RELIABILITY OF RAINWATER HARVESTING SYSTEM IN THE COASTAL BANGLADESH: A CONCEPTUAL FRAMEWORK FOR CLUSTER APPROACH TANK SHARING MODEL

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Master in Disaster Management

Postgraduate Programs in Disaster Management (PPDM)

Department of Architecture

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A thesis submitted to the Department of Architecture in partial fulfilment of the requirements for the Degree of Masters in Disaster Management

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Declaration

This is hereby declared that

1. The thesis submitted is my original work while completing my degree at BRAC University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material that has been accepted or submitted, for any other degree or diploma at a university or other institution.
4. I have acknowledged all main sources of help.

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Approval

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Ethics Statement

The study was conducted with full ethical competency and integrity. Conscious ethical considerations were made in terms of decision-making and compliance with applicable legal as well as socio-cultural and ecological consequences.

During the field survey and data collection, consent was secured from the interviewers as well as the participants of the Focus Group Discussion (FGD). The purpose of the research was clearly explained to the survey participants, including the intended use of the information from the survey, interview and FGDs. In addition, consent was also obtained from the participants regarding note taking and the use of information solely for research purposes. During the field survey and FGDs, local volunteers were engaged as interpreters to ensure cultural appropriateness as well as proper understanding of the questions.

The principle of "Do no harm" was strictly followed during the field study. All the participants were consulted in advance and the interview/ FGD schedule and place were selected to minimize disruption to their daily lives. In addition, proper credits and citations were rigorously maintained for all the intellectual properties and studies consulted in this study. In some cases, written permission was also secured from the authors to cite their study.

Abstract

Despite having an average annual rainfall of 2400mm- 2600mm rainwater harvesting is still considered as "**Seasonal solution"** for drinking water sources in the coastal area of Bangladesh. Given the phenomenon of "**Too much or too little rainfall**" during different seasons that result in a huge waste of rainwater makes it difficult to design a rainwater harvesting system that can provide adequate and year-round drinking water yet economically feasible for the low-income households. However, the needs for drinking water, especially in the multi-hazards coastal area of Bangladesh is a "**must-have**" survival issue that goes beyond any technical or economic feasibility framework. This leads to a quest of designing a rainwater system, specifically the storage tank which is more "**reliable**" as well as "**affordable**" for the low-income households including the 35 million people living in the coastal area of Bangladesh.

Employing a mixed method approach in combination of literature review, Simple Random Survey (SRS), Focus Group Discussion (FGD), in-depth interviews and hypothetical scenario analysis, this paper introduces the "**Cluster Approach Tank Sharing model**" and presents the result which shows improved "Reliability" of the rainwater harvesting system. The concept "**Tank Sharing**" used in this study has already been proven successful in the "**Off-grid"** smart energy sharing (solar) and decentralized water supply as well as sewage system design.

The result of this study can potentially be used by different stakeholders including the government, NGOs, and the private sector to scale up the rainwater harvesting systems, especially in the water-stressed settings such as the coastal area of Bangladesh. This scale-up of the rainwater harvesting system will contribute to achieving SDG 6 targets by providing more "reliable" and "affordable" drinking water for all and thus contributing to the **economic progress** while keeping the **environment safe**.

Keywords: *Rainwater Harvesting, Coastal, Bangladesh, Tank sharing, Off-grid, Reliability*

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List of Acronyms

ADB	Asian Development Bank
BBS	Bangladesh Bureau of Statistics
BCCRF	Bangladesh Climate Change Resilience Fund
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BIP	Bangladesh Institute of Planners
BMD	Bangladesh Meteorological Department
BNBC	Bangladesh National Building Code
DFID	Department for International Development
DPHE	Department of Public Health Engineering
FAO	Food and Agriculture Organization
FIETS Model	Financial Institutional Environmental Technological Social Model
GoB	Government of Bangladesh
HtR	Hard to Reach
IAB	Institute of Architects Bangladesh
IEB	Institution of Engineers, Bangladesh
IFRC	International Federation of Red Cross and Red Crescent Societies
IHME	Institute for Health Metrics and Evaluation
JICA	Japan International Cooperation Agency
MAR	Managed Aquifer Recharge
MBM	Mass Balance Model
MICS	Multiple Indicator Cluster Survey
MoDMR	Ministry of Disaster Management and Relief
MoLGRD	Ministry of Local Government, Rural Development and Co-operatives
MoWR	Ministry of Water Resource
NGO	Non- Governmental Organization
O&M	Operation and Maintenance
PSF	Pond Sand Filter
RIM	Reliability Index Model
MoFA	Ministry of Foreign Affairs
RWHS	Rainwater Harvesting System
SDG	Sustainable Development Goal
SRS	Simple Random Survey
TPh	Transcendental Phenomenological Methodology
UNDP	United Nations Development Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
UNISDR	United Nations Office for Disaster Risk Reduction
WASA	Water and Sanitation Authority
WASH	Water Sanitation and Hygiene
WBM	Water Balance Model
WHO	World Health Organization
WSP-WB	Water and Sanitation Program- World Bank

Chapter One

Introduction

1.1 Background and the current state of the problem

Access to adequate quantity and acceptable quality of water is one of the fundamental elements for human survival (Safe Drinking Water Foundation, 2016). Yet, as of the year 2017, 844 million people are still lacking basic drinking water service, 263 million use a limited service, and 15 million collect drinking water directly from unsafe water sources (UN, 2018). Despite the remarkable progress made in many SDG targets, a significant portion of the total population in Bangladesh, especially in the coastal region do not have access to adequate safe drinking water. According to the 2019 MICS survey, drinking water coverage is the lowest in Khulna (94%) where the national average is 98% (Bangladesh Bureau of Statistics, 2019). About 87% population in Bangladesh are using safely managed drinking water services which is the 2nd lowest water supply coverage among the South-Asian countries (GoB, 2018). Although access to a reliable water supply is a basic human right, many governments fail to ensure this service.

