of strokes and 49% of coronary heart disease. Moreover, when humans drink salt water, their cells are thus taking in water and salt when this salt content is higher, the living cells do depend on sodium chloride (salt) to maintain the body's chemical balances and reactions; however, too much sodium can be deadly. Human kidneys can only make urine that is less salty than salt water. Therefore, to get rid of all the excess salt taken in by drinking seawater, you have to urinate more water than you drank. Eventually, you die of dehydration even as you become thirstier. In addition to this research shows that higher intake of salt, sodium, or salty foods is linked to an increase in stomach cancer and Osteoporosis (loss of calcium and the bone-thinning disease). The biological contamination and higher arsenic amount in the water are also another major causes of water borne community health challenges.

The objective of this document is therefore, to identify site specific water stress related problems of the coastal Bangladesh rural areas and provide a desalination purification technology alternative based on the real actual site situation.

2. Field survey for problem identification

Salt water is damaging the ground water around the south coast region of Bangladesh due to sea level rise resulting from climate change. The goal of this CTCN technical assistance is to propose a solution for a salt water purifier technology to be used at the household level in the coastal region of Bangladesh.

Therefore, the technical assistance team conducted table discussions and designed the following road map and professional approaches and methodologies on how to come up with the optimal purification technology.

- Identify major water challenges of the target community. clearly, list out the major contaminants and prioritize the problems
- Critically review existing water purification technologies and identify why these technologies cannot tackle the prevailing water problem. Spot all the technical, social, economic and environmental problems linked to these technologies.
- Seek for substitute or supplementary non desalination options (if any) pertinent to the fresh water harvesting and treatment.
- Visit selected districts and intervention areas to understand the local settings of coastal Bangladesh, the cultural and economic setup and severity of the problem. Meet different relevant public, governmental and non-governmental stakeholders and get more relevant experience and practices
- Assess and properly document globally available, sustainable, low-cost, low carbon climate resilient purification technologies used locally or in other similar countries and analyze their suitability and applicability in the context of coastal regions of Bangladesh. Prepare a long list of potential technologies and simulate to the local context of coastal Bangladesh. This ultimate report will have best experiences and findings on technologies for purification of saline water at household level implemented nationally and in other countries including a list of relevant stakeholders involved, information on the local requirements and context for purification of saline water at household level, and prioritization criteria for technologies for purification of saline water at household level
- Prepare a summary addressing details of each technology options, explain the design considerations, technical feasibility, potential impact, cost implications, materials, and images, and other information useful for national and local specialists to fully understand and prioritize among these options. Prepare this document in relevant languages, convey to different actors and present to technical groups of primary actors
- Prepare a technical consultation workshop with professional participants, present the entire summary for detailed criticism and ensure all the sustainability pillars are well addressed in the final technology selection. Identify and set a technology selection criterion and prepare a stakeholder consultation report
- Summarize the document based on the inputs from the professional and stakeholders meeting and prepare a final prioritized climate resilient low-cost technology solution based on strategic prioritization criteria with guidance from the National Designated Entity, PKSF and other close stakeholders.
- Prepare a user manual with detailed information in English and Bengali so that all the local actors can easily understand and implement. Along with this document, ensure the existence of conceptual and operational design information with features and minimum specifications for technologies for purification of saline water at the household level applicable for coastal Bangladesh.

Glory & Tech Co., Ltd. and Korea Institute of Civil Engineering and Building Technology (KICT) participated in the two field surveys. The first survey was performed as a questionnaire survey in late June 2018, and the second field survey as a visit survey in mid-September 2018. The project team discussed with the Bangladesh Department of Environment (DoE) and Palli Karma-Sahayak Foundation (PKSF) about the field surveys. In the second field visit survey, the persons in charge from Nowabenki Gonomukhi Foundation (NGF) and Friendship, which are NGOs in Sathkira and Bagerhat joined in the survey and guided the project team to the visiting areas.

2.1 First field survey operations (rainy season)

In the period from June 24 to 26, 2018 during the rainy season of Bangladesh, the project team visited 30 households in the Satkhira Tala upazila and Bagerhat Sardar upazila villages where the salt water damage of groundwater by sea level rise is expected. The project team surveyed the water and drinking water usage status in each household. The following table lists the villages in the two areas that the project team visited during this field survey.

Table 1. Target villages of the First Field Survey

Area	Village name	Number of surveyed households	Total
Satkhira Tala upazila	Kheshora	12	30 households
	Salua	8	
	Kanaidiya	6	
	Balia	3	
	Tala	1	
Bagerhat Sardar upazila	Korori	30	30 households

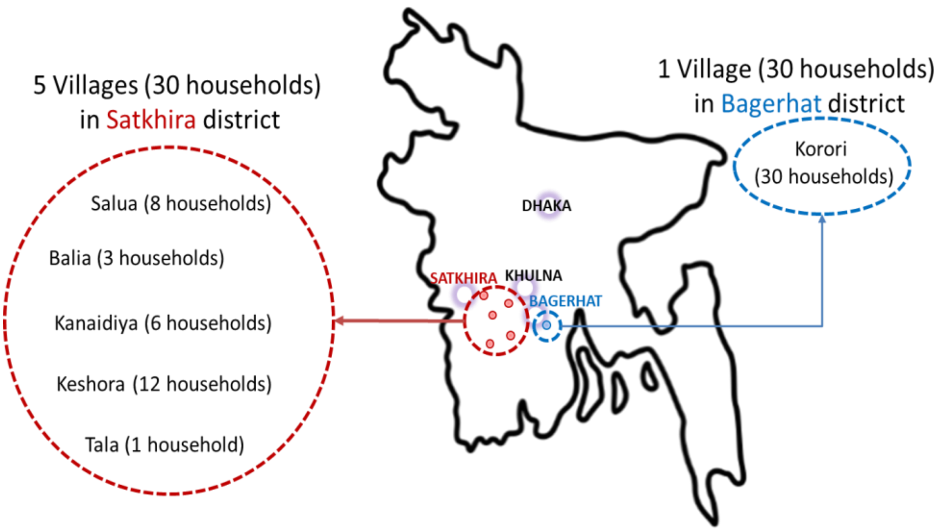

Figure 9. Locations of the First Field Survey target areas

Result:

The number of household members in the Satkhira district villages ranged broadly from 2 to 10 (5.6 on average). The number of 13 years or older members and the number of members younger than 13 years were 4.3 and 1.3, respectively. Meanwhile, the number of household members in the Bagerhat district villages ranged from 4 to 16 (7.7 on average), which was larger than that of the Satkhira district. Among them, the number of 13 years or older members and the number of members younger than 13 were 6.5 and 1.1, respectively. Thus, the number of 13 years or older members of households was larger in the Bagerhat district, whereas the number of population younger than 13 years was larger in the Satkhira district.

Table 2. Household size in the target villages of the First Field Survey (Unit: persons)

District		Largest	Smallest	Average
Satkhira	13 years and older	8	2	4.3
	Younger than 13 years	3	0	1.3
Bagerhat	13 years and older	12	2	6.5.
	Younger than 13 years	4	0	1.1

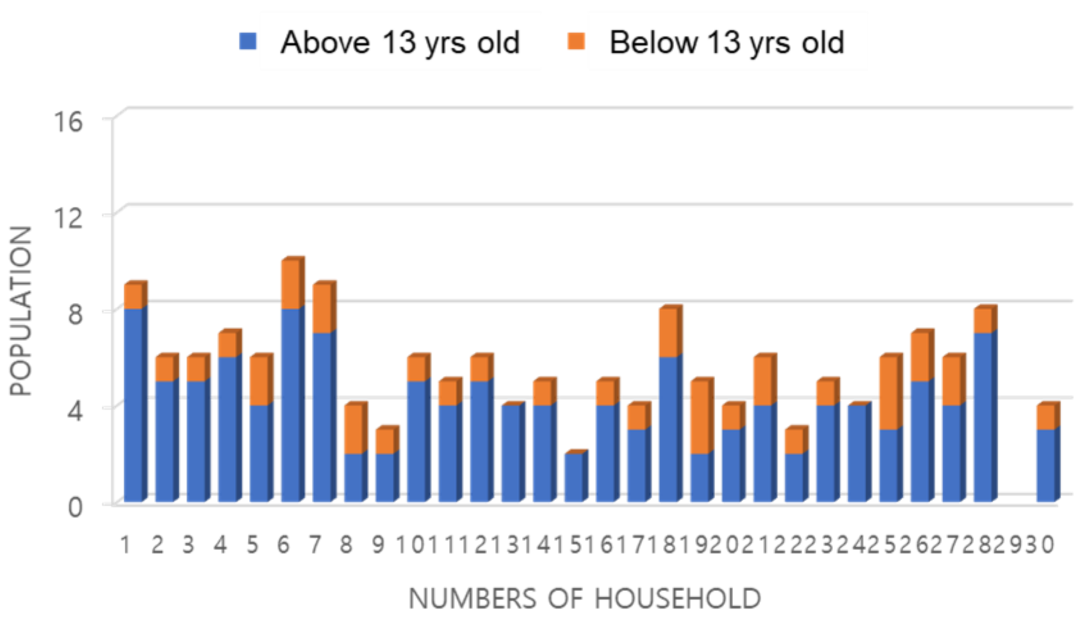

Figure 10. Household size of the Satkhira district villages

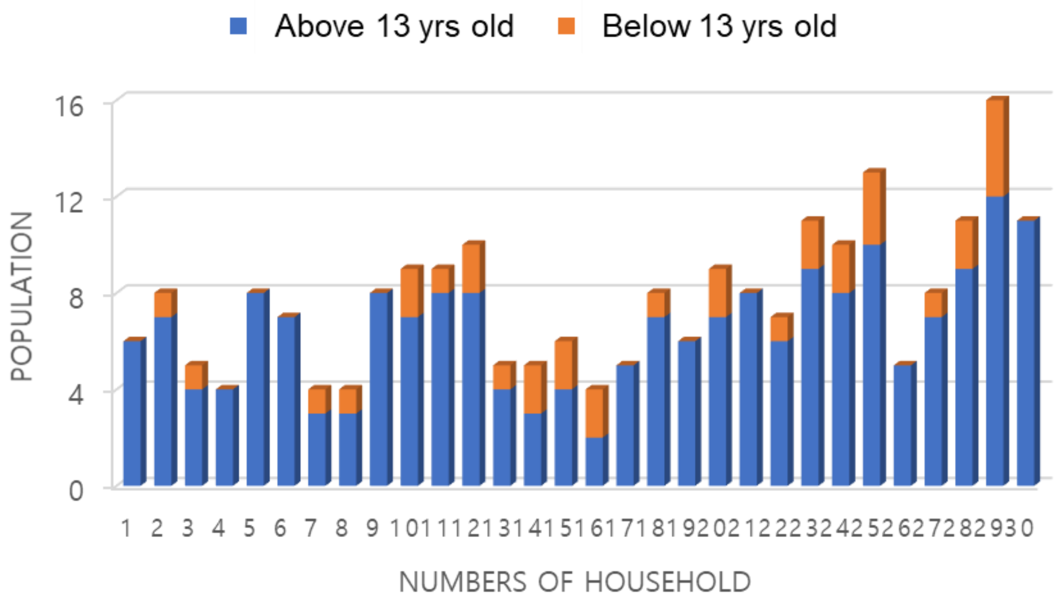

Figure 11. Household size of Bagerhat district

Assuming that the daily drinking water consumption per person is 2 L for adults in the surveyed areas, it is estimated that 20 L and 32 L of drinking water are required per day per household in the Satkhira and Bagerhat districts, respectively (Table 3).

