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Drinking Water Insecurity in Southwest Coastal Bangladesh: How Far to SDG 6.1?

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Abstract: Substantial progress has been seen in the drinking water supply as per the Millennium Development Goals (MDG), but achieving the Sustainable Development Goals (SDG), particularly SGD 6.1 regarding safely managed drinking water with much more stringent targets, is considered as a development challenge. The problem is more acute in low-income water-scarce hard-to-reach areas such as the southwest coastal region of Bangladesh, where complex hydrogeological conditions and adverse water quality contribute to a highly vulnerable and insecure water environment. Following the background, this study investigated the challenges and potential solutions to drinking water insecurity in a water-scarce area of southwest coastal Bangladesh using a mixed-methods approach. The findings revealed that water insecurity arises from unimproved, deteriorated, unaffordable, and unreliable sources that have significant time and distance burdens. High rates of technical dysfunction of the existing water infrastructure contribute to water insecurity as well. Consequently, safely managed water services are accessible to only 12% of the population, whereas 64% of the population does not have basic water. To reach the SDG 6.1 target, this underserved community needs well-functioning readily accessible water infrastructure with formal institutional arrangement rather than self-governance, which seems unsuccessful in this low-income context. This study will help the government and its development partners in implementing SDG action plans around investments to a reliable supply of safe water to the people living in water-scarce hard-to-reach coastal areas.

Keywords: drinking water insecurity; sustainable development goal; safely managed water; low-income region; coastal Bangladesh

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1. Introduction

Ensuring drinking water security, by means of equitable access to affordable water of improved quality and adequate quantity, is one of the greatest global development challenges today. Approximately two billion people have been exposed to unimproved water sources [1]. This is mainly due to a lack of testing to confirm the potability of water from sources perceived to be safe [2]. To address this limitation, the SDGs specify its drinking water goal (SGD 6.1) as to "achieve universal and equitable access to safe and affordable drinking water for all by 2030". A new category of assessment has also been introduced—safely managed water, that is, "improved water source, located on-premises, available when needed, and free from fecal and priority chemical contamination" [1]. Currently, about 71% of the global population have safely managed water services [2]. However, the coverage has remained inequitable between and within regions, as well as in communities of different socio-economic backgrounds [3]. Moreover, widespread contamination of water sources, particularly in developing countries where 80% of all illnesses are related to unsafe drinking water, is the most pressing constraint for potable water supply [4].

Bangladesh, a developing country in South Asia, has provided improved water sources to >97% of its population [5]. However, safely managed water services are inadequate, covering less than 40% of the total population. Moreover, about half of the total supplied water was found to be contaminated with dangerous microbes, heavy metals, or salt [6]. Moreover, the distribution of water services in the country varies spatially and seasonally, and the service quality is usually inferior in hydro-geologically critical and hard-to-reach areas [7,8]. The United Nations has emphasized about alleviating the conditions in vulnerable and disadvantaged areas [9]. Therefore, achieving SDG for Bangladesh requires special attention to hydro-geologically critical hard-to-reach water-insecure areas.

Southwest Coastal Bangladesh: Water Scarcity, Insecurity, and Alternatives

Covering one-third of the country's total land area, the coastal zone of Bangladesh hosts nearly 39 million people. Groundwater extracted by hand-operated tubewell has been the major source of drinking water in this region [10]. However, out of 19 coastal districts, the most southwestern five coastal districts, i.e., Satkhira, Khulna, Bagerhat, Pirojpur, and Barguna, have been identified as the hard-to-reach areas [7]. People in these districts have been exposed to different types of water security risks, particularly groundwater laced with salinity and toxins, which is not suitable for human consumption [11,12]. Previous studies have consistently reported higher salinity, as well as considerable trace and toxic elements in the groundwater samples from this area [13–19]. Hoque (2009) estimated that approximately 30 million people are unable to collect potable water and 15 million people are already forced to drink saline groundwater in this region [20]. This is principally due to the higher degree of spatial variability of salinity in both shallow and deeper aquifers. It is a consequence of the complex coastal hydrogeology and land use of the active Ganges–Brahmaputra delta [21–24]. This water quality constraint, together with complex hydrogeology, leads to the unavailability of suitable freshwater aquifer layers limiting the use of tubewells. Therefore, coastal people of southwest Bangladesh have to rely on alternative options. In these five coastal districts, 12–34% of the inhabitants are using alternative sources such as rainwater, surface water, and other unimproved water sources. Figure 1 illustrates that alternative sources are mainly used in the southernmost unions of each district which can be identified as the most vulnerable and water insecure communities.

Rain-fed pond, pond sand filter (PSF), and rain water harvesting (RWH) are the most commonly used alternative options for drinking water in southwest coastal Bangladesh [25]. Rain-fed pond is an open pond used to preserve rainwater during the monsoon season for subsequent use in the dry period, and PSF is a manually operated low-cost pond water filtration system. This engineered system is usually installed on the bank of a rain-fed pond that uptakes raw pond water and supplies filtrated water. Although Kamruzzaman and Ahmed (2006) reported PSF as the only suitable option for year-round water supply in these regions [26], it is highly prone to dysfunction and very insignificant in number compared to the need [12]. The remaining option, RWH, is an engineered system to store rainwater in a large tank from an artificial catchment (typically the roof of the household) [27,28]. However, all the existing options are highly dependent on rainfall, which is spatially and temporally variable in Bangladesh. Annual rainfall is nearly 5500 mm in the northeast region and 1700 mm in the southwest region. Moreover, 80% of the total rainfall occurs only in four months, from June to September [29,30]. Hence, water scarcity in the southwest coastal region gradually becomes more severe throughout the dry season (November–May). Moreover, the quality and quantity of stored rainwater deteriorate in ponds and tanks [25,31,32]. Therefore, the focus of this study is on the dry season in particular.