The coastal area of Bangladesh has a unique geophysical characteristic that is different from rest of the country. The total area of the coastal region is 47,211 km^2 which is 32% of the country's geographical area. About 35 million people that is 28% of the country's total population live in this region. In terms of administrative consideration, 19 districts out of 64 are considered "coastal districts" (Shamsuddoha & Chowdhury, 2007). National water and sanitation coverage in Bangladesh has improved significantly over the last few years. However, there are some Hard to Reach (HtR) areas including the coastal belt of Bangladesh that need special attention due to their unique geophysical, socio-cultural, and economic situation (WSP-WB, 2011).

Poor water and sanitation infrastructure is one of the key features of these HtR areas and demands specific considerations in different aspects of development. All the six measurable indicators for HtR area confirm that out of 19 coastal districts 6 are classified as hard-to-reach areas (GoB, 2011). Except for some pockets, all the groundwater aquifers down to 600-700 feet in 140 coastal Upazilas have become saline due to saltwater intrusion. More alarmingly, the groundwater in some areas is contaminated with arsenic. Currently, 15 million people are already drinking saline water and another 30 million are unable to collect potable drinking water due to a lack of available safe water sources (Galiulin, et al., 2001).

Demand and supply of drinking water in the coastal area do not correspond due to many complex actors and factors such as **too much or too little rain**, continuous shrinking of freshwater storage due to climate change, salinity intrusion, damage to water supply infrastructure by frequent disasters, abandoned of tube-wells because of an excessive limit of arsenic and population growth. Aging infrastructure, unplanned urbanization, and unplanned infrastructure put a surcharge burden on top (Ahmed, et al., 2013). Groundwater extracted by heavily subsidized tube-well scheme is the most common type of water supply option in the coastal zone. In fact, 90.94% population living in this area use either deep or shallow tube-well and or both as the primary drinking water option (BBS, 2015) whereas alternative water source such as rainwater harvesting covers only 1.72%. But the tube-wells often get out of order after any disaster and need a financial and technical support to make it functional again which in general users cannot afford (Gajghate D. & Reddy P., 2009).

Before '90s, drinking water sources in rural Bangladesh were surface water mainly from rivers, canals, and open freshwater lakes (Agrawal SK., 2003). It is assumed that most of these surface water sources were contaminated with different pathogenic elements, especially E. coli. In response, the Government started the installation of tube-wells to reduce disease from ingestion of pathogen-laden surface waters (Johnston, et al., 2012). Within a few years, around 9.2 million tube-wells have been installed by the private sector, NGOs, and government initiatives. This has provided around 97% safe water drinking coverage which was recognized as a great success. After the increase in tube-well coverage, there was a major decline in diarrheal diseases, though it was not fully clear whether this success is because of access to tube-well alone or not (Bruce, et al., 2003).

However, in 1993, the Department of Public Health and Engineering (DPHE) discovered high concentration of arsenic in tube-well in Chapai Nawabganj. This was confirmed in 1995 with additional surveys in southern and central Bangladesh following which the WHO declared arsenic contamination as a major public health issue (NGO Forum, 2003). Within a decade, the scale and the extent of the problem have started unfolding. It was found that arsenic contamination was present in 62 out of 64 districts (Ahmad, et al., 2018). A report by WHO confirms that due to high salinity and arsenic contamination, most of the groundwater sources in 4 coastal districts (Khulna, Satkhira, and Bagerhat district) is unsuitable for human consumption (WHO, 2004). Along with other hydro-geological challenges, the prevalence of arsenic and salinity in the coastal area forced people to find out alternative means for drinking water sources.

Scientific evidence, explanations, and impacts of climate change are often difficult to grasp by general people. However, the impacts are clearly visible and generally understandable in terms of shortage of availability of fresh water and the decrease of water quality. This takes place mainly due to increased salinity, turbidity, increased impurities and germ load, contamination of arsenic in the groundwater among others. The situation of saltwater intrusion is expected to become more severe in the low-lying coastal areas with sea-level rise and changes in precipitation patterns due to global warming (DFID, 2004). This will have a serious consequence on the availability and the quality of the freshwater stock in the coastal area and thus impact the access and the consumption pattern.

During floods or tidal surges, most of the drinking water sources get contaminated and put the total public health system at risk (Khan, et al., 2011). In addition, climate change contributes to creating enabling environment for the reproduction and survival of bacterial, protozoan, and viral pathogens and enhances the occurrence of spreading out of waterborne diseases (DFID, 2004). Waterborne diseases like diarrhoea, cholera, and skin and eye diseases are likely to increase with the change of precipitation patterns as this compromise the availability, accessibility, coverage, and quality of freshwater (BIRDEM, 2012). This put 35 million coastal people at risk who are already facing increased exposure to diseases like hypertension because of the increased salinity in drinking water (Abedin, et al., 2018). A maximum intake of 5 grams of salt with food and drink per day is recommended by the WHO and FAO. But people in the salinity-affected region of Bangladesh take up to 16 grams of salt just by drinking water (Roy, 2013). High intake of sodium consumption through saline water either by drinking and or cooking is directly associated with the increase of gastrointestinal symptoms, including diarrheal, vomiting, upset stomach, loss of appetite, irritation/bleeding in the throat, and high blood pressure. Specific population groups such as children, elderly and pregnant women are especially vulnerable to this high intake of sodium (Lam, et al., 2018).

A study conducted by (Nahian, et al., 2018) shows that the women have 31% higher chance of being hypertensive than their male counterparts. Excessive Sodium intake also has a great influence on infant and new-born death and maternal health in the coastal area of Bangladesh. Research conducted by (Khan, et al., 2011) in Dacope Upazila found that average estimated sodium intake from drinking water is higher in the dry season (5-16 g/day) compared to the rainy season (0.6-1.2 g/day). This translated that unavailability of rainwater (for drinking) is corelated to higher prevalence of hypertension (during pregnancy) in the dry season (12.2%) in compared to rainy season (5.1%). Another study conducted by (Dasgupta, et al., 2015) found that exposure to saltwater was highly significant to infant mortality.