Table 3. Estimated daily drinking water consumption per household in Satkhira and Bagerhat districts

Districts	Daily average drinking water consumption	Daily maximum drinking water consumption
Satkhira	11.2L	20L[7]
Bagerhat	15.2L	32L[8]

Drinking water consumption status

All households in Satkhira and Bagerhat districts were using groundwater as sources for drinking water and domestic water, except one household in Satkhira who used rainwater as an additional source of water. The ground water was pulled up using shallow tube wells and directly transported to all the surveyed households. The water quantity was sufficient in rainy seasons, but somewhat insufficient in dry seasons. Besides shallow tube wells, they also used separate wells and drinking water tanks. 90% of all the surveyed households in the Bagerhat district had wells in their houses. However, there were fewer households who owned wells and drinking water tanks in the Satkhira district and the facilities were in poorer conditions.

[7] Calculation basis: 2 L (daily drinking water consumption per person) x 10 persons (Maximum household size of surveyed households in Satkhira district) = 20 L

[8] Calculation basis: 2 L (daily drinking water consumption per person) x 16 persons (Maximum household size of surveyed households in Bagerhat district) = 32 L

Table 4. Drinking water sources and facilities in Satkhira and Bagerhat districts

Districts	Drinking water sources		Households with wells	Households with drinking water tank
	Groundwater	Groundwater+Rainwater		
Satkhira	29	1	3	1
Bagerhat	30	0	27	5

Shallow tube well example 1	
Shallow tube well example 2	

Rainwater tank example	

Figure 12. Drinking water facilities for households in Satkhira district

Shallow tube well example 1	
Shallow tube well example 2	

Drinking water tank example	

Figure 13. Drinking water facilities for households in Bagerhat district

Meanwhile, electrical facilities were installed in only one household in the Satkhira district, and six households in the Bagerhat district. It seems that additional equipment such as photovoltaic systems is necessary to operate home water purifiers because power outages occur often in the two districts.

Table 5. Electricity use status in Satkhira and Bagerhat districts

Districts	Households with electrical facilities	Monthly average electric charge (Taka)
Satkhira	1	150
Bagerhat	6	325

(Note: 1 Taka=13.39 KRW, electric charge of the surveyed areas: 5 Taka/kW)

Groundwater quality of the surveyed areas

Electrical conductivity

To examine the degree of salt water damage in the surveyed areas, we measured the electrical conductivity of the groundwater in each household. The results showed that about half of the households in the Satkhira district out of 60 surveyed households showed relatively high electrical conductivities (see Figs. 14 and 15). As it is expected that the electrical conductivity of groundwater will increase in the dry seasons, the electrical conductivity of groundwater should be examined by season and the optimal water purification process conditions should be derived considering the maximum salt concentration in each area.

Table 6. Electrical conductivity distribution of groundwater in Satkhira and Bagerhat districts (Unit: uS/cm)

District	Maximum	Minimum	Average
Satkhira	949	28	480.4
Bagerhat	574	112	175.0

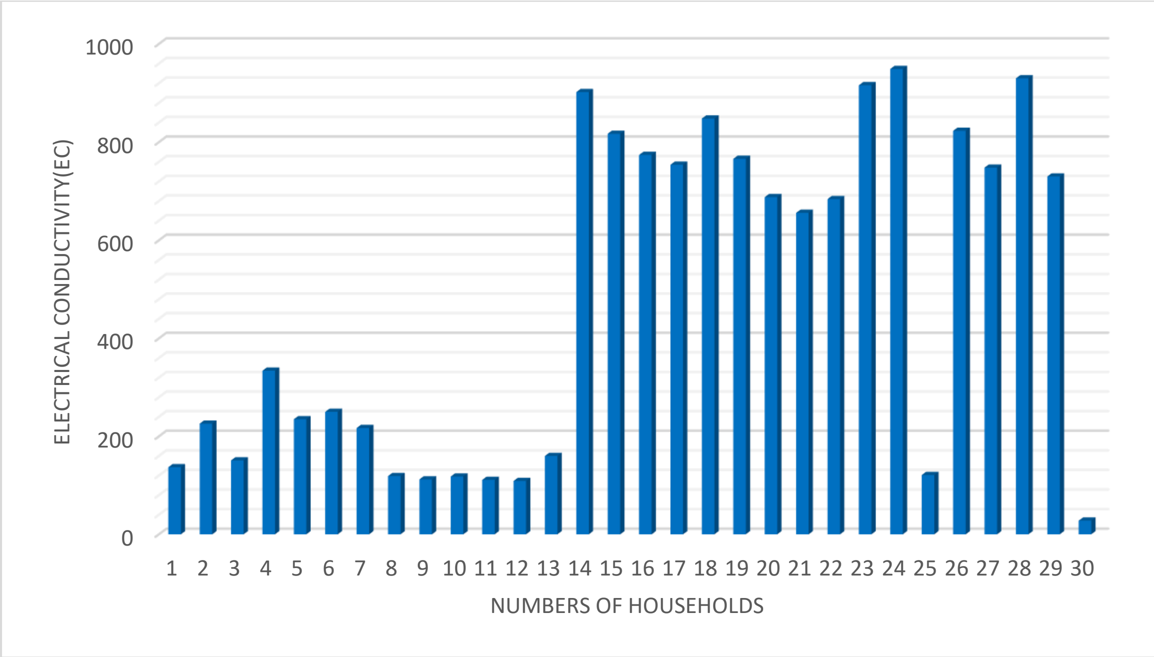

Figure 14. Electrical conductivity distribution of groundwater in Satkhira district (Unit: uS/cm)

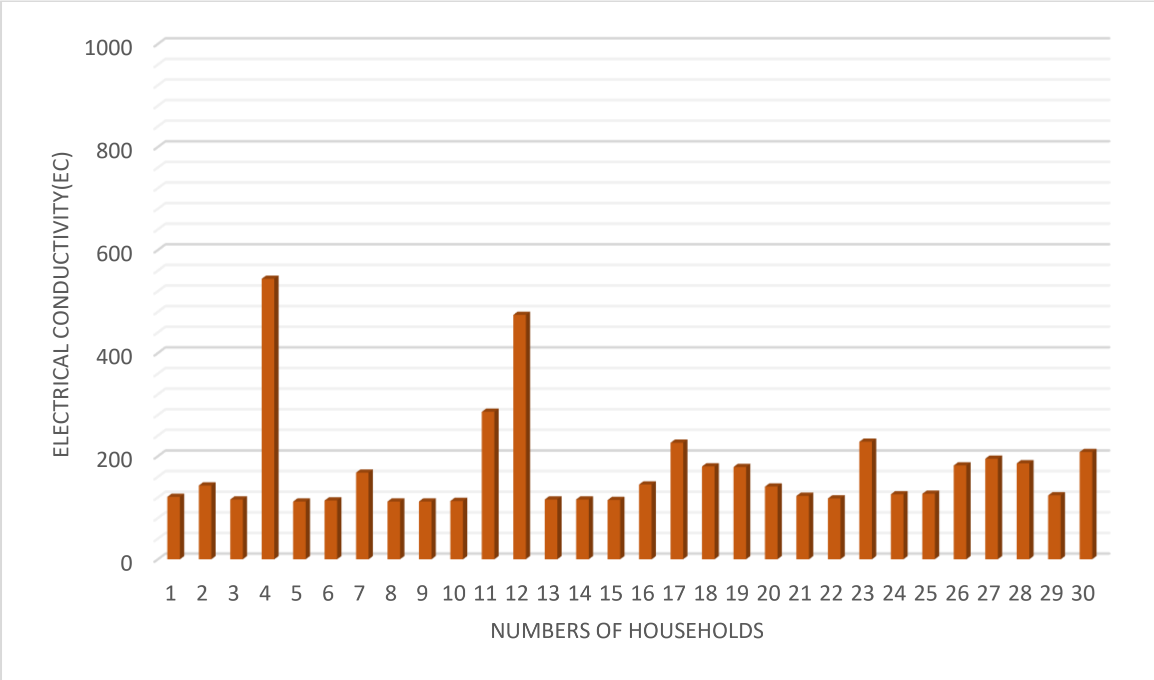

Figure 15. Electrical conductivity distribution of groundwater in Bagerhat district (Unit: uS/cm)

Analysis of other groundwater quality parameters

One household with the highest electrical conductivity of groundwater was selected from each district and the water quality of groundwater was inspected. As a result, the groundwater of the households in Bagerhat Korori satisfied the drinking water quality standards of Bangladesh except for Manganese, but arsenic was detected in groundwater. The arsenic content satisfied the Bangladesh standard, but exceeded the WHO standard. Therefore, it seems necessary to monitor arsenic in groundwater and introduce an arsenic removal process in water purification.

Table 7. Groundwater quality of representative households in Satkhira and Bagerhat districts

Item (Unit)	Groundwater in Bagerhat Korori village	Groundwater in Satkhira Kanaidiya village	Bangladesh standard	WHO standard
Hardness (mg/L)	400	1,400	200-500	-
Potassium permanganate consumption (mg/L)	3.8	10.1	-	10
Manganese (mg/L)	0.342	0.136	0.1	-
Boron (mg/L)	0.04	Undetected	1.0	-
Fluorine (mg/L)	0.27	Undetected	1	1.5
Arsenic (mg/L)	0.032	Undetected	0.05	0.01
Hydrogen ion concentration	7.2	7.3		6.5-8.5
Ammoniacal nitrogen (mg/L)	0.08	2.57	0.5	-
Chlorine ions (mg/L)	55.5	1,727.9	150-600	-
Evaporation residues (mg/L)	642	4,309	1000	-
Nitrate nitrogen (mg/L)	0.1	0.1	10	50 as N
Iron (mg/L)	0.19	Undetected	0.3-1.0	-
Turbidity (NTU)	4.41	0.73	10	-
Electrical conductivity (uS/cm)	574	949	-	-

(Sampling analyzing agency: Institute of Industrial Pollution Co. Ltd.)

2.2 Second field survey operations (dry season)

Based on the first field survey, the Second Field Visit Survey was performed on September 11 and 12, 2018 when the dry season started. We visited 10 villages in Tala upazila and 3 villages in Shyamnagar upazila in the Satkhira district. Officials from NGF and Friendship, which are local NGOs, joined us when we visited each area.

Based on the results of the First Field Survey, we visited representative households of 10 villages in Tala upazila and analyzed the drinking water facilities, drinking water usage status, and groundwater quality. In addition, we visited three villages in Shyamnagar upazila, which is closer to the coast than Tala upazila and investigated the drinking water usage and management status. The following figure shows the villages visited in the Second Field Visit Survey.