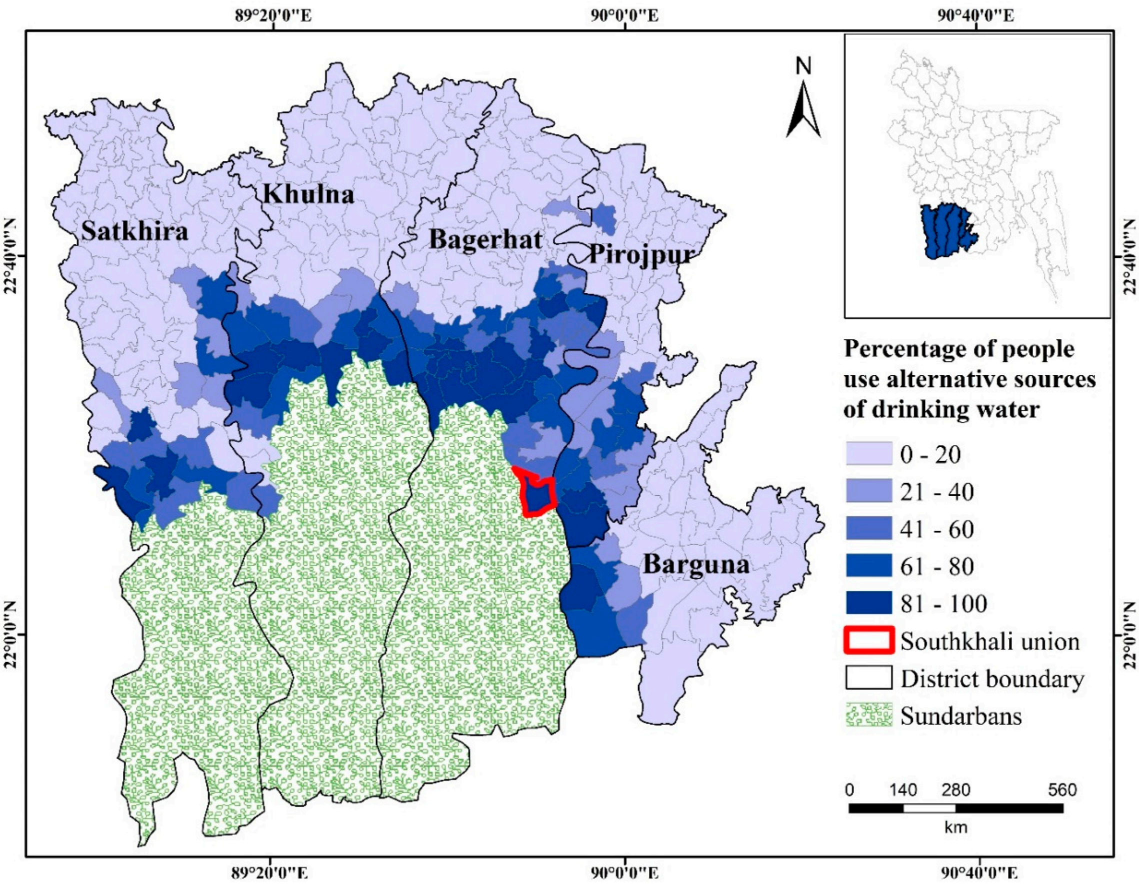

Figure 1. Percentage of population using alternative sources in coastal unions of Bangladesh and Southkhali Union (study area) (source of data: [10]).

Following the context, this study investigated the water insecurity issues and assessed the coverage of water services in a hydro-geologically critical hard-to-reach area, specifically the Southkhali Union (Tier-4 administrative boundary) located in the southwest coastal region of Bangladesh (Figure 1). More than 80% of the people of Southkhali Union are unable to use groundwater due to high salinity and are thus dependent on other alternatives [10]. Recent studies have reported widespread drinking water insecurity scenarios of southwest coastal Bangladesh [11,25,33–36]. However, comprehensive assessment in the context of water insecurity and water services in Southkhali Union is not available. Moreover, Southkhali Union would be an ideal sample to represent the water insecurity in the Unions of southwest coastal Bangladesh, as illustrated in Figure 1. The outcome of this study will help different government and non-government stakeholders to understand the current water insecurity, existing gaps, challenges, and potential solutions in delivering safely managed water services. Broadly, this will aid in developing strategies and policies to fulfill the SDG 6.1 target for the southwest coastal areas of Bangladesh and other similar places around the world.

In this study, drinking water security was investigated using a mixed-methods approach to assess water quality, availability, and accessibility, and the service level was evaluated according to the SDG service ladder. After presenting the current status of water services, we examined the existing water insecurity issues and challenges. Thereafter, the current coverage and user satisfaction were evaluated, and then potential solutions to mitigate the existing water insecurity were explored. Finally, conclusions and policy implications were briefed for coastal Bangladesh and other similar circumstances.

2. Materials and Methods

The study was conducted by employing extensive field study using a mixed-methods approach. A reconnaissance survey was carried out at first to understand the variables related to this study. This helped in preparing the data collection strategy and the contents for household survey, focus group discussion (FGD), and key informant interview (KII). Overall, this study was composed of a questionnaire survey, KII, FGD, observation at water points, and testing of water quality from November 2018 and May 2019.

2.1. Study Area

Southkhali, the southernmost Union of Sarankhola Upazila (sub-district) under Bagerhat district in the southwest coastal region of Bangladesh (Figure 1), is a sea-facing area near the Bay of Bengal. This area is highly disaster-prone compared to other Upazilas of Bagerhat district [10]. Cyclones, storm surges, and tidal waves hit this area almost every year and affect the people, property, and infrastructure, and moreover, greatly damage the drinking water sources [37–39]. This union, adjacent to the world's largest mangrove forest, the Sundarbans, has 6179 units of households in two Mouzas (Tier-5 administrative boundary) covering 10 villages with a total population of 24,980 (12,240 males and 12,740 females) [10]. Approximately 70–75% of the local people live below the poverty line. Their major livelihoods are in agriculture, day laboring, fishing, and collecting honey from the Sundarbans [40].

2.2. Data Collection, Sampling, and Laboratory Analysis

Water supply issues are concerns for the entire family; therefore, individual households were considered as units of the survey in this study. A questionnaire was designed, seeking information regarding socio-economic status; drinking water source, collection, transport, usage, storage and treatment facilities; drinking water resource management; public health issues; user satisfaction; and perceptions on drinking water options.

A close-ended questionnaire was used to conduct a systematic random face-to-face household survey. During this survey, a statistically selected sample (n = 362) of households was considered to have a 95% confidence level and a 5% margin of error. The survey was directly conducted by trained local enumerators using random sampling. Household after an interval of 10–15 houses in each village was selected for the survey. The number of households to survey in each village was calculated by rationalizing the total sample size with the total number of households in that village (Table 1). Respondents were more than 20 years old, and women were the targeted group since they are mainly responsible for water management activities for their families in Bangladesh. In cases where women did not participate, the men were asked the questions instead. Moreover, two FGDs (in Sarankhola and Sonatola Mouzas) with local villagers were conducted using a separate checklist to understand the water supply scenarios. In the FGDs, the existing challenges and potential local solutions were focused upon. Both male and female respondents participated in these sessions.

After selecting the water sampling site, we conducted a KII at the water point with its owner, or the president, or an executive member of that water point's committee. An informal water-user committee consists of several nominated executive members who work under a nominated president for operation and maintenance of the water supply system. The president was typically the first preference for the KIIs. However, for four water points, the president was absent during the field visit, and hence an executive member who actively works to keep the system functional was interviewed. In total, 28 KIIs were conducted to obtain detailed information, i.e., existing condition, practice and behavior, reliability and performance, causes of dysfunction, labor and financing for O&M, and other relevant issues in management of the water sources. Ethical considerations such as confidentiality and consent of the respondent were respected during data collection.