Shrimp farming was introduced in the early 90s in the Khulna region turning a vast area of land into shrimp ponds. With an annual increase of 20%-30% since 1990, currently, 0.276 million hectares of land are under brackish water and being used for shrimp cultivation. Unplanned Shrimp cultivation has a multifarious negative impact on freshwater resources (Rahman, et al., 2013). Due to increased shrimp culture in the last few years, the level of salinity has exceeded 960 micromhos/cm and that made large storage of natural surface and groundwater unfit for human consumption (Awal, 2014).

A study conducted in the Satkhira district by (Kabir & Eva, 2014) reveals that due to continuous unplanned shrimp culture, the salinity level of soil and water increased to 1.6 ppt and 13.6 ppt respectively. In addition, the increase of salinity due to direct use of saline water for shrimp culture, seepage of saline water through shallow water aquifer also contaminates the nearby natural freshwater aquifer (Marshall B. & Falconer A., 2000).

1.2 Objective of the study.

A number of studies including (Rahman, 2019) show that Rainwater Harvesting System (RWHS) is becoming a popular alternative potable water supply source over the traditional groundwater-based options, especially in the coastal area of Bangladesh. However, RWHS with its current features is still considered as a "**Seasonal**" solution as due to its limited storage capacity the system can provide water only during rainy season. Even though several studies conducted on the sustainability of the current RWHS provided a common finding that the storage tank is not enough to meet the water demand throughout the year, there has been limited study done to further investigate alternative solutions such as the feasibility of a large-scale underground storage tank. Employing a mixed-method approach consisting of literature review, Simple Random Survey (SRS), Focus Group Discussion (FGD), in-depth interviews, and hypothetical scenario analysis, this research has explicitly investigated the challenges around reliability and the feasibility of using a large-scale underground storage tank following "**Cluster approach tank sharing method**". The following three specific objectives have been derived from the objective of the study:

a) To investigate the current state of reliability of the RWHS in the coastal area of Bangladesh

b) To understand the key issues around the reliability of the RWHS from the end-user, practitioner, and expert perspective

c) To propose a conceptual framework to increase the reliability of the RWHS.

1.3 Significance and contribution of the research

Rainwater has never been considered as a standalone reliable primary water supply option, at least not with its current features. Mainly because it is completely dependents on rainfall. However, given the amount of rainfall Bangladesh receives, rainwater can be a reliable option to supply adequate safe drinking water round the year at the convenient proximity of the households. But in the current RWH system, one of the key design limitations is its storage capacity to be able to collect and store enough water, especially when there is no rain. The findings and recommendations of this study is expected to influence and facilitate a better decision-making process by the community people, governmental and non-government organizations, and other stakeholders who are planning to invest in sustainable water supply system. This study will also encourage policymakers and stakeholders to emphasize on alternative options such as rainwater and thus will ensure improved availability and better access to lifesaving drinking water for the communities in the coastal area of Bangladesh.

1.4 Organization of the Study

Chapter One - Introduction: This chapter provides an overview of the problems around water supply systems including associated hazards and risks as well their impacts. It also discussed existing challenges, coping mechanisms, and potential alternatives to address the problems.

Chapter Two - Literature Review: A brief overview has been provided on relevant literatures and studies around different water supply systems. Then it discussed knowledge gaps on alternative water supply options and associated challenges around the reliability of the RWHS.

Chapter Three - Geographical Context of the Study Area: This chapter provides a general overview of the study area including geographical context, demography, and climatic conditions. This chapter also provides rational for the selection of the study area.

Chapter Four - Research Methodology: Chapter four discusses the research framework and the methodology of the study including research question, tools & techniques, target population and sampling technique used as well as the criteria for selection of participants for interview.

Chapter Five - Findings and Discussions: This chapter focus on presenting key findings and the interpretation of the findings and results.

Chapter Six - Conclusion and Recommendation: Based on the findings, specific recommendations have been made in this chapter. It also briefly discussed and elaborated each of the recommendations to be understood better by the audience.

Chapter Two

Literature Review

2.1 Overview and background information

About 20 million people in the coastal area are at a high risk of drinking water scarcity and the situation is expected to get worsen with the impact of climate change, unplanned urbanization, frequent disasters, and other hydrogeochemical phenomena such as arsenic contamination and salinity intrusion (Islam, et al., 2014). Community people, government, non-government, and private sector actors are constantly investing in potential alternative options for potable water supply such as rainwater harvesting. However, as per (BBS, 2015) only 4.77 percent population in Bangladesh are using alternative options including rainwater harvesting. Several studies conducted across many countries have shown rainwater harvesting as a promising alternative option to address potable water scarcity, especially the countries located in tropical climates. In addition to this, a wide range of studies conducted in different locations, settings, and contexts have presented enough empirical evidence that rainwater harvesting is a sustainable alternative to address increasing climate change risks.

However, most of these studies also presented different limitations of the rainwater harvesting system as well. A significant drawback of the current system is its limited storage capacity thus not being able to meet the water demand for whole year. This drawback of limited storage capacity forces people to collect drinking water from contaminated sources which leads to many public health concerns including water-borne diseases and outbreaks. Health data from 2009-2019 shows water-borne diarrheal diseases remain the 7th top cause of death in Bangladesh (Institute for Health Metrics and Evaluation (IHME), 2021). However, there have not been significant studies done explicitly to explore the possible solution for this challenge around limited storage capacity of the RWHS. Historically rainwater harvesting system has always been an essential part of the coastal survival strategy. However, the current use of rainwater harvesting is limited to the dry season or part of the dry season only. Current RWHS are focused on small-scale above-ground tanks and mainly designed for HH level with a storage capacity ranging from 200L to 5,000L (Karim, 2010) which is not sufficient to meet the drinking water demand for the whole dry season (Islam, 2019); (Naus, et al., 2020).