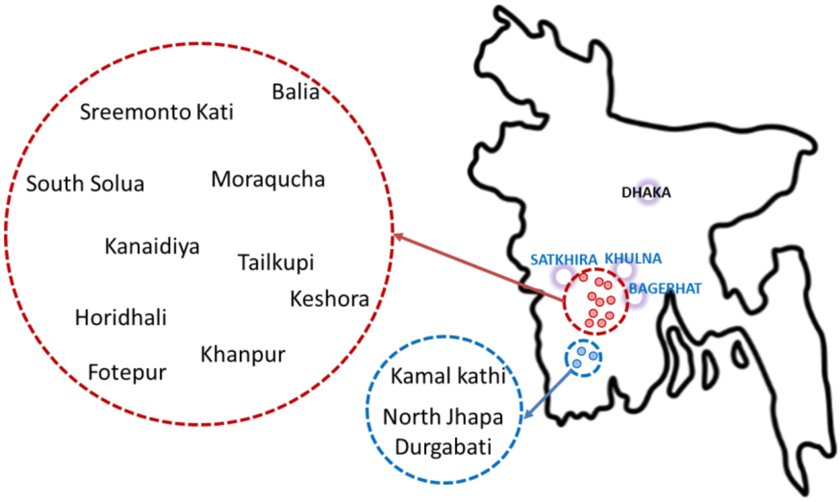

Figure 16: Locations of Second Field Survey areas

Survey in Tala upazila

In similar fashion with the previous first round field survey, the following table also outlines the views, shallow tube wells (STWs), electrical facilities, and groundwater quality analysis results of each representative household in 10 villages in Tala upazila.

Household Views	Shallow Tube Well
	

Characteristics

- There is sufficient space for installing drinking water facilities.

- Photovoltaic systems or power generators should be used because electricity supply is unstable.

- Items exceeding groundwater quality standards*: Hardness, PPC**, Iron, Arsenic, Ammonia, Turbidity, EC***

(*Groundwater quality standards: WHO standard, **PPC: Potassium permanganate consumption, ***EC: Electric Conductivity)

Figure 17. Representative households of the Keshora village

Household Views	Shallow Tube Well
	

Characteristics

- The spaces between households in the village are narrow and there are rice paddies and ponds, which may pollute the groundwater.

- A shared drinking water facility of the village has been installed but is not used now.

- Items exceeding the groundwater quality standards: Hardness, PPC, Iron, Arsenic, Ammonia, TDS, Turbidity, EC

Figure 18. Representative household in Balia village

<table>
<tr><th>Household Views</th><th>Shallow Tube Well</th></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Characteristics
- The STW is in the backyard of the households.
- There is an electrical facility in the household, but power outage occurs often.
- Items exceeding the groundwater quality standards: Hardness, PPC, Iron, Arsenic, Ammonia, Turbidity, EC</td></tr>
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Figure 19. Representative household in Sreemonoto Kati village

<table>
<tr><th>Household Views</th><th>Shallow Tube Well</th></tr>
<tr><td>
</td><td></td></tr>
<tr><td colspan="2">Characteristics
- There is a pond beside the STW.
- The household has installed a groundwater storage tank on the rooftop but is using the water with no purification.
- Items exceeding the groundwater quality standards: Hardness, PPC, Manganese, Iron, Arsenic, Ammonia, Turbidity</td></tr>
</table>

Figure 20. Representative household in South Solua village

Household Views	Shallow Tube Well
	

Characteristics

- An STW is installed in the household.

- They sometimes use a small solar panel on the rooftop.

- Items exceeding the groundwater quality standards: Hardness, Manganese, Iron, Arsenic, Ammonia, Turbidity

Figure 21. Representative household in Kanadiya village

Household Views	Shallow Tube Well
	

Characteristics

- There is a pond and an STW beside the household.

- There is a severe iron odor from the groundwater.

- Items exceeding the groundwater quality standards: Hardness, Manganese, Iron, Ammonia, Turbidity

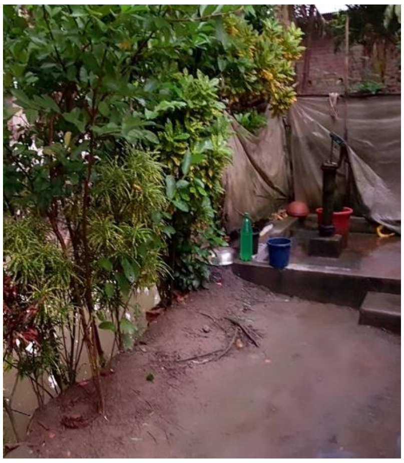
Figure 22. Representative household in Horidhali village

<table>
<tr><th>Household Views</th><th>Shallow Tube Well</th></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Characteristics
- A shared STW is located beside a pond.
- It is far away from the large road and it is difficult to access the village.
- Items exceeding the groundwater quality standards: Hardness, Manganese, Iron, Ammonia, Turbidity</td></tr>
</table>

Figure 23. Representative household in Fote Pur village

<table>
<tr><th>Household Views</th><th>Shallow Tube Well</th></tr>
<tr><td>
</td><td></td></tr>
<tr><td colspan="2">Characteristics
- An STW is located right beside a cattle cage and there is severe ammonia odor from the groundwater. It seems that the manure from the cattle cage contaminated the groundwater.
- Items exceeding the groundwater quality standards: Hardness, Manganese, Iron, Ammonia, TDS, Turbidity</td></tr>
</table>

Figure 24. Representative household in Khan Pur village

Household Views	Shallow Tube Well
	

Characteristics

- There is a pond beside the STW.
- They can use electricity because each household has power facilities.
- Items exceeding the groundwater quality standards: Hardness, PPC, Arsenic, Ammonia, EC

Figure 25. Representative household in Taikupi village

Household Views	Shallow Tube Well
	

Characteristics

- There is severe iron odor like other raw waters, which requires proper treatment.
- There is a stream near the households and the groundwater may be contaminated by livestock manure.
- Items exceeding the groundwater quality standards: Hardness, PPC, Iron, Arsenic, Ammonia, Turbidity, EC

Figure 26. Representative household in Moragacha village

Table 8. Groundwater quality of 10 villages in Tala upazila in Satkhira district

Items	Balia	Sreemonto Kati	South Solua	Kanadiya	Horidhali	Fotepur	Khanpur	Tailkupi	Moraqacha	Keshora	Bangladesh standards	WHO Guide Lines
Hardness as CaCO3 (mg/L)	560	340	400	450	510	360	640	500	550	440	200-500	-
Potassium permanganate consumption(mg/L)	22.8	21.5	13.3	3.8	4.1	8.9	8.5	19.6	19.6	17.1	-	10
Manganese (mg/L)	0.024	0.015	0.21	0.468	0.127	0.044	0.176	0.029	0.022	0.02	0.1	-
Boron (mg/L)	0.11	0.11	0.06	0.04	0.03	0.04	0.04	0.07	0.13	0.1	1	-
Fluoride (mg/L)	0	0	0	0.17	0	0	0	0	0	0	1	1.5
Arsenic (mg/L)	0.05	0.413	0.102	0.084	0.024	0.04	0.025	0.08	0.124	0.144	0.05	0.01
pH	7.4	7.5	7.2	7.4	7.4	7.2	7.1	7.3	7.3	7.3		6.5-8.5
Ammonia (mg/L)	5.6	10.9	7.75	0.43	2.1	4.7	5.1	6.5	12.2	9.15	0.5	-
Chloride (mg/L)	403.4	167.3	18.1	45.6	4.9	26.3	179.2	70.7	424.8	146.4	150-600	-
Total Dissolved Solids (mg/L)	1322	965	588	629	672	602	1037	856	1746	729	1000	-
Nitrate (mg/L)	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	10	50 as N
Iron (mg/L)	0.41	0.44	0.74	1.74	0.98	1.2	2.7	0.27	0.44	0.45	0.3-1.0	-
Turbidity (NTU)	16.5	23	17.7	7.75	38.6	22.3	94.1	3.9	5.13	26.5	10	-
Electric Conductivity(μS/cm)	2310	1760	881	901	794	695	1490	1400	2450	1360	-	-

All the families of the 10 villages visited were using drinking water directly through the Shallow Tube Well. The strange thing is that there was a pond near the water source and the water looked bad. The electrical installations were installed in the village of Tala upazila, where electricity was supplied to each household. Some households were using solar panels intermittently. However, the electricity supply was cut off from time to time, so it needed a stable supply of electricity and a backup system using renewable energy such as solar energy. The results of a survey of the water quality in 10 villages of Tala upazila is presented in Table 8. Total 14 items of drinking water quality were tested. The pH, Boron, Fluoride, Nitrate showed a safe level within the Bangladesh water standards. But the groundwater collected from Khanpur and Balia village, compared to the tap water in Dhaka, has light yellow color, with some brown sediment, and smells of iron and ammonia.

The groundwater in all villages has the concentration of calcium carbonate exceeding the standard level in Bangladesh, which will be an important factor to consider when removing saline compounds. In addition, the consumption of potassium permanganate, an indicator of the amount of organic matter, exceeds the World Health Organization (WHO) standard, indicating that more than half of the areas surveyed have high concentrations of organic matter in groundwater.

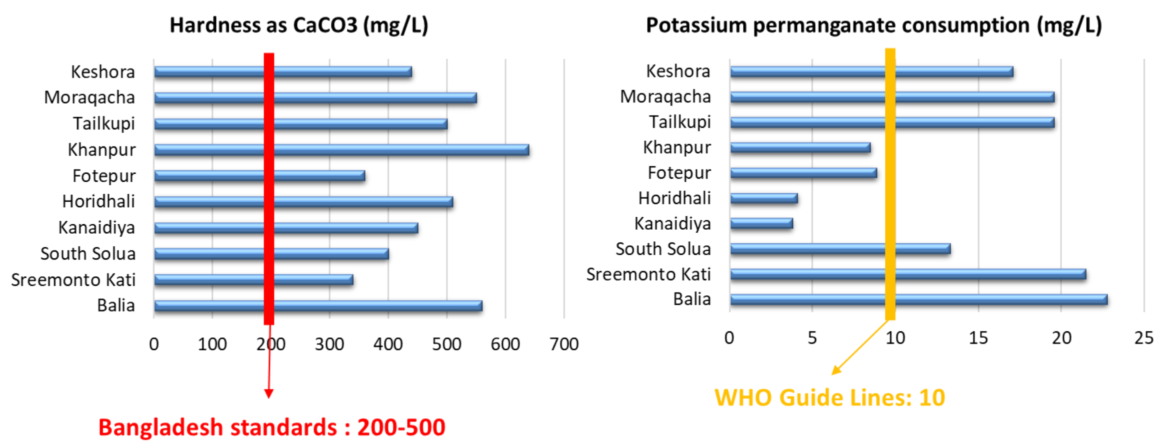


Figure 27. Hardness and potassium permanganate level of ground water samples compared with the standards

According to the WHO, the number of manganese compounds that can negatively affect brain nerve development and cognitive abilities. Concentration of manganese in a few groundwater samples exceeded the level of Bangladesh standards. In particular, the groundwater in Kanaidiya exceeded the standard over four times.

A more serious issue is arsenic. Although Bangladesh and WHO have different standards, all groundwater in the areas surveyed have exceeded the WHO threshold of 0.01ppm. Removing arsenic should be an important consideration when using groundwater.