The sample size for the laboratory analysis of water quality was determined on the basis of the survey responses. For 3% of users of a specific source (i.e., PSF, RWH, and pond), one sampling point was selected. In combination, 28 samples (13 functional PSFs, 5 RWH systems, and 10 rain-fed ponds) were collected for laboratory analysis of water quality (Table 1). Maintaining all the precautions, we sampled water from the collection point, i.e., outlet tap of PSF, storage tank or outlet tap of RWH, and collection point of pond, where pre-sterilized high-density polyethylene bottles were used for the sample collection. Samples were kept in an icebox container and immediately transported to the nearest laboratory at Jashore University of Science and Technology.

Table 1. Sampled sources and the number of respondents from different villages.

No.	Village	Mouza	Total HH (N_v)	Sampled HH ($n_v = (N/n) * N_v$)	Sample ID
1	Dakshin Southkhali	Sarankhola	660	39	PSF-1, RWH-1, Pond-1
2	Uttar Southkhali		400	23	PSF-2, RWH-2, RWH-3, Pond-2
3	Bogi		455	27	PSF-3, Pond-3
4	Chalitabunia		635	37	PSF-4, Pond-4
5	Khuriakhali		752	44	PSF-5, PSF-6, Pond-5, RWH-4
6	Sonatola	Sonatola	1132	66	PSF-7, Pond-6
7	Bakultola		584	34	PSF-8, PSF-9, RWH-5, Pond-7
8	Uttar Tafalbari		570	33	PSF-10, Pond-8
9	Dakshin Tafalbari		439	26	PSF-11, PSF-12, Pond-9
10	Rayenda		552	32	PSF-13, Pond-10
Total			N = 6179	n = 362	

Here, HH = household, N_v = total household in village from BBS (2012), n = total household in the union, n_v = sample household in the village, n = total sample household in the union, PSF = pond sand filter, RWH = rainwater harvesting.

All the water quality tests were conducted within six hours of reaching the laboratory. The total coliforms and fecal coliforms were examined by the membrane filtration technique following the standard method described by the APHA (2005) [41]. Turbidity and pH were measured on site using HACH 2100 Q portable turbidity meter and MARTINI instruments pH 56 m, respectively. HACH Sension 156 multi-parameter was used to determine the level of salinity. Chemical analyses involving ammonia, nitrate, phosphate, and sulfate were conducted using a HACH DR2700 Spectrophotometer according to the manual supplied by HACH.

2.3. Assessment of Drinking Water Security and Service Level

Drinking water security was assessed by addressing (1) availability—types of water sources available, water use and demand, ownership of the sources, reliability of services, operation and maintenance of the sources, available treatment facilities, and the performance of regulating institutions; (2) accessibility—reasonable time and distance for collection, affordability, and gender equity; and (3) quality—free from pathogens and priority chemicals, and finally, accepted with satisfaction [34].

Coverage of drinking water services was assessed following the methodology of the WHO&UNICEF Joint Monitoring Program [42]. Existing services were categorized according to the SDG service ladder, i.e., safely managed—an improved water source located on-premises, available when needed, and free from fecal and priority chemical contamination; basic—an improved water source for which collection time is not more than 30 min for a roundtrip including queuing; limited—an improved water source for which collection time exceeds 30 min; unimproved—water from an unprotected dug well or spring; and surface water—water is directly taken from a river, dam, lake, pond, stream, canal, or irrigation canal [42].

Among the available water sources in the study area, surface water (pond and river) is the unimproved source. On the other hand, RWH, protected dug well, and commercially delivered water are improved sources. Furthermore, PSF—supply treated pond water—is also deemed to be an improved source. A limited number of people use improved sources such as vended water supply (commercially supplied bottled water) from water treatment plants situated outside of the study area. Considering the low-income context of the study area, this water is not cost-effective (40 L/USD) and inaccessible to the majority of the population. Therefore, the bottled water quality was not considered in this research, and safely managed water service was assessed on the basis of the quality of the investigated improved water sources only (PSF and RWH), which is a limitation of this study.

3. Results

3.1. Status of Drinking Water Services

Socio-demographic characteristics of the studied population are presented in Table 2. A total of 2245 people lived in the studied households. Most families have resided in the same community for more than 20 years. Day laboring (42%) was the main occupation, with more than 40% of the families earning less than BDT 60,000 (around USD 700) per year. This identifies the study area as a very low-income community.

Table 2. Sociodemographic status of the studied households in Southkhali Union.

Sl.	Aspects		Frequency	Percent (%)
1	Gender	Male	78	21.55
		Female	284	78.45
2	Age (years)	<21	0	0.00
		21–40	191	52.76
		41–60	163	45.03
		>60	8	2.21
3	Education	No formal education	95	26.24
		Primary (grade I–V)	138	38.12
		Secondary (grade VI–X)	85	23.48
		Higher secondary (grade XI–XII)	33	9.12
		Graduate	11	3.04
4	Occupation of the family head	Agriculture	122	33.70
		Services	14	3.87
		Business	38	10.50
		Labor	153	42.27
		Other	35	9.67
5	Annual family income (BDT)	Below 40,000	38	10.50
		40,001–60,000	112	30.94
		60,001–80,000	125	34.53
		80,001–1,00,000	53	14.64
		More than 1,00,000	34	9.39
6	Family size (number of persons)	Less than 5	55	15.19
		5 to 7	193	53.31
		8 to 10	95	26.24
		More than 10	19	5.25

Note: USD 1 = BDT 85 (approximately).

In the study area, only 13.3% of the studied households had engineered RWH facilities to store rainwater. The rest had to rely on rain-fed pond water for drinking and domestic uses. The study found more than two-thirds of the population used rain-fed pond water purified through PSF (38%) or consumed directly from the pond (31%). The remaining people (17.7%) accessed vended water supply and other sources such as tubewell, dug well, and river. About 60% of these water sources were privately owned, while 40% were public (source: household survey). The average drinking and cooking water demand in the study area were 3.73 and 4.51 L per person per day ($LP^{-1} \cdot D^{-1}$), respectively (Table 3). From the results of the survey, with increasing family income, the drinking water consumption decreased, but cooking water consumption increased. On the other hand, both drinking and cooking water consumption fell when the family size increased. The rest of the study concentrates on the three main water sources i.e., RWH, pond, and PSF.

Table 3. Water consumption in the studied households of Southkhali Union.