A few decades ago, in Bangladesh, especially people living in rural areas used to capture rainwater by excavating large-scale ponds (*Dighi*). Most often these excavations were supported by the government and or wealthy people (*Jaminder*). In fact, one of the mandatory responsibilities of the local government was to excavate these *Dighis* to ensure adequate water for the community. These large ponds were the main if not the only source of water including water for drinking. But with the increased economic prosperity gradually social fabric has changed, and the definition of the community started getting smaller and smaller which now has reached to almost "individualistic" level. Together with other socioeconomic factors, it impacted the number and the size of these *Dighis* which became smaller, and instead of community-level (large-scale) *Dighi*, the size became smaller overtime. In late 1971, tube-wells were introduced into the rural areas on a large scale by the government to reduce frequent diarrheal outbreaks. The tube-wells were provided free of cost, through the DPHE. Over time, the acceptance of this technology increased immensely and, in parallel, the capacity of the local market also increased. In 1970s only a nominal number of private tube-wells were installed by individuals. But by now the private individuals have installed about 80 percent of the total tube-wells in the country, majority of which are shallow tube-wells.

Along with the DPHE, NGOs are also providing some tube-wells mainly for the poor communities. By 1990, tube-well became a comfort zone for the water supply system in rural Bangladesh. However, this has led us not to have a serious thought about any other alternative water supply option, up until the discovery of arsenic and salinity. However, by this 30-40 years' time, the rural water supply system became very much dependent on tube-well and a separate narrative as well as public perception has been created. The over-representation of Tube-well as a "**magic solution**" by media embedded so deeply in the people's perception that it was hard to explore anything beyond tube-well. No doubt of the contribution made by the tube-well in the '70s- '90s when survival was the main issue and there was no other suitable alternative but to accept this. But now it is well-known fact that, tube wells come with heavy tolls such as arsenic and groundwater table depletion.

In the broader spectrum of water governance and management system, especially around rainwater harvesting, there is no concrete regulatory framework neither at the central level nor at the local government level. In most of the regulatory framework documents including policy documents, regulations, strategies or guidelines, the word "Rainwater" is almost absent or appeared in a lousy way classified under the category of "Other". Rainwater has been always a low-priority topic in most of the regulatory framework documents. Here are some examples from different key policy/ regulatory documents from the water sector:

Table 1: # of times RWHS is mentioned in Strategic & Policy Document

SL	Name of the document	Reference	# of times the word "rainwater harvesting" appeared	Page #	Phrase(s) in the sentence
1	National Water Management Plan, 2004	(Ministry of Water Resources, GoB, 2004)	1	P # 61	"Currently mandated and to be preserved as core activities: **Rainwater harvesting**"
2	Coastal Development Strategy, 2006	(Ministry of Water Resources, GoB, 2006)	1	P # 14	"An essential prerequisite is …. such as **rainwater harvesting** and …. techniques"
3	Coastal Zone Policy, 2005	(Ministry of Water Resources, GoB, 2005)	1	P # 5	"**Rainwater harvesting** and conservation shall be promoted"
4	Environmental management Framework (EMF) for River Management Improvement Program (RMIP), 2015	(Bangladesh Water Development Board , 2015)	1	P # B-5	"Mitigation measures: Details of **rainwater harvesting** to recharge the ground water"
5	Five Year Strategic Plan of BWDB: Roadmap for realizing Organizational Goals ((2009 – 2014)	(Ministry of Water Resources, GoB, 2009)	0		
6	National Strategy for Water and Sanitation Hard to Reach Areas of Bangladesh 2012	(Ministry of Local Government, Rural Development and Cooperatives, Local Government Division, 2012)	3	P # 10 and 12	A) "Strategies for Coastal Areas: Strategies……. desalination plants and **rainwater harvesting** with underground reservoirs…." B) "Strategies for Char Areas: Strategies …. such development includes individual tube-wells,

SL	Name of the document	Reference	# of times the word "rainwater harvesting" appeared	Page #	Phrase(s) in the sentence
					rainwater harvesting, …." C) "Strategies for Char Areas: Strategies ….Tube-wells with raised platforms, **rainwater harvesting** and storage at ………. subsurface storage of rainwater ….."
7	National Hygiene Promotion Strategy for Water Supply and Sanitation Sector in Bangladesh 2012	(Ministry of Local Government, Rural Development and Cooperatives, GoB, 2012)	3	P # 12	A) "To allow access to safe water round-the year, …….. The probable sources include: **rainwater harvesting** and storage ……" B) "Investigate alternative water supply options like pond sand filter, **rain-water harvesting** system, deep tube well …. technologies" C) "Investigate and make available alternate water sources like **rainwater harvesting** and water reservoirs/ impounding reservoirs."
8	National Plan for Disaster Management (2021-2025)	(Ministry of Disaster Management and Relief, GoB, 2020)	0		

SL	Name of the document	Reference	# of times the word "rainwater harvesting" appeared	Page #	Phrase(s) in the sentence
9	National Water Policy, 1999	(Ministry of Water Resources, GoB, 1999)	1	P # 11	"Facilitate availability of safe ….. various means, including **rainwater harvesting** and conservation."
10	National Strategy for Water Supply and Sanitation 2014	(Ministry of Local Government, Rural Development and Cooperatives, GoB, 2014)	1	P # 15	"Strategy 13: Institutionalize research …. (e.g. arsenic removal technologies,… **rainwater harvesting**, …."
11	Pro-Poor Strategy for Water and Sanitation Sector in Bangladesh	(Ministry of Local Government, Rural Development & Cooperatives, GoB, 2005)	0		
12	Bangladesh Delta Plan 2100: Baseline Studies on Water Resources Management	(Bangladesh Planning Commission, Ministry of Planning, GoB, 2018)	2	P # 101 and 299	A) "Technical Perspectives: The water bodies ….., in addition **rainwater harvesting** needs proper reinforcement…." B) Footnote 23: "**Rainwater (rooftop) harvesting** is tested in the Barind tract, with positive results"
13	Bangladesh Climate Change Strategy and Action Plan (BCCSAP), 2008	(Ministry of Environment and Forests, GoB, 2009)	1	P # 38	"In Bangladesh, the increasing prevalence ….. conservation of water and **rainfall harvesting**, in some regions."