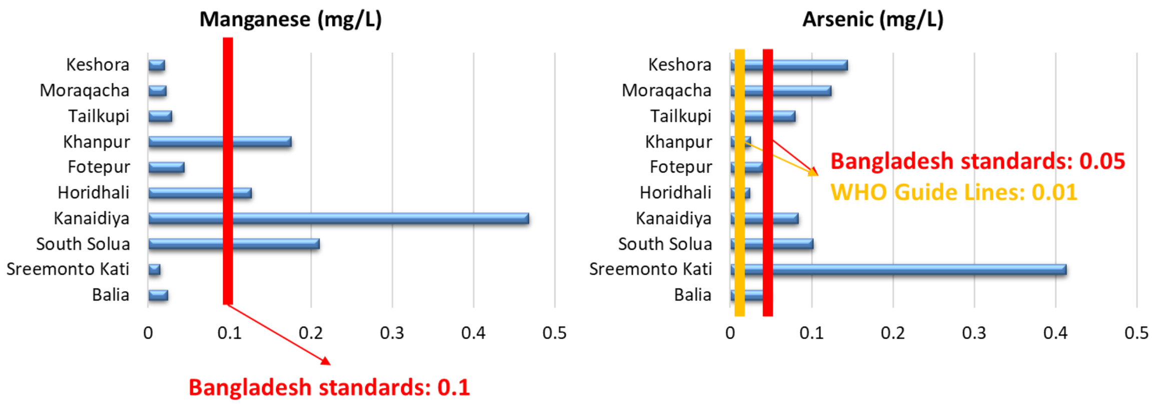


Figure 28. Manganese and Arsenic level of ground water samples compared with the standards

Ammonia in all groundwater also exceeded the standard value of Bangladesh and the possibility of odor and microbial contamination was high. Indeed, livestock seemed to be a major source of pollution in many households, and further analysis of microbial contamination is needed. Iron content also exceeded the Bangladesh standard in all regions. Unlike Dhaka's tap water, all water in the area showed light yellow and smelt of iron.

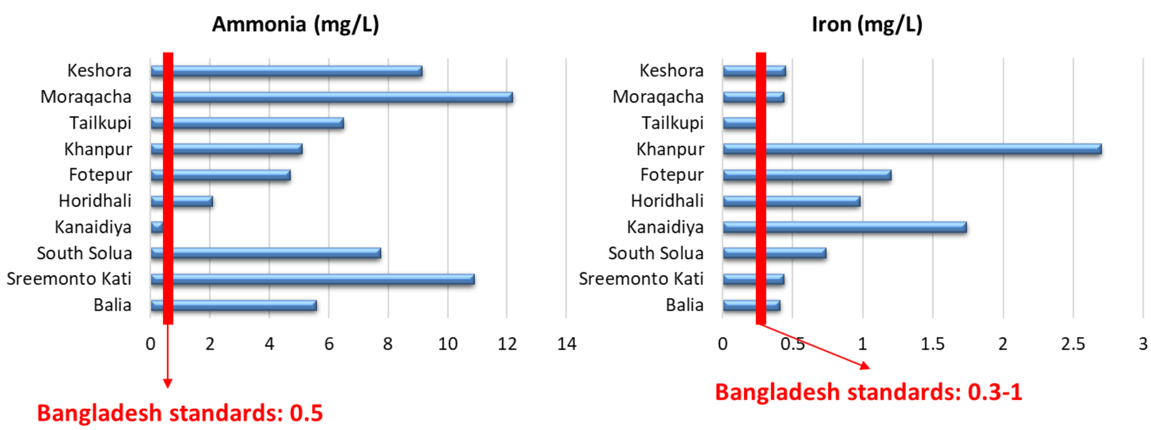


Figure 29. Ammonia and Iron level of ground water samples compared with the standards

And total dissolved solids and turbidity, 3 and 7 villages in the survey region respectively exceeded Bangladesh's standards, and in some groundwater, brown deposits formed and sank. This will be an important consideration when removing ionic and particulate matter in the design of water treatment.

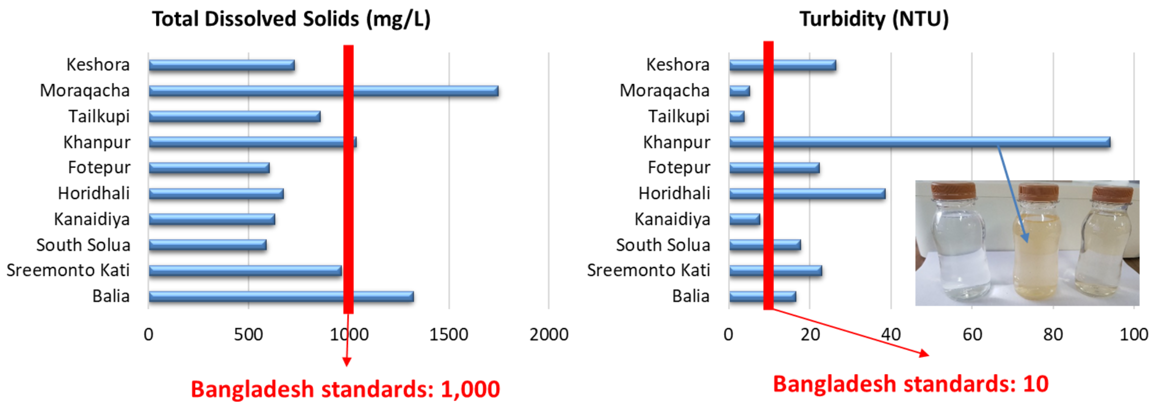


Figure 30. TDS and Turbidity level of ground water samples compared with the standards

In addition, the chlorine concentration of groundwater, which is an indirect indicator of sea penetration, exceeded the standard value of Bangladesh by half, which is similar to the trend of the electric conductivity concentration. In the case of electric conductivity, the majority of the surveyed areas have exceeded concentrations compared to the standard in Bangladesh, and further investigation will be needed during the dry season, which is expected to be higher concentrations. Based on this survey, appropriate technologies should be selected and reflected in desalination process design. Generally, 300–600 ppm is a desirable and safe salinity range for drinking water.

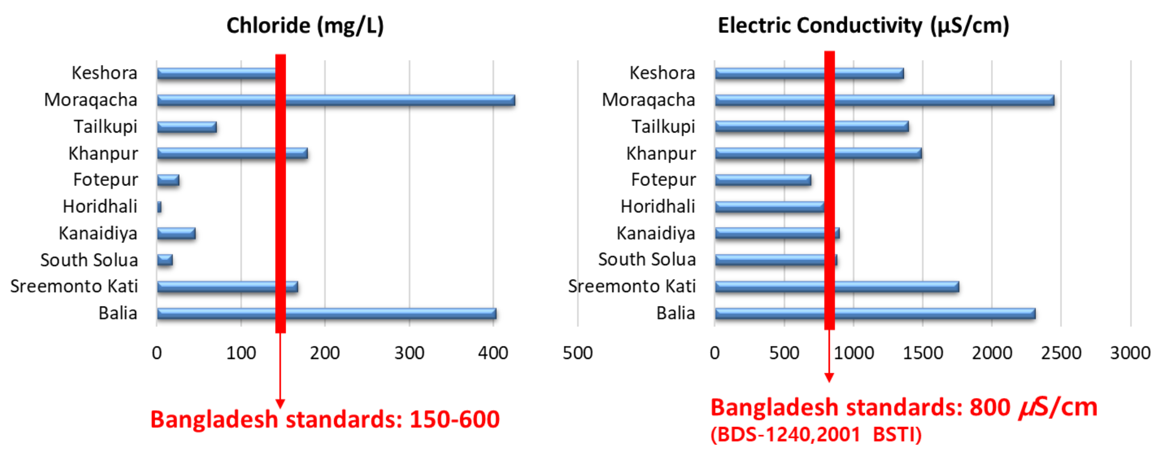


Figure 31. Chloride and EC level of ground water samples compared with the standards

Survey results in Shyamnagar upazila

The following is the KICT survey of three villages in Shyamnagar upazilla, which are closer to the coastal region. It was found that in 3 villages, besides groundwater, RO system and rain water were used as drinking water. The following table describes the number of people in the three villages, the salt content of groundwater, the pH of drinking water, and the current state of drinking water management.

Table 9. Drinking water consumption status of three villages in Shyamnagar upazila

Village	Kamal kathi	North Jhapa	Durgabati
Population	300	1,000	1,500
Chloride content for soil and underground water(g/L)	0.17 - 0.42	0.05 - 0.15	<0.01
pH of drinking water	7.95 - 8.04	6.74 - 6.95	6.56 - 6.72
Drinking water management status	Use of groundwater pumping at the base of 70m (manual work)	Drinking Water Supply by the community water RO system	Use drinking water after storing rainwater

Figure 32. Reverse osmosis drinking water facillities in North Jhapa village

The North Jhapa village used the RO system to water supply for about 200 households. The residents were coming to get their own water. However, the power supply is unstable and can sometimes be interrupted. Therefore, it is necessary to secure a stable power supply system and a water supply network using piping etc.

The Durgabati village was using a variety of rainwater tanks as a source of drinking water. In rainy season, rainwater seemed to be a good alternative to groundwater. A rainwater storage tank with a capacity of 2 tons was installed to collect and use rainwater from the roof, but the tank was used for drinking water without any water treatment. In addition, some families stored rainwater in small jars and used it for drinking or living water.

Figure 33. Rainwater catchment facility of Durgabati village

3. Overview of Water Purification Technologies

In order to address the water challenges, the government of Bangladesh along with different local and international organizations has established various technologies to avail potable water to the community. Accordingly, many areas in the coastal area are equipped with community desalination plants, however because of lack of technological adaptability, environmental and socio-economic problems before, during and after implementation, they may not be working properly. In addition, these plants are mostly expensive and hence up-scaling and installing these plants on a large scale was not found to be a good option. Almost all the technologies under implementation were not well studied and not based on the local socioeconomic and cultural context. There is not yet best technology fitting the area as the condition in every village is quite different. As per the field assessment above, in some area, the best option could be preserving rainwater in artificial ponds and distribute it to communities and in some other area decentralized desalination of brackish and sea water could be the best option. The design of multipurpose house addressing roof water harvesting can also be the best option in some localities. Filtration and desalination plants in this water stressed areas are expensive, moreover, the groundwater and river water depletion resulted from the climate change is leaving a deep-rooted problem in the locality. However, most professionals still agree that desalination in a decentralized, low cost and the environmentally sustainable way could perhaps be the only possible solution to avert a forthcoming crisis. Hence this study forwarded a sustainable purification technology options based on detailed environmental and socio-economical study of the existing technologies (both indigenous and established by NGOs and local government) in the area and other global experiences.