	Household Number	Drinking ($LP^{-1}\cdot D^{-1}$)	Cooking ($LP^{-1}\cdot D^{-1}$)
Total	362	3.73	4.51
Income group (BDT/per annum)			
Below 40,000	38	3.86	4.12
40,001–60,000	112	3.81	4.38
60,001–80,000	125	3.66	4.39
80,001–100,000	53	3.62	4.90
More than 100,000	34	3.80	5.21
Family size (number of persons)			
Less than 5	55	3.98	5.67
5 to 7	193	3.75	4.45
8 to 10	95	3.62	4.08
More than 10	19	3.44	3.93

Pond and PSF are community-based water points, while RWH at individual households generally serves a single family. Therefore, RWH-users can easily access drinking water within the household premises. However, when collecting water from community-based sources, the users were facing difficulties with time and distance (Table 4). About 60% of the PSF-users need >30 min to collect water because of long distance and waiting in a queue. On the other hand, almost all the pond-users have access to a pond within half a kilometer and can collect water in <30 min. It was also found that if the pond-using families want to access improved water sources such as PSF, more than 80% of them would have to travel at least half a kilometer spending more than 30 min (Table 4).

Table 4. Time and distance difficulties to fetch water in Southkhali Union.

	PSF from PSF-User (n = 138)		Pond from Pond-User (n = 112)		PSF from Pond-User (n = 112)	
	Household Number	Percent (%)	Household Number	Percent (%)	Household Number	Percent (%)
Distance (km)						
On premises	23	16.7	31	27.7	0	0.0
Within 0.5	56	40.6	69	61.6	15	13.4
Between 0.5 to 1	38	27.5	12	10.7	36	32.1
More than 1	21	15.2	0	0.0	61	54.5
Required time * (Minute)						
Available in no time	23	16.7	40	35.7	0	0.0
Within 30	32	23.2	72	64.3	19	17.0
Between 31 to 60	37	26.8	0	0.0	33	29.5
More than 60	46	33.3	0	0.0	60	53.6

* Time required to collect water includes roundtrip travel time from household to source, filling, and queuing time.

Table 5 summarizes the water quality analysis of the collected RWH, pond, and PSF samples. Ammonia, nitrate, phosphate, and sulfate concentration in all the water sources were below the Department of Environment, Bangladesh [43], and World Health Organization [44]-described standards for drinking water (Supplementary Table S1). All RWH samples met Bangladesh standards for turbidity; however, all the pond water highly exceeded the limit, and 77% of PSF water was within the limit. Salinity in PFS and pond water was above the Bangladesh limit, while no RWH exceeded the limit. Coliform was detected in almost all the samples (except one PSF and one RWH water for fecal coliform) while the drinking water quality standards' recommended value is non-detectable per 100 mL of water [44].

Table 5. Water quality parameters of PSF, RWH, and pond in Southkhali Union.

Parameter	PSF (n = 13)				RWH (n = 5)				Pond (n = 10)			
	Mean	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**	**Mean**	**Median**	**Min**	**Max**
pH	7.38	7.2	6.6	8.7	7.94	8.1	7.4	8.3	7.48	7.4	6.8	8.4
Turbidity (NTU)	8.92	7	3	21	3.6	2	1	8	97	96	76	126
Salinity (ppt)	2.1	2	1.2	3.2	0.14	0.1	0	0.3	2.28	2.18	1.35	3.5
NH_4-N (mg/L)	0.39	0.39	0.28	0.54	0.168	0.11	0.03	0.37	0.458	0.435	0.25	0.75
NO_3-N (mg/L)	1.08	1.1	0.6	1.7	3.84	3.9	2.5	5.1	1.26	1.2	0.8	2.1
PO_4 (mg/L)	0.47	0.55	0.15	0.81	0.086	0.08	0.02	0.16	0.613	0.59	0.33	0.95
SO_4 (mg/L)	31.8	30	10.7	65.6	13.58	14.7	2.3	25	39.46	37.65	16.3	77
Total coliform (CFU/100 mL)	680	340	10	2900	944	280	20	3600	7290	4400	2400	17,000
Fecal coliform (CFU/100 mL)	135	46	0	600	52	15	0	150	1602	1150	120	5000

Here, PSF = pond sand filter, RWH = rainwater harvesting, n = number, Min = minimum, Max = maximum.

Household water treatment using low-cost conventional techniques is also practiced in the study area (Figure 2). However, more than half of the RWH- and PSF-users did not use any water purification technique as they perceived the water to be safe and clean to the naked eye. On the other hand, ponds were mostly found unclean, forcing more than half of the pond-users to carry out cloth filtration and apply alum (locally called *fitkeri*, which is cheap and locally available) for treating the pond water. Another conventional technique—boiling—was not popular due to being a time- and fuel-consuming process. Moreover, the respondents reported the appearance of a smoky odor in water after boiling, which adds to their aversion. A few families (<15% of each source) can afford high-cost portable filters to purify water before consumption. Due to resource constraints, the effectiveness of these techniques in improving water quality was not measured in this study. However, when it comes to different sources, pond users were found to be more susceptible to water-related health hazards (Figure 3). The rate of diarrhea and dysentery occurrences was twofold in pond-using families (at least one member) in comparison with PSF- and RWH- using families (source: household survey and FGDs).

3.2. Water Insecurity Issues: Challenges in Ensuring Safely Managed Water

3.2.1. Unavailability of Reliable Sources

The SDGs seek a reliable water source that will be available when needed. This means a 24/7 continuous supply is expected. Barring that, the acceptable alternative is a continuous supply for at least 50% of the time, which means 12 hours per day or 4 days in a week, but not half of a month or half of a year [42]. However, seasonality determines the source of drinking water in the study area. Despite being highly variable temporally, rainwater is the only way to have freshwater. Almost every household uses rainwater for drinking. Harvesting the necessary amount of rainwater using rudimentary techniques within the household is possible throughout the rainy season (June to October). However, during the dry period starting from November, there is little to no rainfall. Moreover, these techniques can only support a few days' water supply. Consequently, drinking water scarcity becomes worse day by day until the next rainy season starts in June. To meet the daily need for water during the dry season, people have to depend on the RWH, PSF, and pond (source: FGDs).