2.2 Current state of potable water in the study area

"**Water, water, everywhere, nor any drop to drink**." (Samuel Taylor Coleridge). No analogy could better express the situation in the coastal of Bangladesh when it comes to water. There is an extreme scarcity of safe water in many parts of Bangladesh, especially in the coastal areas (Khan, et al., 2011). The coastal region of Bangladesh faces different scenarios when it comes to availability of water. It has excess water during the monsoon and is in shortage during the dry period which creates the phenomenon of "**too much or too little**" water during different seasons of the year. Due to excess rains, almost every year the lower parts of Bangladesh especially the southern parts remain underwater for a long period. On the other hand, in the summer or dry season, Bangladesh faces an acute scarcity of drinking water. In recent times, Bangladesh, especially the coastal area has been experiencing more rains than usual in the rainy season whereas it is relatively low in the dry season (Dasgupta, et al., 2015).

Traditionally, rainwater has been always considered as a "**supplementary**" option to the main

Figure 1: SONO Filter

Figure 2: Tube-well with Elevated Platform

water supply system. Given the recent changes such as the impact of climate change and its subsequent phenomena, arsenic contamination, and increased demand for water for food production and industrial as well as household use, it is time to start making a mental shift that rainwater can also be considered as the "**Primary**" source. However, this would take time as most of the institutional arrangements and skill-base have been built considering rainwater as a supplementary option. However, making legislative changes on rainwater may not need to start from sketch and may not necessarily be a separate set of policies and regulations. Rather, there are existing policies, regulations, and guidelines such as Coastal Zone Management Policy, and Climate Change Adaptation Policy others where the use of rainwater can be incorporated easily.

Beside RWHS, people in the coastal areas also started exploring different safe water options such as PSF, MAR, Protected Pond, desalination etc. In figure 1 shows that some families use SONO filter to remove arsenic from contaminated tube-well water. Figure 2 an elevated tube-well platform which some communities adopted to cope with recent tidal surge. But most of these options are partially safe and or not reliable to provide adequate safe drinking water throughout the year. This leads people to use multiple water supply options in the different seasons of the year to cope with the unsafe and unreliable supply.

A study conducted by (Naus, et al., 2020) in Khulna and Sathkhira using the RANAS approach found that RWHS is the top choice in terms of quality and convenience in comparison to TW, PSF, Pond etc. But least choice when it comes to reliability in comparison to the same. This is because of the large seasonal fluctuation in the availability of the required quantity of water. The same study also claims that during the dry season, 17% of the people had to drink pond water as other drinking water options including RWHS, tube-wells and PSF are either dry or contaminated. In this context, the author has recommended investing on large volume of rainwater reservoirs.

As per the Multiple Indicator Cluster Survey (MICS) 2019 report, the percentage of the population using improved sources of drinking water is 98.5% having the lowest coverage (95.5%) in Khulna (Bangladesh Bureau of Statistics (BBS) and UNICEF Bangladesh, 2019). However, down the line, this statistic does not reflect the comprehensive situation. There are five service levels/ladders (with specific quantitative indicators) to measure from any improved source to realize a comprehensive picture of coverage such as availability, access, utilization, adequate coverage, and effective coverage (WHO and Unicef, n.d.). The quantitative indicators of five levels/ladders of water service are:

1. Availability: Capacity of a functional and improved water sources sufficient to supply 20 liters of safe water per person per day to the whole population
2. Accessibility: % of HHs located within 150 m of a functional water source.
3. Utilization: % of HHs using a functional water point located within 150 meters.
4. Adequate coverage: % of households using at least 20 liters/person/day round the year from a functional water point located within 150 meters.
5. Effective coverage: % of households using at least 20 liters/person/day round the year from a water point within 150 m that meets national drinking water standards for arsenic and fecal coliforms.

Using these quantitative indicators mentioned above, the Multiple Indicator Cluster Survey (MICS) 2019 report (Bangladesh Bureau of Statistics (BBS) and UNICEF Bangladesh, 2014) has presented that the average effective coverage of drinking water falls to 13% in comparison to 98.5% total coverage in Khulna. This clearly explains that using 'improved water sources' does not necessarily mean that an adequate quantity of safe drinking water is available all year-round at convenient proximity for all the target population (Staddon, et al., 2018). MICS 2019 report (Bangladesh Bureau of Statistics (BBS) and UNICEF Bangladesh, 2019) states that 88.4% population of the Khulna district use tube-well as the highest using drinking water source followed by 2.5% for rainwater harvesting.

However, the same report also shows that 4.4% population use surface water which is classified as an unimproved source. As it is presented in a number of studies including (Ministry of Local Government, Rural Development and Cooperatives, GoB, 2011) that the tube-well alone cannot provide adequate quantity of water all the year round and to some extent rainwater is filling the gap. However, as the rainwater is solely dependent on rainfall, it has not been ever considered as a "**reliable**" source at least not with its current features. But, with a few technical modifications, the rainwater system has full potential to be able to supply adequate quantity of safe water round the year at the convenient proximity. The percentage of the population using rainwater (as an improved source) and the percentage of the population using surface water (as an unimproved source), both are high in the Khulna district. Only 2.9% of the population in Khulna has access to piped water supply including 0.8% using public tap. This provides an overall scenario of the level of water vulnerability in the coastal districts of Bangladesh.

A study conducted by (Islam, et al., 2013) explored possible alternative water supply options in Mongla and Dacope Upazilas found that people living in the water-stressed coastal area choose their potable water source depending on the season. Most people choose RWH during the rainy season which lasts for 4-5 months (Jun–Sep). However, during the dry season (Oct-May) they have no choice but to use inferior sources such as a pond, river, rainfed pond, and sometimes PSF. Though the amount of rainfall during monsoon should have been enough to meet their annual demand, due to lack of storage facility, the demand meets for 4-5 months only. A number of studies including (Betasolo & Smith, 2020), (Islam, et al., 2020), (Kabir, et al., 2017), (Khan, et al., 2017), (Biswas & Mandal, 2014) have shown that the storage counts 60-70% of the total cost of any RWHS. Another set of studies by (Islam, 2019) and (Rahman & Moniruzzaman, 2020) concluded that PSF is the 2nd best choice for alternative potable drinking water source. However, a necessary component of the PSF is a protected freshwater pond which is not that much available in the coastal area as most of the water bodies are being used for shrimp cultivation that uses saltwater. That's why the feasibility of PSF is limited.