3.1 Globally pioneered potential purification technologies

Currently, water supply sources in the coastal rural areas of many countries are mainly taken from brackish water source using shallow or deep wells. There are many technologies used in small scale desalination processes. Almost all the technologies used in the desalination processes require capital, operation, and maintenance costs that cannot be easily paid by the communities. Rural poor communities mainly need cheap, efficient and easily manageable technology. Some of the rural low-cost desalination technologies available and potentially relevant to this project have been extensively studied and organized from literature and from our field experience. Generally, desalination technology can be categorized and be adapted to different local situations based on scale of the project, detailed study of the system, and adaptability to specific area. Desalination processes fall into four main categories based on the fundamental physical and chemical principles governing the saline water separation process. 1) Thermal methods rely on phase change: thermal energy is used to evaporate water (leaving salt behind) and then the water vapor is condensed to collect fresh water. 2) Membrane desalination processes physically separate salt from water using differences in osmotic (chemical) potentials across a semi-permeable polymer membrane. 3) Charge-based separation techniques take advantage of the fact that salt is comprised of charged ions, which can be separated from water by simply applying a small electric potential. 4) other technologies: include methods such as solar humidification, freezing distillation, Adsorption desalination, Membrane distillation, etc[9]

[9] M. S. Islam et al., "Desalination Technologies for Developing Countries: A Review," *Journal of Scientific Research*

Some of the most common desalination/purification technologies has been summarized as follows: [10]

a) **Thermal (distillation) process:** This method is like the hydrological cycle in that salty water is heated producing water vapor that in turn condensed to form fresh water free of salts. The fresh water is ultimately re-mineralized to make it suitable for human consumption. From a cost standpoint, thermal technologies are a better choice for desalination of higher-salinity than lower-salinity sources. Generally, there are several different commercially available thermal technologies, but the three most widely used are:

Multiple-effect distillation (MED): feed water is sprayed onto heated tubes carrying steam to generate vapour. The vapour produced is collected and used as a heat source in the subsequent stage while brine is collected at the bottom of the chamber. MED plants are usually built for capacities of between 2,000 and 10,000m3 /day, with a maximum operating temperature of 70ºC. This method is getting obsolete due to the high energy needs of thermal methods in comparison with membrane-based technologies (See Fig. 34).

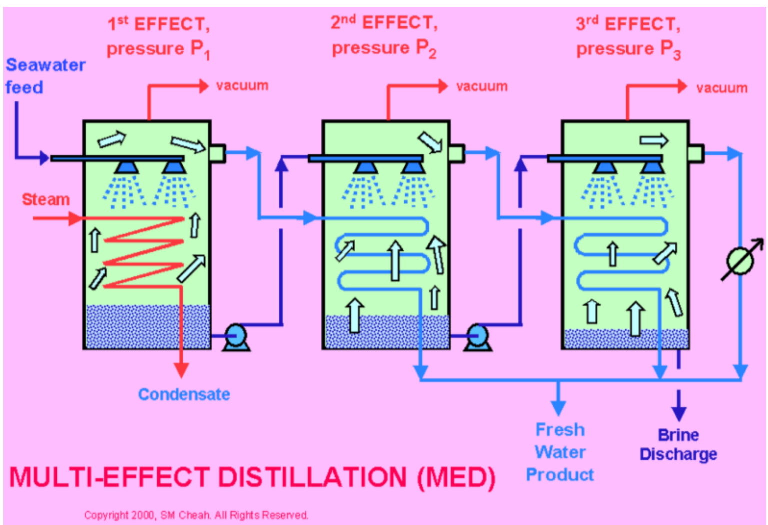


Figure 34. Schematics of Multiple-effect distillation [11]

Multi-stage flash distillation (MSF): This method is based on the fact that evaporation happens when the vapor pressure is equal to the external pressure in the chamber. Thus, by initially heating water in a high-pressure environment and then progressively reducing the pressure, evaporation can be stimulated at successively lower pressures and temperatures (See Fig. 35).

10, no. 1 (January 1, 2018): 77–97, https://doi.org/10.3329/jsr.v10i1.33179.

[10] Boden Kathryn and Chinmayee Subban, "A Road Map for Small-Scale Desalination: An Overview of Existing and Emerging Technology Solutions for Cost-Efficient and Low-Energy Desalination in South and Southeast Asia | Oxfam Policy & Practice," Technical briefing (OXFAM-GB, March 22, 2018); Islam et al., "Desalination Technologies for Developing Countries."

[11] "Separation Processes Home Page," accessed March 25, 2019, http://www.separationprocesses.com/.

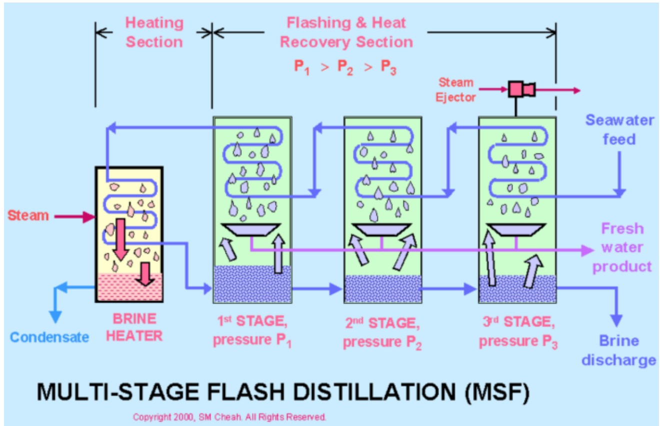


Figure 35. Schematics multi-stage flash distillation [12]

Vapor compression distillation (VCD): Vapor compression involves evaporating the feed water, compressing the resulting vapor, and then using the pressurized vapor as a heat source to evaporate additional feed water. The compression of the vapor is done either with a mechanical vapor compression, MVC or a steam ejector.

Typically, MED, MSF and VCD are only cost-effective at capacities above 3,000m3 /day, and are ideal for desalination of higher-salinity sources (≥35,000 ppm) (See Fig. 36).

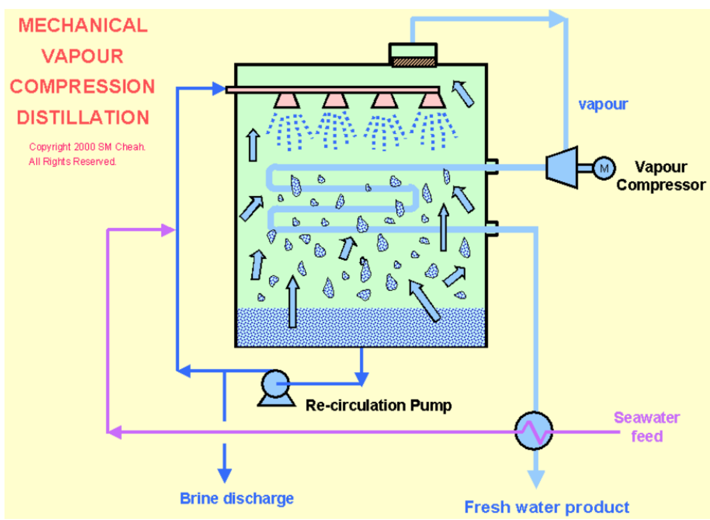


Figure 36. Schematics Vapor compression distillation [12]

Solar still distillation (SSD): This technology uses the sun as the heat source for evaporation. Saline water is evaporated in a large sealed basin, whose size is determined by the desired fresh water output. The vapor condenses as fresh water on the underside of the basin's cover, which is sloped so that the water moves down into a collection trough. Its simplicity and ease of installation have made it attractive to users. However, the productivity is generally quite low and is affected by seasonal variations, making it less practical even on a small scale. A simple SSD system produces 2– 5L/m2/day and a modified system optimized for maximal output around 30 L/m2 /day. If this technology is to be implemented as a desalination option, it is important that its low water output and consequent large land requirements and high capital cost are carefully considered. This can be a good option for localities in arid regions having large open land area available. This technology generally can be used for desalination of both seawater and brackish water sources (See Fig. 37)

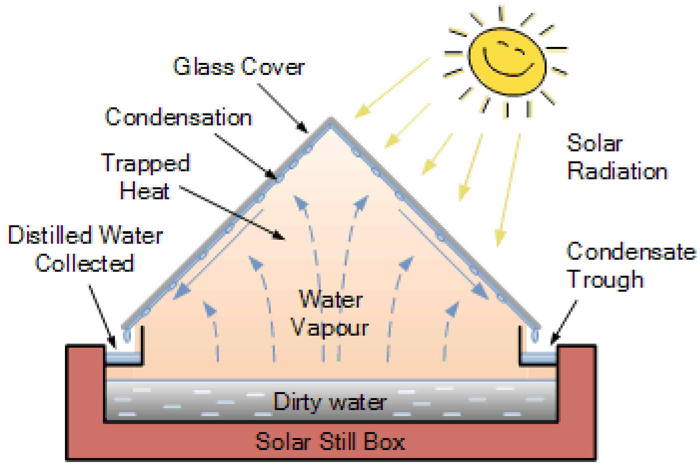


Figure 37. Schematics Solar still distillation [12]

b) **Membrane process:** This method uses a thin film of semi-permeable material to physically separate salt from water. The driving force for transport can be a pressure gradient, a temperature gradient, a concentration gradient or an electrical potential gradient. Synthetic polymeric membranes are mostly utilized for their best quality and are the primary material used for desalination applications today. Polyamide-based thin film composite membranes. Although membrane-based desalination technologies have been successfully demonstrated at large scale and for treatment of both low- and high-salinity water sources, the processes are generally energy-intensive and suffer from issues of membrane fouling. There are mainly two types of membrane process usually used for desalination: reverse osmosis (RO) and forward osmosis (FO).

Reverse osmosis: Reverse osmosis (RO) is a membrane separation process where water from a pressurized saline solution is separated from the dissolved salts by flowing through a water-permeable membrane. The liquid flowing through the membrane is encouraged to flow through the membrane by the pressure differential created between the pressurized feedwater and the product water, which is at near-atmospheric pressure. The remaining feedwater continues through the pressurized side of the reactor as brine. No heating or phase change takes place. The operating pressure for brackish water systems ranges from 15- 25 bar and for seawater systems from 54 to 80 bars. Reverse osmosis can remove from brines not only dissolved solids, but also organic material, colloidal material, and some microorganisms. RO is typically used for brackish water with salt concentrations ranging from 100 to 10,000 ppm. RO membranes are expensive and have a life expectancy of 2-5 years. If the plant uses seawater there can be interruptions to the service during stormy weather. This can cause re-suspension of particles, which increases the extent of suspended solids in the water. Pre-treatment of the feed water is required in order

[12] "Freshwater Production Using Renewable Energy Sources," *Alternative Energy Tutorials* (blog), accessed March 25, 2019, http://www.alternative-energy-tutorials.com.

to remove particulates so that the membranes last longer. RO membranes are sensitive to pH, oxidizers, a wide range of organics, algae, and bacteria and of course particulates and other foulants. Therefore, pretreatment is very important especially since all the feed water, even the 60% that will eventually be discharged, must be pretreated before being passed to the membrane. Reverse osmosis has been developed and widely commercialized over the past 50 years and is by far the most prevalent desalination technology in use worldwide today. In 2013, RO was responsible for 71% of the world's fresh water supply produced by desalination. RO still faces three key challenges: high energy use for brackish water treatment, low water recovery rates, and membrane fouling. The operating mechanism has been indicated in the following two figures.