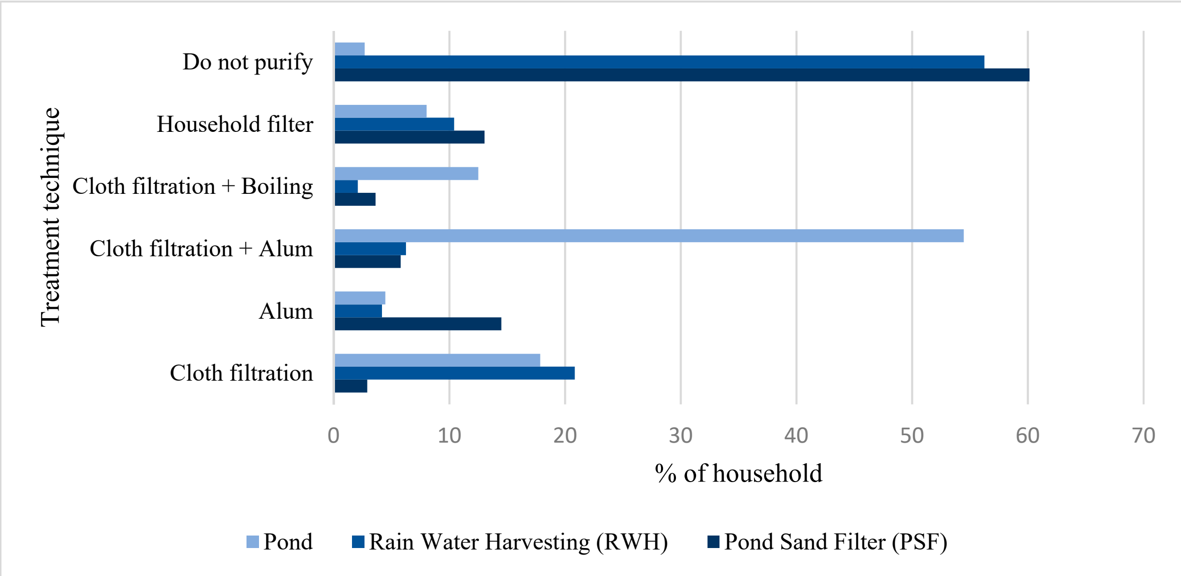

Figure 2. Water treatment facilities in households of Southkhali Union.

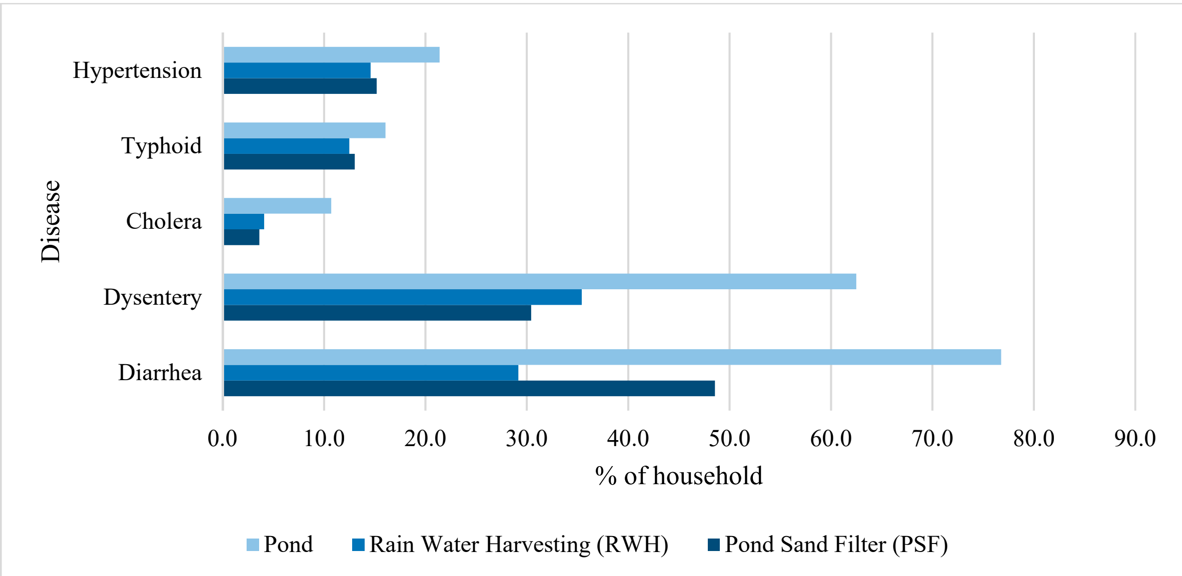

Figure 3. Families affected in different water-borne diseases in Southkhali Union.

In the late dry period, small rain-fed ponds with PSFs on the bank get dried up due to excessive consumption. This compels people to change the drinking water source, or refill the pond by pumping river water to meet the demand. Subsequently, more adverse issues such as increased salinity, turbidity, odor, and other contaminations ensue. On the other hand, stored rainwater finishes up well before the following rainy season in most of the RWH-using families due to insufficient storage in respect to the demand, which forces them to change their water source as well (source: KIIs and observations). Karim et al. (2015) also reported that most RWH-using households in coastal Bangladesh can survive on stored rainwater for six months and have to depend on other unreliable or distant sources for the rest of the year [45]. Due to the high variability of rainfall, neither RWH, PSF, nor pond can be considered as reliable sources for year-round water supply. Due to the unreliability, most people would like to have resilient alternative sources as a backup to their principal source. Therefore, shifting to reliable safe alternative water sources alongside continuing the use of the existing sources is a prime requisite for achieving SDGs.

3.2.2. Weak Institutions and Poor Operation and Maintenance (O&M)

Effective institutions are the prerequisite for sustainable O&M and the reliable delivery of water services. Yet, the existing institutional arrangements and O&M policy for rural water supply in Bangladesh, "the government install water point but the users are fully responsible for O&M in its lifetime", are the key constraints in delivering required services in the study area. For example, many government and non-government agencies with the aid of donor agencies have been establishing community-based PSF and ponds to supply drinking water. Once a PSF is equipped, it counts as an improved source in the official statistics, irrespective of its state of O&M. However, the implementation of an improved source does not mean that it will remain serviceable in the long run. PSFs have been installed in most of the ponds used as drinking water sources, but almost half of them are dysfunctional due to poor O&M (source: KIIs).

In the southwest coastal areas of Bangladesh, community-based PSFs were preferred by the public and donor agencies where O&M costs and responsibilities are fully borne by the community. However, this study found that such a strategy often fails in the low-income settings where intensive O&M such as regular cleaning, unclogging, periodical changing of the sand bar, pond protection, and some major repairs are required to keep the system functional. Even though informal water-use committees had been formed during or very soon after the installation to manage the system, most committees were found to be ineffective. In such cases, conflicting issues such as who will pay and how much should be paid, or who take the responsibility, have arisen. In most cases, the family closest to the PSF takes responsibility for looking after the minor issues. However, beneficiaries' unwillingness to pay (for example, 80% of PSF-users did not pay for O&M) and lack of consensus regarding water supply issues are the greatest challenges in keeping the system functional. Moreover, most of the villagers being day laborers restrict their willingness and scope to participate as a volunteer worker for the O&M. These difficulties inevitably compromise the performance, leading to neglect, and dysfunction becomes the norm after a certain time. Afterwards, people resort to going long distances for collecting water from a functioning PSF or the nearest pond (source: household survey, KIIs, and observations).