Given the tropical climate, average annual rainfall, and rainfall pattern Bangladesh has a great potential for successful rainwater harvesting. (Shahid, 2010); (Ministry of Foreign Affairs of the Netherlands, 2018); (Noorunnahar & Hossain, 2019) shows that the average annual rainfall in Bangladesh is 2,200 mm distributed between 60-100 rain-day which makes a perfect case for successful rainwater harvesting. With this annual rainfall, the country can **capture 200-250 billion m^3** of water each year, which is much higher than the basic requirement of **160 billion m^3 per year** (Amin, 2019). In addition, the type and average size of the roofs make this case even stronger.
With the gradual increase in disposable personal income (FX Empire, n.d.), in recent years, the use of CGI sheets as roofing materials has grown at least two folds (UNDP, Bangladesh, 2014); (Gutiérrez, et al., 2018). However, the actual quantity of rainwater captured is far below the potential water. This is mainly because of the limited storage capacity of the current rainwater tanks. During the heavy rainfall, most of the time the small tanks get filled up quickly which leads to a vast quantity of water going back to the soil and other water bodies. This phenomenon can be expressed as "**Too much or too little water**".

2.3 Water scarcity and impact on public health

Lack of adequate safe drinking water throughout the year can cause a serious negative impact on public health and thus increase the diseases burden, especially diseases like diarrhoea and malnutrition. The global share of preventable water-borne and water-related diseases is very high. Each year a huge number of people, especially children >5 die because of these diseases. In Bangladesh, child mortality due to preventable water-borne and water-related diseases is truly remarkable. Like many other countries in the world, Bangladesh also suffers from such diseases and in the coastal areas, this issue is clearly visible. Thus, how well this public health issue is managed significantly depends on how well the drinking water issues are addressed. Diarrhoea, cholera, malnutrition, and other water-borne diseases can be incurred because of inadequate as well as poor quality drinking water (Khan, et al., 2011).

In addition to health issues, consumption of inadequate as well as poor quality water can cause additional financial burden and loss of productivity which mainly affects people in the low-income segment. However, traditional groundwater-based water supply and management systems have already been proven not very effective to cope with this situation and solve the public health problem. This leads to exploring alternative options including investing on rainwater harvesting systems at scale. Another problem in the tube-well water is presence of excessive arsenic. It is proven that severe health problems can be created from heightened exposure to high arsenic concentrations. There are many tube wells in Bangladesh which are not tested properly and maybe mixed with arsenic poison (Kabir & Eva, 2014). In this context, rainwater can be used to solve this issue as rainwater is free from arsenic.

A number of studies including (Khan, et al., 2011), (Islam, et al., 2013), (Abedin, et al., 2014), (Abedin, et al., 2018), (Nahian, et al., 2018), (Shammi, et al., 2019) and (Naus, et al., 2020) conducted in the coastal area of Bangladesh shows severe public health issues due to access to inadequate safe drinking water as well as consumption of water with high quantity of sodium. (World Bank, 2020) reported that 53% of the coastal area has high salinity in soil and groundwater. This leads to three main challenges: a significant decrease in agricultural yield, entering sodium into the food chain, an increase in per-unit agricultural production cost.

Another study conducted in Dacope Upazila by (Shammi, et al., 2019) shows that high consumption of salt has a serious negative consequence on public health, especially on pregnant mothers. The study found that the women who consumed saline water have high urine sodium concentrations which indicate that they are more susceptible to diseases like hypertension, high blood pressure, and pregnancy complications including (pre)eclampsia as well as high infant mortality in comparison to those consumed rainwater.

The study has recommended that the installation and consumption of rainwater can significantly reduce the risk of salinity exposure and lower sodium intake. (Dasgupta, et al., 2015) conducted a study specifically focused on the relationship between consumption of high sodium (through drinking water) during pregnancy and child mortality established a strong correlation between consumption of high salinity drinking water and hypertension, preeclampsia and post-partum morbidity and mortality (Nahian, et al., 2018). The study claims that the pregnant women who drank tube-well water during the dry season had significantly higher urinary sodium than women from the sample group who drank rainwater during that period. The study also revealed that the salinity of tube-well water in the study area was far higher during the dry season compared to the rainy season. These findings urge exploring an alternative option for drinking water sources that can guarantee adequate supply throughout the year. From the study, it is very clear that Tube-wells with high sodium do not fit as suitable option for the coastal areas.

2.4 Water scarcity and impact on Food Security

Freshwater demand in Bangladesh is still dominated by agriculture, especially irrigation which takes 80% of the total demand. However, this pattern is changing gradually as the country's service and industrial sector is growing rapidly. Currently, the industrial and service sector uses only 2% of the demand which is expected to rise to 440% by 2050. On the other hand, the current household water demand is about 10% of the total freshwater demand. However, given the rapid urbanization and population growth, a sharp increase of 200% is expected by 2050. These increased demands will lead to some major strategic changes including a focus on more localized and context-specific water resource management and infrastructure planning (World Bank, 2020). Most of this water is extracted from groundwater in various forms, mainly tube-well.

However, this overdependency on groundwater is unsustainable and exposes the sector to a high degree of vulnerability toward extreme water stress situations. One of the key elements of food security is the availability of required food in the market. Other elements of food security such as access and utilization cannot come into play without the availability of adequate food in the market. Availability is very much dependent on food production which is a water-intensive process. Without having the required amount of water on time, food production will fail hence food insecurity will increase. Globally agriculture sector uses on average 70% of the total groundwater withdrawn annually (The World Bank Group, 2020). Due to population growth which leads to more demand for food production, the demand for water for the agriculture sector will increase multi-folds in coming years. Since the groundwater table is shrinking constantly, the cost of withdrawing water also increases proportionately and thus the cost of food. Increasing the use of alternative water sources such as rainwater for non-agriculture use including drinking will reduce the pressure on groundwater.