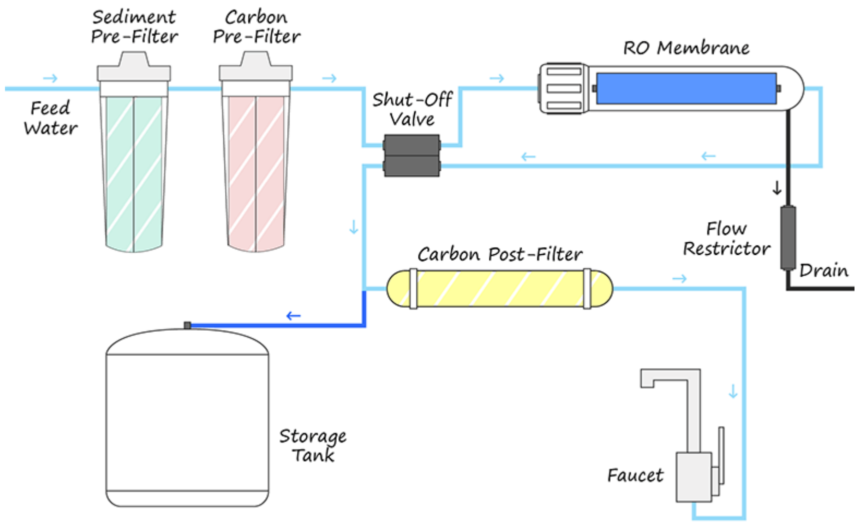


Figure 38. Schematics of reverse osmosis membrane system [13]

Forward osmosis: is a membrane separation process where water transports across a semi-permeable membrane that is impermeable to salt utilizing the natural osmotic pressure gradient. This process may have the ability to desalinate saline water sources at a reduced cost and at high recovery with the use of osmotic driving forces which can be significantly greater than hydraulic driving forces in RO. the energy and resources required to recover fresh water from the draw solute often outweigh the energy saved from pumping, resulting in comparable operational costs overall. More importantly, the health risk of residual draw solute in the freshwater product is a concern that currently prevents the use of FO for the treatment of drinking water.

[13] "What Is Reverse Osmosis Water and How Does an RO Filter System Work," BOS, accessed March 25, 2019, https://www.best-osmosis-systems.com/ro-water-filter-guide/.

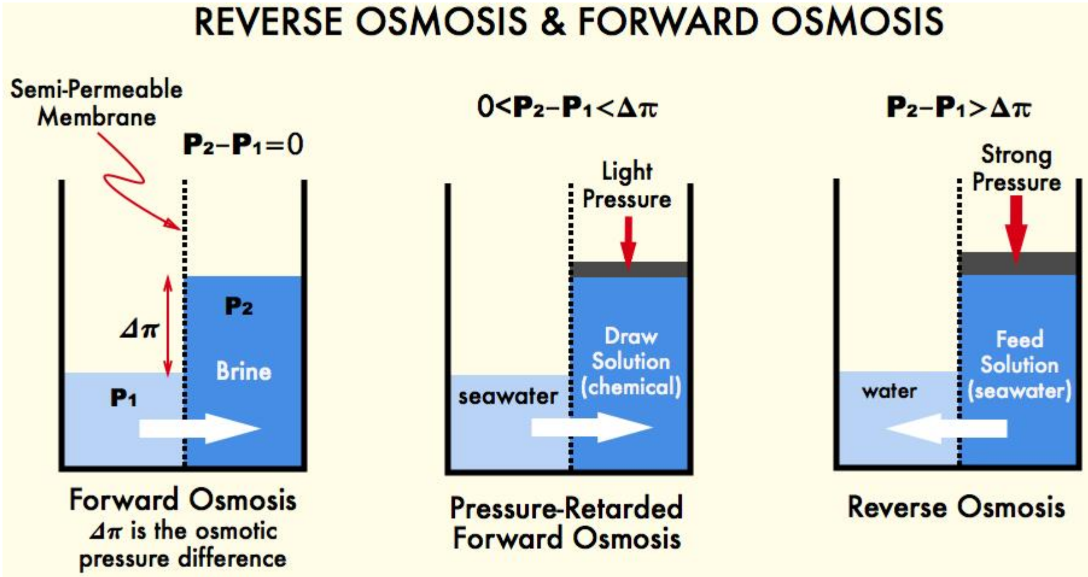


Figure 39. Schematics of forward and reverse osmosis membrane system [14]

c) Charge-based separation technology: This kind of technology take advantage of electrostatic attraction and repulsion to separate out positively charged sodium (Na+) and negatively charged chloride (Cl-) ions (as well as other salt ions) from water. This is often done by applying a small voltage across two pieces of metal – electrodes – placed in saline water. The Na+ ions are attracted to the negative electrode (cathode), and the Clions to the positive electrode (anode). Charge-based technologies are ideal for low-salinity brackish sources. The reason for this is that, unlike RO and all thermal processes, charged-based technologies desalinate water by capturing the salt out of the saline source, instead of selectively removing the water molecules. Thus, for charged-based technologies, the more salt in solution the more energy required to remove it, or to put it another way, energy use scales with source salinity. Charge-based technologies tend to have higher water recovery rates (85–90%) than either RO (25–80%) or typical thermal technologies (35%). The most technologically advanced and widely available for purchase charge-based separation technologies are electrodialysis (ED), reverse electrodialysis (ERD), and membrane capacitive deionization (CDI)[11].

Electrodialysis/ Reverse Electrodialysis: This method separates salts from water by using an applied voltage and ion-selective membranes. is a series of parallel cells composed of alternating membranes for the selective transport of positively charged ions (cations) and negatively charged ions (anions), bounded by two electrodes. The electrodes are typically made of titanium and are connected to a direct current. The membranes are mainly Cation exchange membranes (CEM) - allow only cations, and anion exchange membranes (AEM) which only allows anions. This system can also be easily adapted to be powered directly by photovoltaics, making them environmentally sustainable and technically feasible for off-grid communities.

[14] Antweiler Werner, “Seawater Desalination: Technology to Quench the World’s Growing Thirst for Water,” accessed March 25, 2019, https://wernerantweiler.ca.

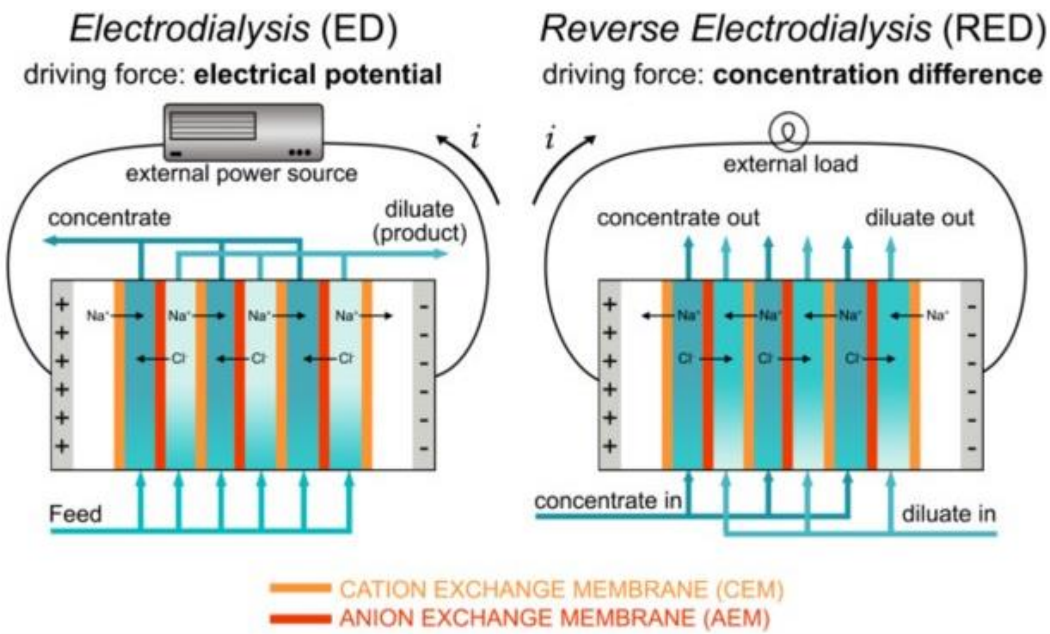


Figure 40. Schematics showing Principle of electrodialysis (ED) and reverse electrodialysis (RED)[15]

Membrane capacitive deionization (CDI): Systems are driven by an external voltage. However, the fundamental salt removal mechanism in CDI is capacitive, resulting from the adsorption of ions onto the electrode surface, and is not a membrane-assisted separation as in ED or EDR. CDI involves two stages: electro sorption of the ions onto the electrodes followed by desorption of the ions to 'clean' the electrode surface. The membranes in CDI are used to increase the energy efficiency of the process by preventing unintended ion transfer from one electrode to the other during regeneration[11] (See Fig. 41).

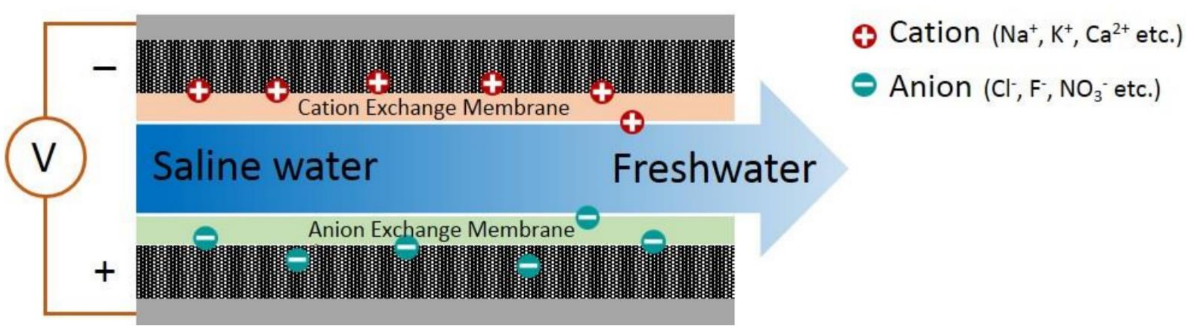


Figure 41. schematics of CDI technology [11]

[15] M. Tedesco, H. V. M. Hamelers, and P. M. Biesheuvel, "Nernst-Planck Transport Theory for (Reverse) Electrodialysis: I. Effect of Co-Ion Transport through the Membranes," *Journal of Membrane Science* 510 (July 15, 2016): 370–81, https://doi.org/10.1016/j.memsci.2016.03.012.

d) **Others:** These are additional desalination technologies that can be operated by either autonomous or hybrid system other than those stated above. Some technologies have been identified as follows:

Adsorption desalination: This emerging technology utilizes low-grade heat (75–90ºC) to evaporate saline water, which is then adsorbed onto an adsorbent matrix. The adsorbed water is subsequently desorbed from the matrix using low-grade waste heat, followed by condensation to obtain fresh water. The technology is still in the development stage and is not commercially available.