These ponds were also found to be poorly managed. Only one-fifth were found to have a high bank to protect overland flow and surface runoff, and fences to protect against cattle disturbance. Fish cultivation in drinking water ponds was a very common practice in the study area where fish feed was extensively used as well. Moreover, unhygienic practices such as bathing and washing—using soap, detergent, and shampoo—and even cattle washing were very common in the same ponds used for drinking water (source: KIIs, FDGs, and observations). One of the respondents in Sarankhola stated:

> "*Like many of us in this community, my family consumes pond water. The PSF, installed here, has been nonfunctioning for a long time. No one repairs it. We all take baths and wash our household goods in that pond. The owner of the pond has made a cowshed on the bank of the pond. They (owner) also wash the cows in the pond. The pond has no peripheral fence and embankment. Runoff from the surrounding area always enters the pond. Ducks swim there but we cannot say anything, as they own it. We have no other option but to use it. But the owners do not use pond water themselves; they buy it from the vendors.*" (FDG, Sarankhola, Bangladesh)

On the other hand, the majority of the RWH systems had corrugated iron sheet-based smooth roof surfaces followed by thatched-based roofs. Lack of first flushing facility, irregular cleaning, and manual uptake of water by inserting a bucket were very common (source: KIIs and observations). Such practices may increase microbial contamination in the harvested water [46,47]. Moreover, corrugated iron roof facilitates self-cleaning and unfavorable environment for microorganisms due to the rooftop's high temperature, but thatched-based roof facilitates higher microbial contamination [47]. For these reasons, developing an effective and practical installation and O&M strategy with appropriate institutional arrangements remains a major challenge towards SDGs.

3.2.3. Time and Distance Difficulties in Access

The SDGs require on-premise improved water sources, but the majority of the sources in the study area are located far away from the household. Apart from on-premise sources, the next best alternative is basic service, an improved source within 30 min of total collection time. However, distance and travel time affect water consumption, and it is estimated that when collection time exceeds five minutes, water use is expected to decrease [48,49]. This study found that more than half of the PSF-users need >30 min and travel more than half a kilometer to collect water (Table 4). However, the situation is even worse for other coastal unions where previous studies have reported greater distances (2 to 12 km) for collecting water [12,33].

The low flow rate of PSF was found to prolong the pouring time and ultimately enlarge the queue at the collection point. The situation worsens when an individual pour multiple pitchers at a time. Generally, long queues at the community water points were evident in the mornings and evenings, after the respective meals when women get free time out of their household responsibilities to collect water. In the study area, women (89%) were mainly responsible for collecting the water for their families. Doing so is difficult given the number of pitchers to fill and the distance to carry them. Consequently, they lose substantial time, which could otherwise have been invested in productive activities, children's education, nutrition, etc. Some of the PSFs were reported to not be gender-friendly due to operational difficulties, i.e., the hand pump was too high to operate for a local woman (source: household survey, KIIs, FDGs, and observations). One woman from Sonatala village described her predicament:

> "*I only get free time in the afternoon. So that I had to go to the PSF at that time though I generally wait for a long time. I took four of my pitchers together. My little daughter accompanies me. We pour all of them when my turn comes. Then she looks after the pitchers and I carry them home one by one. Sometimes the sunsets but water collection still has to be completed*" (FDG, Sonatala, Bangladesh)

Moreover, PSFs in the study area are constructed mainly on the basis of the availability of rain-fed ponds. On the other hand, villagers prioritize time and distance to choose a drinking water source. Therefore, people usually collect water from sources closer to their households without considering whether the source is improved (e.g., PSF) or not (e.g., pond). As safety and hygiene issues get little attention, about one-third of the people are still using pond water. Pond-users are mainly located in the areas where the nearest PSFs were dysfunctional. Moreover, not having to stand in a queue encourages them to collect pond water. Long queues in collecting PSF water sometimes force villagers to fetch water from the PSF's adjacent pond (source: KIIs, FDGs, and observations). These difficulties gravely affect human health, education, productivity, and school attendance [50–52]. As a result, time and distance difficulties have restricted access to desirable options for this coastal community, which must be mitigated to achieve SDG.

3.2.4. Unaffordable Services

Affordability demands that water is available for everyone, even the most vulnerable and disadvantaged groups, irrespective of their income. The cost should not discourage users to expect the least required amount or force them to reduce their attention to the basic needs. This study found that people in the study area were forced to use unimproved sources due to the unaffordable cost of on-premises water sources such as RWH (source: FGDs). According to the Department of Public Health Engineering (DPHE) of Bangladesh, the installation cost of a RWH system for a single household is BDT 29,000 (nearly USD 350). Additionally, it requires regular O&M during its lifetime [25]. Since the annual income of half of the families in the study area was below BDT 50,000 (approximately USD 600) (Table 2), such a high initial investment for RWH is hardly possible in this setting. Consequently, it is unrealistic to expect people to pay for their drinking water. The existing RWHs were installed either through public or donor agencies investment or by wealthy villagers who have an annual income greater than BDT 80,000 (nearly USD 950) per year. To ensure on-premise water services for the marginal communities, the government has focused on RWH systems. However, this study found that the relatively wealthy households are using these limited public resources. Although NGOs are providing storage tanks to the poor through monthly installments, it imposes a further economic burden on the low-income community (source: KIIs and FGDs).

On the other hand, community-based PSFs have been installed by public and donor agencies since 1983 to supply drinking water in these areas at a low cost [53]. It is still the most affordable option as the installation cost of a PSF to serve 60 households is only 1100 BDT (around USD 13) per household [25]. However, the community had to bear a significant O&M cost throughout its lifetime while the low-income people can hardly manage food expenses. The majority of the families were unwilling to share the costs, and therefore, dysfunction of the system was inevitable. Thus, people had to seek alternatives—either buy vended water, or use pond water. Pond waters are preferred in the poorer households due to easy and free of cost access (source: KIIs and FGDs). Hence, ensuring affordable water supply irrespective of income status in these poorer coastal communities is one of the greatest challenges for SGDs.

3.2.5. Contaminated Water

The SDGs seek water that is free from pathogens and priority chemical contamination. However, all the studied samples were contaminated by total coliforms (TC), and more than 92% of the samples were contaminated by fecal coliform (FC) (Supplementary Table S1). Pond water showed greater bacterial contamination than PSF and RWH (Table 5). Previous studies also reported higher bacterial count in drinking water ponds in coastal Bangladesh [47,54–56]. The presence of a large number of coliforms in pond water indicates pollution through defecation from people and animals. According to the field study, this mainly occurs through surface runoff. Lack of high peripheral embankment; cultivating fish using various sources of feed; and bathing, cattle washing, and other unhygienic practices contribute to this. Cowsheds and poultry firms were found in the peripheral area of the ponds. Moreover, the materials used in those firms usually drain in the drinking water ponds. (source: KIIs and observations). Ahsan et al. (2017) also identified surface runoff as a reason for the contamination of pond water in coastal Bangladesh [54].