2.5 Water scarcity and Migration

Migration and internal displacement are not new phenomena. But the global trend of migration and displacement has dramatically increased since 1990 (Nagabhatla, et al., 2020). By 2050, worldwide up to 200 million people may be migrated due to climate change drivers (Mcdonnell, 2019). Only in the year 2016 around 23.5 million people were displaced (temporarily and permanently) mainly because of extreme weather-related events. This does not include slow-onset environmental events and forceful displacement due to conflict. The water crisis is clearly one of the key drives of migration and internal displacement. Life without the provision of water is not possible. Looking at the ancient civilization, it is very evident that all major cities were grown around the water bodies. Water (both drinking and agricultural use) has been the key determining factor that influences people to decide on migration and internal displacement. The explicit drivers that contribute to climate migration can be broadly categorized into water quality, quantity, and water-related hazards. Often a combination of multiple categories coupled with other drivers such as unplanned urbanization, complex socioeconomic and sociopolitical factors accelerate the climate migration process.

A report published by United Nations University Institute for Water, Environment and Health (Nagabhatla, et al., 2020) provided a clear three-dimensional framework showing the interconnectivity of these factors. According to EJF, by 2050 one in seven people in Bangladesh will be a climate-displaced statistic within a few years' time. In addition, another 18 million people may be displaced due to sea-level rise alone among which coastal populations are the most vulnerable because of their exposure to multi-hazard climate change phenomena including salinity, riverbank erosion, frequent and intense cyclones, and flood. Among others, the crisis of drinking water, as well as the water for agriculture is the major driver of this kind of displacement (Environmental Justice Foundation (EJF), n.d.). Women and children are particularly vulnerable to this climate displacement including an increased risk of trafficking and child labor. In Bangladesh, almost every day around one to two thousand people migrate to different cities, but mainly in Dhaka as a self-discovered "Adaptation Strategy". However, due to poor economic conditions and lack of marketable skills, most of the people who migrated to Dhaka and other major cities end up living in slum-like vulnerable locations which are susceptible to floods and other hazards.

2.6 Rainwater as a promising alternative option

"Rainwater Harvesting" is a widely used term to refer to a process that systematically collects and stores rainwater for current and or future use. In the early 80s, Makoto Murase, one of the pioneers in the modern rainwater harvesting system designed a RWHS including a collection, filtration, and large-scale underground storage tank (Espíndola & Sánchez, 2020). There have been many types of systems built afterward using this process for a variety of purposes including domestic use, agricultural use, flood control among others. Domestic use can further be classified into two categories: potable (mainly for drinking) and non-potable (cooking, washing, bathing, toilet flushing, etc) use. Rooftop rainwater harvesting however refers to a specific system built using the existing roof as a catchment area where the run-off water gets collected in a storage tank (either above or underground). The intended use of the water can be for potable and non-potable purposes. Given the scope of the study, the term "rainwater harvesting" system only refer to the rooftop system mainly intended for potable use.

People living in the coastal area of Bangladesh are familiar with the RWHS in general. A competitive advantage of the RWHS over other options is that most of the components needed for constructing a RWHS are already there and being used for something else as their primary function. For example, the primary function of the roof is to protect dwellers from adverse weather conditions and provide privacy. In terms of adaptation to climate change-related issues such as drought, the traditional rainwater system can be modified and adapted to store enough water for the known drought period and thus ensure water security, at least for drinking.

Though in many countries there is enough rainfall to meet a significant portion of the water demand, only 1.3% of the global population uses rainwater as the main source at the household level. However, in developing counties this is a bit higher up to 2.4%, mainly in the rural settings (Espíndola & Sánchez, 2020). There have been studies that show if well managed, rainwater can adequately meet drinking water demand for 6-8% of the global population (Heijnen, 2020). However, even though rainwater harvesting has immense potential, it also comes with certain limitations, and storage reservoir is one of them. The main challenge with the storage reservoir is its limited capacity which could only satisfy seasonal demand, mainly during the rainy season. A tropical climate with 1-4 months of the dry period and with multiple short but high-intensity rain segments is the most suitable climatic condition for rainwater harvesting (Betasolo & Smith, 2020).

In the coastal Bangladesh where people have limited earnings, often cannot afford the size of the tank required to meet the water demand to cover the whole dry spell. In this situation, some experts suggest using an "adaptive demand strategy" which means to reduce demand based on the availability of water (Thomas & Martinson, 2007). This raises a critical question around undermining basic human rights to access to adequate water. Water as a basic human right has been mentioned in many globally recognized binding and non-binding laws, conventions, declarations, and covenants such as the UN Charter (Art. 55), Universal Declaration of Human Rights, Geneva Convention and Protocols and the 1966 Covenant among others (John, et al., 2004); (United Nations, 2019). Instead of "adaptive demand strategy", a situation like this requires out of the box thinking such as the concept of "cost-sharing" which provides the full benefit of the intended system within the affordability limit. to a group. The Cluster approach tank sharing model developed based on "cost-sharing" concept presented in this study has a significant potential in this case. When it comes to "cost-sharing", one aspect needs to keep in mind that, though in the last few years with the consistent increase in personal income, the average disposable personal income in Bangladesh has reached to BDT 65.34K ($ 770) in 2019 (FX Empire, n.d.), still, 20.5% of people are living below the national poverty line (ADB, n.d.).

Most of the studies around RWHS have been done in the recent past year (mainly 2011 and