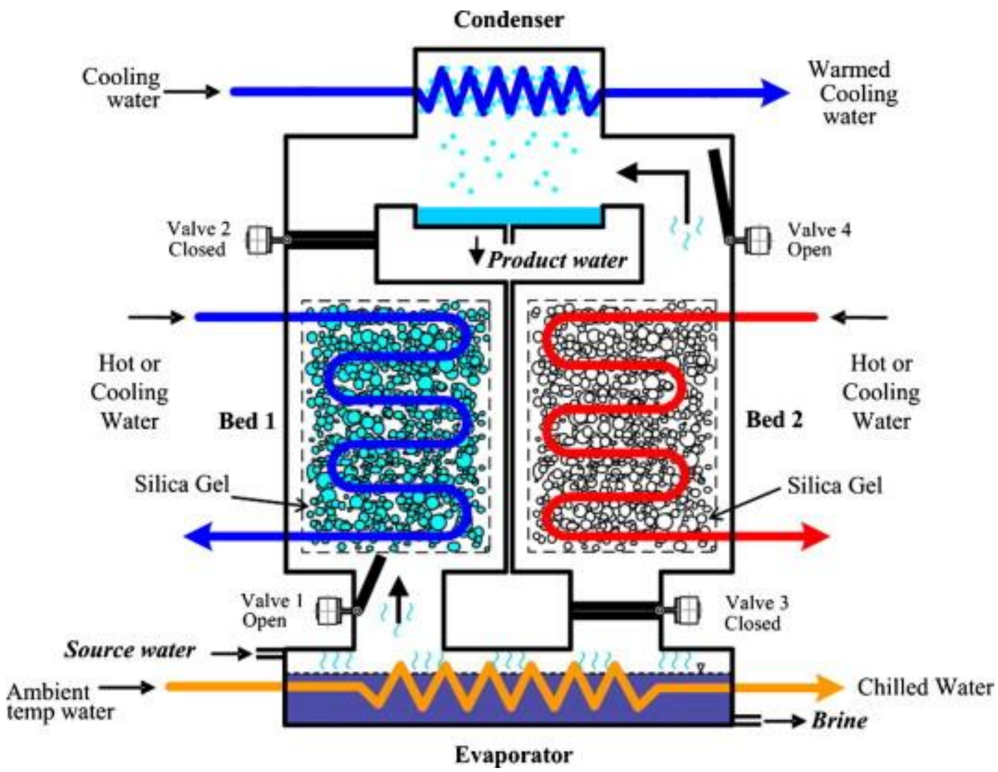


Figure 42. Schematics of adsorption desalination [16]

Membrane distillation: MD is an emerging technology that produces fresh water by evaporating saline water to vapor, which is passed through a porous membrane, cooled and collected. In general, most work on MD is still taking place in the lab and the technology is not commercially available.

[16] Jun W. Wu, Eric J. Hu, and Mark J. Biggs, "Thermodynamic Cycles of Adsorption Desalination System," *Applied Energy*, Energy Solutions for a Sustainable World, Special Issue of International Conference of Applied Energy, ICA2010, April 21-23, 2010, Singapore, 90, no. 1 (February 1, 2012): 316–22, https://doi.org/10.1016/j.apenergy.2011.04.049.

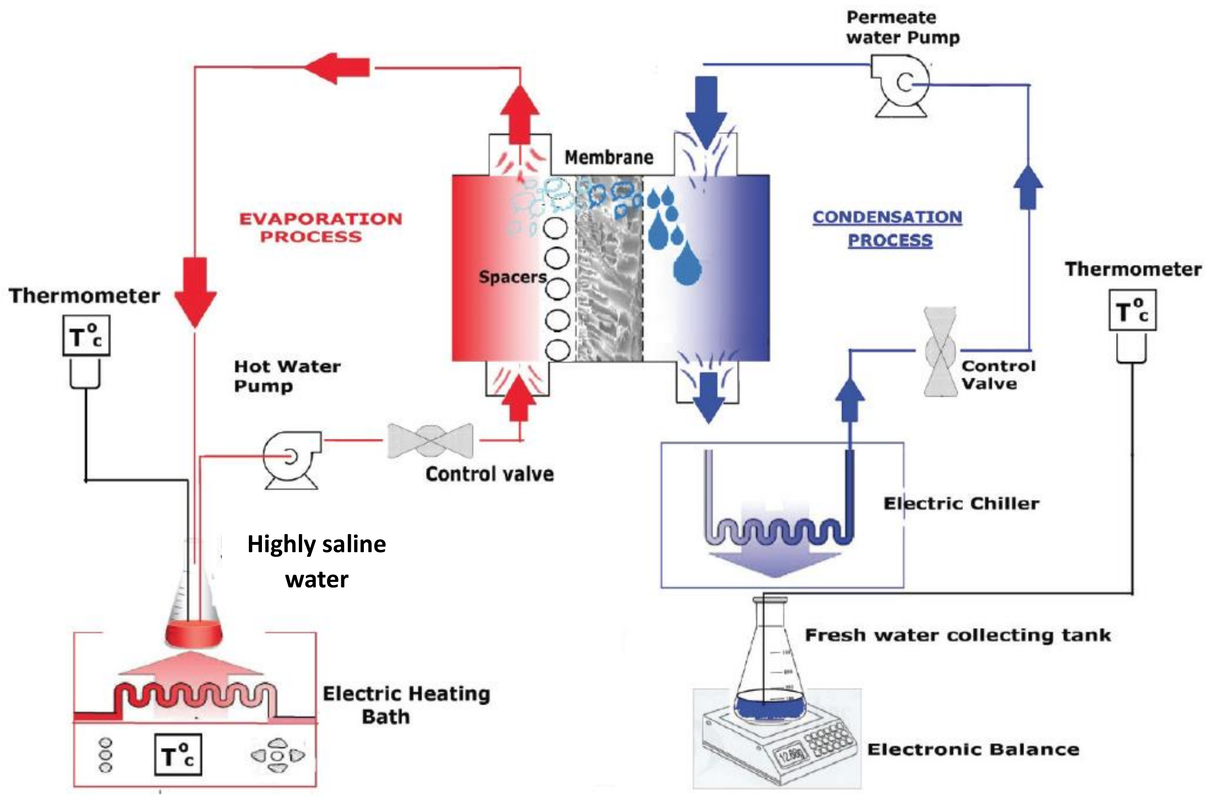
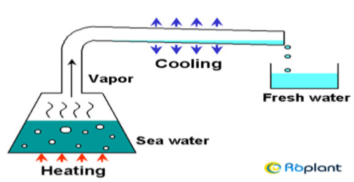


Figure 43. Schematics of Membrane distillation process [17]

e) **Indigenous desalination practices of the communities in Bangladesh coastal area:** From the early times, in the project area, it has been indicated by the target community that their ancestors have been practicing some sort of desalination techniques in search of sweet water. Even though, these technologies are now fully updated and substituted by the modern technologies, there are still some sort of lessons to adapt as a means to evaluate the appropriate technology fitting the target area. A technology which has been practiced for long time is easy to be adapted when it modernized (e.g MED, MSF, VCD, and SSD can be easily accepted in localities where steaming/evaporation process has been practiced for ages). Some of the most common local experience stated by the people in the districts of the coastal Bangladesh includes Boiling/Evaporation (see Fig. 44). In addition to this, there has also been various traditional rain water and flood water harvesting techniques from which stored water can later be utilized as a means of getting fresh water for drinking and other domestic purpose.



Source: Water industry network

Figure 44. Schematics of the old the old evaporation/boiling/steaming technology for desalination

[17] Mekdimu Mezemir Damtie and June-Seok Choi, "Modeling and Application of Direct Contact Membrane Distillation for Fluoride Removal from Aqueous Solutions," *DESALINATION AND WATER TREATMENT* 97 (2017): 23–40, https://doi.org/10.5004/dwt.201x.21690.

Table 10. Cost of plant capacity and Energy sources for different technology options[10]

Feedwater	Plant capacity (m^3/d)	Cost (€/m^3)
Brackish water RO	<20	4.50–10.32
	20–1,200	0.62–1.06
	40,000–46,000	0.21–0.43
Seawater RO	<100	1.20–15.00
	250–1,000	1.00–3.14
	1,000–4,800	0.56–1.38
	15,000–60,000	0.38–1.30
	100,000–320,000	0.36–0.53
MSF	<100	2.00–8.00
	12,000–55,000	0.76–1.20
	>91,000	0.42–0.81
MED	23,000–528,000	0.42–1.40
VC	1,000–1,200	1.61–2.13

Feedwater source	Energy source	Cost (€/m^3)
Brackish water	Conventional energy	0.21–1.06
	Photovoltaic panels energy	4.50–10.32
	Geothermal energy	2.00
Seawater	Conventional energy	0.35–2.70
	Wind power	1.00–5.00
	Photovoltaic panels energy	3.14–9.00

3.2 Practices of Small-scale desalination plant in Bangladesh and other countries

The above indicated technologies are currently the most common and state of the art technologies available to desalt different concentration from brackish and sea water. Some of the technologies have already been implemented at both large and small scale and some of the others are still under laboratory and pilot scale. However, the application of these technologies in the decentralized and rural setup has been limited for long time due to its cost implications. In order to for this project to pick the appropriate technology fitting the context of the coastal Bangladesh area, the technical team has gone through good and bad experiences of similar small-scale desalination plants from other countries as summarized below.

- SOLAR STILL DISTILLATION IN **BANGLADESH**: NGO called Oxfam has successfully implemented a household level solar still distillation in the coastal Noakhali district of Bangladesh which is exactly similar situation with the target districts of this project. The system treated a salinity of up to 6,000 ppm with maximum installed capacity of 15 L/day and a water recovery rate of ~20%. Even though the plant provided good quality of potable water, the quantity of supply has been significantly very small (~max 15L/day). The only possible way to increase the yield is installing some more additional units (which costs 450$/unit) but the land requirement will also increase drastically. Generally, the combination of low output and high capital cost makes this technology the most expensive commercially available desalination technology in terms of price per litre of treated water.

The facility was deemed not to be feasible for the specific community due to its high per household cost, minimal water output and large land requirement.

- SOLAR-POWERED REVERSE OSMOSIS IN **INDIA**: Barefoot college has successfully implemented solar RO with a plant capacity of 3.6m^3/d and recovery rate of 50% to a water with maximum salinity of 4,000ppm. In addition to the establishment, the college has also worked exemplary work on the soft components toward ensuring sustainability. These includes helping to establish water committees consisting entirely of community members, which are responsible for ensuring that the plant stays operational and teaching interested community members the technical skills necessary to operate and maintain the facilities.
- WAVE-POWERED REVERSE OSMOSIS IN **PUERTO RICO**: The University of Delaware has implemented 6.8m^3/day plant capacity RO system to treat very high salinity sea water (35,000 ppm). The system was developed long time ago (1980) before RO parts has been getting cheaper like these days. But it was meant for small remote rural communities with abundant ocean water and consistent swells. Even though the system was successfully piloted in Puerto Rico and was shown to work, it was never fully sustained owing mainly lack management and close follow-up.
- SOLAR AND WIND ENERGY POWERED RO IN **NAMIBIA**: Desert Research Foundation of Namibia has been implementing very high capacity large scale project from which the pilot-scale at two different sites having total capacity of 53 m^3/day. The project has been started since 2017 and planned to purify a subsurface brackish borehole water with salinity close to 800 ppm and has successfully started the establishment. The project energy source is purely renewable source from wind and sun.
- SOLAR-POWERED ELECTRODIALYSIS IN **INDIA**: A project jointly implemented by TATA and MIT to treat 1,800 ppm TDS source brackish water with installed capacity of 500 LPH, energy use ~0.8kwh/.m^3 in 2015 in off-grid communities of rural India has implemented electrodialysis process. The project has been implemented with a target of utilizing 75%, 50% and 25% less energy to treat brackish water sources of 1,000, 2,000, and 3,000 ppm respectively than currently used RO facilities. [11]
- WIND POWRED MEDIUM TO SMALL-SCALE RO **VIETNAM**: a theoretical research study in Mekong Delta estimated that in the absence of all other water supply facilities, off-grid wind desalination RO plant could provide clean water to 5.4 million rural residents living in 18.9 thousand km2 of the Mekong Delta coastal provinces at the rate of 60 liters per capita per day [18]
- MEMBRANE CAPACITIVE DEIONIZATION IN **INDIA**: There was a joint project by AquaSphere, Idropan, and InnoDI to treat 2000ppm brackish water with maximum installed capacity of 10m^3/day, recovery rate 80% and energy use close to ~0.8kwh/m^3 in 2004. It considered both EDR and CDI, but the high cost of the Ti electrodes used in EDR compared with the inexpensive carbon electrodes in CDI led it to focus on developing

[18] Ha T. Nguyen and Joshua M. Pearce, "Renewable Powered Desalination in the Coastal Mekong Delta," January 1, 2010, 935–46, https://doi.org/10.1115/ES2010-90224.