The highest value of TC was found in an unprotected pond while the lowest was found in a well-protected and maintained PSF water sample. Moreover, one PSF water, which was properly managed and operated by a local NGO, had zero FC (source: KIIs and observations). These findings emphasize the necessity for protective measures and regular maintenance along with sound operation of the PSF systems to maintain acceptable water quality. Harun and Kabir (2013) also reported that the effectiveness of PSF in reducing coliform bacteria largely depends on the raw (pond) water quality and overall management of the PSF and its adjacent pond [56]. Islam et al. (1994) reported that a pond protected from human use with a high bank and no drain can provide water with a fecal coliform count of 1 CFU/100 mL year-round. Therefore, source protection is an important factor [57].

In addition, only one RWH water was found to be free from fecal contamination (Supplementary Table S1). This study suggests that the coliforms in the RWH might be due to manual first flushing, which was not found in a good condition; dirty roof catchment; types of tanks and catchment materials (e.g., thatch); irregular cleaning of tanks; and manual water collection using contaminated pots (source: KIIs and observations). Several studies also found that types of catchment area, water tank, and overall O&M of the system exert a great influence on the quality of harvested rainwater [31,58]. This study also found that the contamination in RWH and PSF water could take place through secondary pollution. Using storage tanks with unstable or broken roofs; using a stick instead of a tap to control the outflow; and lack of care in tank washing, cleaning, and other maintenance activities lead to secondary pollution, as also reported by Islam et al. (2013) [25]. On the other hand, rainwater contains fewer minerals, which might be a concern for long-term public health benefits [59]. A total bacterial count of 100–500 CFU/100 mL in drinking water is harmful to human health [41]. Therefore, the contaminated water sources pose dangerous health risks to people.

Besides the presence of microbes, pond water was found to be highly turbid (Table 5). The surface runoff and fish feed can increase the turbidity of pond water by the association between micro-organisms, organic matter, and suspended solids [47]. The lower range of turbidity (3–21 NTU) of PSF water indicates PSF is efficient in reducing turbidity. On the other hand, salinity was higher in pond water (Table 5) due to the influence of highly saline shallow aquifers and river water [60,61]. Since PSF cannot efficiently reduce salinity [56], PSF water was as saline as pond water (Supplementary Table S1). Despite high salinity, very few respondents mentioned their PSF and pond water as saline, likely because they have become used to it (source: FGDs). However, saline contamination of drinking water sources might be causing higher rates of (pre)eclampsia and gestational hypertension of pregnant women in coastal Bangladesh [62]. These problems may be exacerbated by future sea-level rise and climate change [32,37,63,64].

3.2.6. Climate Change and Natural Disasters

Global climate change has caused unreliability in water availability, increased the frequency and severity of water-related disasters, and aggravated the adverse situations in water-stressed regions such as coastal Bangladesh [65]. Frequently occurring natural hazards, e.g., cyclones, tidal surges, and storm surges greatly damage the existing water infrastructure (i.e., RWH, PSF). Inundation and contamination of freshwater ponds and disruption to the water supply systems in the study area are common (source: KIIs and FGDs). Previous studies also highlighted the consequences of climate change—sea level rise, erratic rainfall, high evaporation, and increasing frequency and intensity of disasters accelerating drinking water insecurity in southwest coastal Bangladesh [33,63,66,67]. As the annual rainfall is expected to decline in the future due to climate change in Bangladesh [68], the existing model relying on rainwater for year-round water supply will make these regions more water-insecure. Therefore, the policies and practices regarding potable water in these regions must be revised accordingly.

3.3. Current Coverage and User Satisfaction

Following the SDG service ladder, only 1 in 10 people were found to have safely managed water service, and about one in three people were found to have basic water service (Table 6). The rest of the people, about two-thirds of the total population, are using limited service (30.7%) or surface water (33.4%). This study found that the travel time to collect water from a PSF increased manifold when the nearest PSF became dysfunctional. This ultimately increased the number of people with limited water service. Moreover, people who are unable to spend much time collecting water from further away from a functional PSF were using the nearest pond water. The findings also suggest that if the dysfunctional PSF were rehabilitated, coverage of basic water services may expand up to more than 90% of the population (source: household survey).

As people in the study area live with a variety of water services, their satisfaction varies accordingly (Table 7). RWH-users were identified as the most satisfied group, with about 65% of them being satisfied. This was mainly because of the access to water within the household. The rest of the RWH-users pointed out two major causes of dissatisfaction: firstly, low capacity of storage tanks, and secondly, the bad odor of harvested water in the late dry periods, which force them to change the water source. On the other hand, PSF was highly satisfying (>20%) for those who could avoid extreme time and distance burdens and were living close to their PSFs. Nevertheless, more than half of the PSF-users having to spend a long time traveling over a large distance for collecting their drinking water were very dissatisfied (source: household survey).

In addition, frequent malfunctioning and higher O&M requirements were identified as the significant reasons behind dissatisfaction for the PSF-users. More than 90% of pond-users had lower satisfaction, mainly because of bad taste, high turbidity, and poor hygiene of the pond (source: household survey).

Table 6. Current coverage of drinking water services in Southkhali Union.

Source Category	Percent (%) of Meeting Criteria				Service Level	Criteria (i) Accessibility and Availability	Percent (%) of Meeting Criteria			Criteria (ii) Water Quality	Percent (%) of Meeting Criteria			Overall Coverage
	PSF	RWH	Pond	Other			PSF	RWH	Other		PSF	RWH	Other	
Improved	100	100	Nil	86	Safely managed	Located on-premises, available when needed	16.7	100	23.4	Free from fecal and priority chemical contamina-tion	7.7	20	Not ana-lyzed	11.1 *
					Basic	Roundtrip collection time below 30 min	39.9	100	42.2	Criteria not established	-	-	-	35.9
					Limited	Roundtrip collection time exceeds 30 min	60.1	0	43.8	Criteria not established	-	-	-	30.7
Unimproved	Nil	Nil	100	14	Surface water	Criteria not established	-	-	-	Criteria not established	-	-	-	33.4

* Considering water quality of studied improved sources, excluding the other sources. Here, PSF = pond sand filter, RWH = rainwater harvesting.

Table 7. Level of satisfaction among different water users in Southkhali union.

Level of Satisfaction	PSF		RWH		Pond	
	Household Number	Percent (%)	Household Number	Percent (%)	Household Number	Percent (%)
Very high	10	7.2	19	39.6	-	-
High	21	15.2	12	25.0	2	1.8
Medium	35	25.4	15	31.3	10	8.9
Low	18	13.0	2	4.2	33	29.5
Very low	54	39.1	0	0.0	67	59.8
Total	138	100	48	100	112	100

Here, PSF = pond sand filter, RWH = rainwater harvesting.

3.4. Potential Solutions

Against the challenges presented above, solutions are complex and difficult to implement. In order for universal on-premise safe and affordable water services to be established, strategies should be data-driven and based on solid research and people's perceptions. In the case of southwest coastal Bangladesh, the following measures should be considered by the policymakers to achieve SDG 6.1.

Firstly, improved water sources with on-premise access must be available for all. Similar to the other studies [2,33,69,70], this study found that roof-top RWH at the household level is the preferred drinking water source in southwest coastal Bangladesh. However, during FGDs, the villagers advocated initiating a need-based allocation approach using a combination of available technologies instead of promoting a single source (such as RWH) to ensure on-premise water service. Further, they suggested that as households in the study area are situated in clusters generally sharing a common yard and pond; installing a PSF on that pond could be an on-premise improved source for supplying water. On the other hand, RWH could solve the problems of discrete households. Therefore, to eliminate the use of unimproved and surface water sources, damaged PSF should be rehabilitated, and new infrastructure (RWH and PSF) should be built where needed. In this way, access within premises might be ensured.

Secondly, considering the income level of the coastal inhabitants, the water services should be made more affordable and free of cost where possible. PSF is the cheapest improved water source (6400 L/USD) followed by RWH (362 L/USD) for a 15-year economic life in coastal Bangladesh [25]. However, both technologies require a high initial cost for installation (almost 90% of total cost). Since more than three-fourths of the families earn less than USD 1000 annually (Table 2), paying for one's water source is very difficult. Therefore, there is no other option but to increase public investment to ensure the provision of cost-free water. In this context, government and donor agencies should play a pivotal role to improve drinking water security in this region.

Thirdly, existing policies, practices, and institutional arrangements for water services in southwest coastal Bangladesh should be revised. This study confirms the findings reported by Islam et al. (2013) that inappropriate O&M of water sources is the most prominent cause behind the lower quality of service [25]. The responsible authority for rural water supply in Bangladesh—DPHE—usually deploys only three mechanics in charge of O&M in each sub-district. The well-functioning water services largely depend on community support (Zamanur Rahman, personal communication, 5 February 2020). This arrangement for O&M is successful in other parts of the country to supply groundwater via tubewells, which require minimal O&M. However, the same arrangement is not very effective in areas where alternative options such as PSFs are used, which require continuous technical support to keep the system functional. In this regard, a lesson can be learned from the two Bangladesh Water Development Board (BWDB) projects for agricultural water management in coastal Bangladesh, namely, (1) the Integrated Planning for Sustainable Water Management (IPSWAM) project, and (2) Blue Gold program. It applied a participatory approach to create formal water management committees so that community and local government institutions (LGIs) can work together to manage the dynamic water resources of coastal Bangladesh. Thus far, these projects have been successful and the committees remain active [71]. Here, similar initiatives can be undertaken to formally engage the community and LGIs in participatory drinking water management. Therefore, current policy and practice should not be generalized. Situation-specific strategies need to be devised to solve particular problems and special attention is required for these hydro-geologically critical hard-to-reach areas.

Fourthly, disinfection of water should be implemented to ensure potability. Although PSF and RWH have the potential to supply zero bacterial water, this study suggests that it would be very hard under the existing circumstances. Moreover, there are secondary sources that can contaminate the drinking water. Thus, to be in line with the SDGs target of pathogens-free water in regions where centralized water supply and treatment systems are not applicable, point-of-use (POU) implied household water treatment and safe storage (HWTS) can be an appropriate alternative [72].

Finally, research and scientific investigations should be continued to discover climate-resilient sources to cope with this complex hydrogeological problem. Many initiatives have already been taken such as desalination plant and reverse osmosis (RO). However, these options are not popular due to time and distance difficulties; higher energy consumption; requirement of highly skilled manpower for O&M; public health impact; and, most importantly, cost ineffectiveness [69,73,74]. In such cases, modified PSFs such as the submerged pond sand filter [75] and modified design pond sand filters [76] could be cost-effective water sources for this low-income rural area. These innovative techniques require minimal O&M and can serve for a longer period than traditional PSFs. Furthermore, managed aquifer recharge (MAR) system could be a potential climate-resilient technique considering the consequence of sea level rise and climate change in coastal Bangladesh, despite having technical difficulties in installation and O&M challenges [77,78].

4. Conclusions

This research has revealed the water insecurity issues of Southkhali Union in the southwestern coastal region of Bangladesh. Existing water services are well behind schedule in terms of reaching the SDG 6.1 target of safely managed water services. In the meantime, a significant number of people still live without basic water service. While many initiatives have been taken by the government and donor agencies, drinking water security remains an alarming issue. Unimproved, unaffordable, and unreliable water sources are having to be used, which cannot satisfy the water quality standards. Moreover, higher rates of nonfunctioning water infrastructure have created a significant time and distance burden to access improved water sources, ultimately worsening the water scarcity.

Overall, the drinking water supply through the rain-fed pond, PSF, and RWH is constrained by water quality, availability, and accessibility. People are still using heavily contaminated surface water and do not have an on-premise water supply facility, a situation that conflicts with the goal of SDG 6.1. Of the available drinking water sources, RWH and PSF have the potential to supply safely managed water, but both options require trade-offs in these poorer coastal communities. At the same time, given the hydrogeological complexities and water quality constraints (e.g., salinity, arsenic), it is unlikely that groundwater-based sources would solve the drinking water problems. Therefore, considering the numerous challenges and limitations of RWH and PSF, as illustrated in this study, carefully thought-out initiatives should be undertaken by the relevant authorities to mitigate drinking water insecurity for the coastal people of southwest Bangladesh.

As worrying as the issue of water insecurity is in Southkhali Union, its situation is no different from the other hard-to-reach coastal unions, nor what other countries are now going through. There are many water-insecure and underserved communities globally that are facing different levels of difficulties to ensure safely managed water. Moreover, climate and increased natural disasters will worsen the situation in the future. This case demonstrates that in achieving the universal provision of safe and affordable water, these types of water-insecure areas should receive more emphasis and require case-specific measures when traditional water supply technologies fail. While facing harsh environmental and socioeconomic conditions, these communities deserve a strategy that focuses on the sustainable management of existing resources along with the development of affordable strategies to ensure safely managed water services in Bangladesh and across the globe.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/w13243571/s1, Table S1: Water quality parameters with WHO and Bangladesh standards.

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