CDI technology. By partnering with local Indian company AquaSphere in 2012, it has successfully brought its Plimmer CDI units to India. There are currently 150 CDI units in India.

- GRID CONNECTED RO AND RAINWATER HARVESTING IN OUR PROJECT AREA, BANGLADESH: From the field survey assessment result in two stages, it is also identified that some alternative water supply options and purification technologies have been practiced in our target districts. For instance, RO system and rain water harvesting were found as drinking water options in 3 villages. 200 households in the North Jhapa village has been utilizing the RO system powered from the national grid system. However, problems pertinent to intermittent power supply and traveling distance of the beneficiaries to the water point need to be thoroughly considered in the next technology dissemination stage. In addition to this, the roof and flood harvesting storage mechanisms, tanks and traditional pond structures in Durgabati and other villages were also a good source for drinking and domestic consumption. The most important lessons to be conceived from such practice was the integration of appropriate treatment mechanism linked to the storage mechanism. Once the fresh rain water with very small salinity is available, the rest biological and chemical contaminants can be easily treated with cheaper conventional treatment mechanism such as rapid and slow sand filter.

4. Summary of Local Requirements and Conclusion

The extensive field survey conducted by the technical team in two rounds has revealed various interesting issues pertinent to the coastal areas of Bangladesh. Limited spatial variation has been detected among all the districts under investigation. However, the temporal variation has been indicated to be significant. Therefore, the team has investigated the field survey in different best representative villages in two major seasons of the year. Our filed survey result has revealed the following important conclusions to be addressed in the technology design and recommendation report.

- ✓ The number of household members (family size) in all district villages has been significantly high (up to 10) inferring that there is a potential of higher water demand per each household and bigger capacity purification system might be required to address the existing water demand of the community. The water supply system in consideration with population forecast should consider this point.
- ✓ Depending on the season, most households in the investigation area were mainly using groundwater as sources for domestic consumption, followed by rainwater harvesting as an additional source of water to supplement other further demands. The technology and water source selection, therefore, have to mainly focus on such sources. Moreover, hand pump operated shallow tube wells are most commonly utilized infrastructure to draw water from the ground sources which implies that most of the community members have already been acquainted with the establishment, operation, and maintenance of such infrastructures. There is high tendency that the community might easily adopt any kind of purification technology linked to such setup.
- ✓ Water quantity is abundantly sufficient in the rainy season and the water supply and treatment facility to be suggested should focus on delivering sufficient water mainly in water stressed months of the year. Moreover, it has been revealed that over 90% of all the surveyed households had wells in their backyards which can secure water supply during wet and semi-dry seasons.
- ✓ In rainy season, rainwater appears to be a prominent alternative source to the groundwater in terms of quantity and quality because it is observed that some households were storing water using small pots and other economically better families will even install high capacity storages to harvest rainwater from the roof. Hence establishing this kind of tanks with a bigger capacity for the three to five nearby households could significantly address the water shortage in dry season. However, there should be economical treatment mechanism integrated to such storage mechanism as the community is currently drinking such long-time stored water without any treatment.
- ✓ Shallow wells are commonly utilized as a direct primary sources for drinking water. Moreover, most households also frequently own a highly polluted open ponds near their shallow well which indicates that sufficient amount of water can be generally available for treatment once a good purification technology has been recommended and community awareness has been raised on how to properly manage and keep the water source clean.
- ✓ Direct electric power supply from the national grid has been discovered to be erratic and difficult. Hence any

purification or pumping systems should seek alternative power sources preferably from renewable energy sources (solar, wind, tidal etc). The community recently started utilizing solar panel for their household energy source which asserts implementing such system might have higher likelihood of being easily accepted by the community. Wave/tidal powered RO was tested in Puerto Rico but was never successfully commercialized

- ✓ Generally, the water quality status of all the water points has been found to be below the domestic water use standard. Some of the most common physical, chemical and biological parameters investigated in the study includes hardness, potassium permanganate, iron, arsenic, chloride, ammonia, turbidity, total dissolved solid, odor, color, organic matter, microbials and pH. Therefore, the technology recommendation has to focus toward removing such pollutants to the desired local standard.
- ✓ The community in these districts has quite significant cattle and domestic animal (livestock) population. However, owing to limited sanitation, the cattle cage, human toilet, and the water points are mostly closer leaving a bad smell both to the environment and the water body. Release of higher concentration of volatile gases (e.g has ammonia, methane, H_2S and others) has been detected and there has been severe odor in the water samples of some of the wells. The technology recommendation hence has to also seriously address the removal of such hazardous substances which induce higher public health concern to the localities.
- ✓ There are also centralized reverse osmosis membrane system in some spots of the districts and some of the residing communities are traveling far to fetch water for drinking. This might be a lesson in that the purification technologies to be recommended has to address the issue of traveling distance to the water point as well as the affordable tariff. Moreover, the RO membrane system adaptability rate can also be easily taken as a good lesson to support the purification technology selection task.
- ✓ The purification technology setup can be designed in two ways. The *centralized* communal service system in which the RO or electrodialysis chamber can be connected to the grid or big renewable energy sources (solar/wind/) and the *decentralized* system in which the community can utilize the solar still technology which can be integrated to the house roof or window system.
- ✓ Although final water output is quite low, the design of solar still distillation process (SSD) is simple and easy to implement. The SSD unit tested in Bangladesh was deemed to be too expensive for rural communities and given its low water production rate of 8–15L/day. It is also a proven technology and may still be an option for very small communities that need only tens of litres of water a day and have abundant land and solar resources. Therefore, this technology is a good option for rural settings than other thermal based methods (e.g. MED, MSF, and VCD).
- ✓ Due to its various limitations, FO could not be a potential purification solution for this specific project. However, RO, is one of the most commonly available desalination technologies worldwide and has been commercialized at the household, community and industrial scales. The prevalence of RO makes it easy for communities to find local distributors, replacement parts and partners willing to help install, operate and maintain facilities. Having been optimized and commercialized for decades, RO technology is relatively

inexpensive and low risk. Therefore, RO can be a very promising potential option for desalination in this area.

- ✓ Charge-based desalination technologies have higher recovery rates (80% to 95%) while RO offers less than 50%. Therefore, these technologies are good options for communities that need solutions for saline groundwater with high water recovery rates. All CDI, ED, and EDR have potential to be cheaper than RO for the treatment of brackish waters. Hence these purification technologies can also be a good candidate for this specific project. From several literatures and experiences, even though the ED is good option, it is less commercialized.
- ✓ Consideration of hybrid technology would also be very interesting to consider in such coastal areas of Bangladesh. Because the field studies have revealed in rainy season, rainwater seems to be a good alternative to groundwater so that the household, or community-based desalination plant can be halted or left operated partly. Where as in dry season, the yield from the desalination technology can be subsidized from stored rain water and a simple treatment mechanism can be designed.
- ✓ The experience from field study has also clearly indicated that, before deciding on the technology selection, further primary data collection and stakeholders meeting, and consultation will be required to decide the best desalination technology set up. Moreover, participatory prioritization and selection criteria have to be set to for sustainable purification technology recommendation. (see Technology option and selection criteria report)

Appendix

Appendix 1. Field survey primary data collection format for local residents

KICT GAT

Checklist of Water Usage in Bangladesh

Date : 2018.06.( ) Name : ( )

Check list	Result
1) Household information	
- Location	Bagerhat( ), Satkhira( ); Detail area name: ( )
	GPS(Latitude: , Longitude:)
2) Water using population	
- Number of adults (above the age of 14)	( )
- Number of children (under the age of 13)	( )
3) Present state of Drinking water (duplicate checks)	
- Type of water source	groundwater ( ), riverwater( ), lakewater( ), rainwater( ), purchase( ), others( )
- Conductivity(EC) & TDS	1. Water Source: EC(uS/cm), TDS (mg/L) 2. Endpoint Water: EC(uS/cm), TDS (mg/L)
- Method of transporting	pipe+pump( ), self-transportation( ), collecting rainwater( ), delivery( ), others( )
- Available amount(dry season)	sufficient( ), adequate( ), slightly insufficient( ), insufficient( )
- Available amount(wet season)	sufficient( ), adequate( ), slightly insufficient( ), insufficient( )
*** How to secure water when is lacking?**	( )
- Treatment of drinking water	filter( ), boiling( ), others( )
4) Present state of Living water (duplicate checks)	
- Type of water source	groundwater ( ), riverwater( ), lakewater( ), rainwater( ), purchase( ), others( )
- Method of transporting	pipe+pump( ), self-transportation( ), collecting rainwater( ), delivery( ), others( )
- Available amount(dry season)	sufficient( ), adequate( ), slightly insufficient( ), insufficient( )
- Available amount(wet season)	sufficient( ), adequate( ), slightly insufficient( ), insufficient( )
- Usage	laundary( ), bath( ), others( )
5) Present state of water using cost	
- Payment for public water supply system	Yes( ), No( )
- Amount of water using for month	( )L
- Cost for water using for month	( )USD
6) Present state of water using	
- Water tank	Don't have( ), Have(; Capacity: ( )L, Material: stainless( ), PE( ))
- Water tap	Don't have( ), Have (number:)
- Well water	Don't have( ), Have (number:)
7) Present state of electricity	
- Power equipment	Don't have( ), Have ( )
- Electricity supply	supply everyday( ), supply sometimes( ), cost: ( )USD/kW, electric charges ( )USD/month
- Electrical power outage	No( ), Yes(; number of frequency ( )/day)
8) Local awareness for water usage	
- Satisfaction for drinking water	Satisfaction( ), Dissatisfaction(; specifically:)
- Requirments for improvement	Satisfaction for water standard( ), Stable water supply( ), Installation and replacement of water purification system( ), etc( )
9) Photos	

1) Panoramic view	2) Drinking water supply system(pipe line, water tank etc.)	3) Living water supply system(rainwater facility etc.)

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