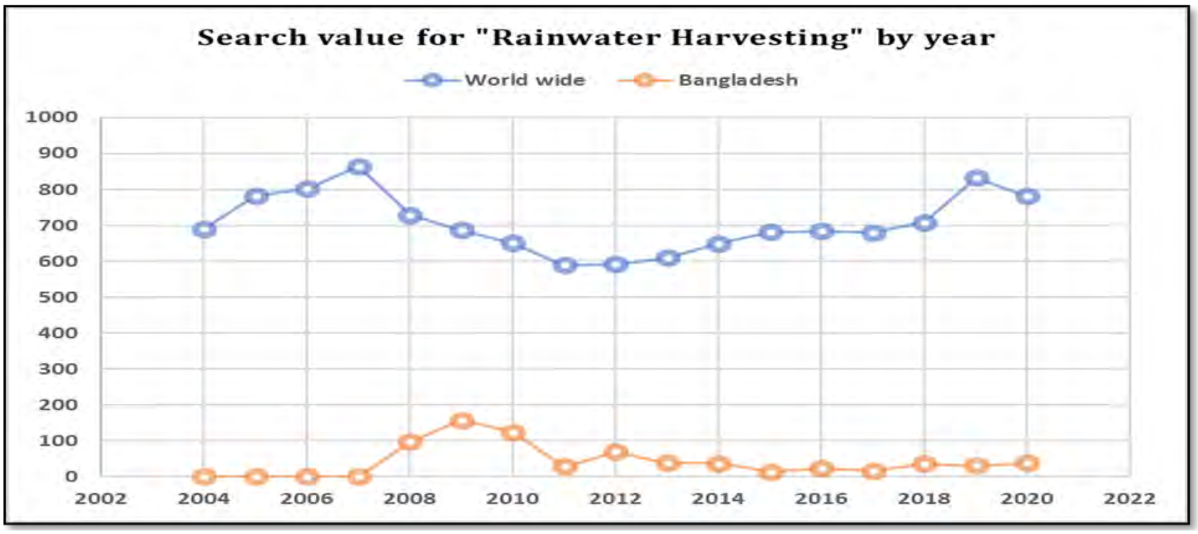


Figure 3: Search value for the work "Rainwater Harvesting"

onwards). One of the reasons is that the issue of climate change, global warming, the adverse impact of climate change, and potential mitigation and adaptation measures came into the limelight very recently. That could influence the public interest as well as the academic interest which subsequently leads to increased interest in this field of research. With the advancement of modern technology, nowadays it is relatively easy to find out what is the trend of people's interest and their thinking on a particular topic or issue by using "Google Trend".

A search on Google can be made for a specific topic or issue at a global scale down to a local scale such as a country or even a specific area of a country or territory. This helps to fathom a broader understanding of different schools of thought as well as public interest and perception on a particular topic or issue. This is a free tool that is available in the public domain managed by the tech company Google. The search result can be further filtered down to the sub-topics, interest over time, or a specific timeframe, specific query just to mention a few. Options are also available to compare search results between two different topics and or two different geographical locations over a particular period of time. In addition, all the search variables can be customized according to the use needs. The search result is presented in graphical forms and can be downloaded in different formats including CVS and JPG/PNG. When a search was made (access: 14 May 2021) by "Rainwater harvesting" in Google trend, it turns out that over the past 5 years, people's interest in this topic is steady i.e., 38-100 times (average 60 times) per week globally between 2016 to 2020, though the specific search for Bangladesh did not show any uprise trend in the last 5 years. But given the average annual 2200 mm rainfall, rainwater harvesting could be a significant, yet untapped source of water for Bangladesh.

A study conducted by (Abedin, et al., 2014) in 4 Upazilas in Khulna and Sathkhira found that RWHS was a popular adaptation method/ coping practice at individual, community, and institutional level. A 45% of responder at induvial level followed by 28% community level and 35% institutional level responded that they have adopted RWHS in response to water scarcity. (Department of Public Health and Engineering (DPHE), n.d.) has developed and piloted a Community Based Rainwater Harvesting System to serve 3 to 5 households (approx. 25 to 30 people) to meet their drinking and cooking water demand for 7 months. They used a 2,500-liter water storage tank to store water for the dry season. The total cost of this system was BDT 11,000 where the targeted households contributed 20% of the total cost. The system was closely monitored for 7 months (the dry period) and found promising results including meeting water demand for the dry season where there was little rain. The success of this pilot project can be replicated in different geographical settings at a larger scale. However, as per DPHE, option wise RWHS accounts only for 0.75% (Department of Public Health Engineering (DPHE), 2019) which indicates that RWHS is still very much considered a low priority option.

Annual rainfall in Bangladesh provides 200-250 billion m^3 of water each year where the basic requirement for consumption is 160 billion m^3 per year. Meaning that rainwater alone can meet this basic requirement and, also can provide some surplus as well (Amin, 2019). A well-managed rainwater harvesting system fulfills SDG 6.1 criteria and qualifies as an "improved water supply option" almost in all indicators. It provides in the premise quality water supply. However, what it does not full fill are adequate quantity and availability for any time (all year-round). Both of these challenges are very much liked to the current limited storage capacity of the rainwater system. Solving this storage capacity would make the rainwater a reliable eco-friendly water source as well as fully qualified as an "Improved option."

However, most of the RWHS currently used in the coastal area cannot meet the water demand due to its limited storage capacity. That's why RWHSs are being used only as rainwater collector, not as collector and storage. The system can only function if there is adequate rain throughout the year. But that's not the reality. Using a small storage tank (usually from 500L-5,000L) can improve this situation to a certain limit but cannot eliminate it. That is the reason a number of studies including (Ahsan, et al., 2015), (Rahman, et al., 2019), (Rahman & Moniruzzaman, 2020), (Biswas & Mandal, 2014), (Dakua, et al., 2013), (Islam, 2019) found that a RWHS user always uses other water sources as a backup source. These studies also revealed that people are reluctant to invest in the RWH as the system only meets seasonal water demand. However, adopting a "Cluster-based Approach" where a large-scale underground water reservoir can eliminate this problem and can make RWHS a reliable option. This will gradually influence people's behavior toward making more investments in RWHS as its reliability increases.

2.7 RWHS "Right" Tank Size Dilemma

Rainwater Harvesting System (RWHS) is a relatively simple technology and can be customized to the user's capacity, preference, needs as well as to the local environment and socioeconomic context. However, the functionality of the RWHS is fully dependable on rainfall. During the rainy season, often the quantity of rainwater supply is way beyond the demand and that is why a large portion of the rainwater goes back to nature unused. In contrast, during the dry season, the supply is inadequate, though in general, the demand remains the same throughout both seasons. This creates a phenomenon of "**too much or too little water**" illustrated in figure 2. Therefore, the question of adequate storage comes in which will allow the users to meet their demand during rainy season as well as to capture and store the required quantity of water to be used during the dry season. But, by far the storage facility is the most expensive part (approx. 30%) of the RWH system and often people with low income cannot afford to construct a large enough storage facility. This leads them to accept a low-reliability water supply system that can meet only partial demand.

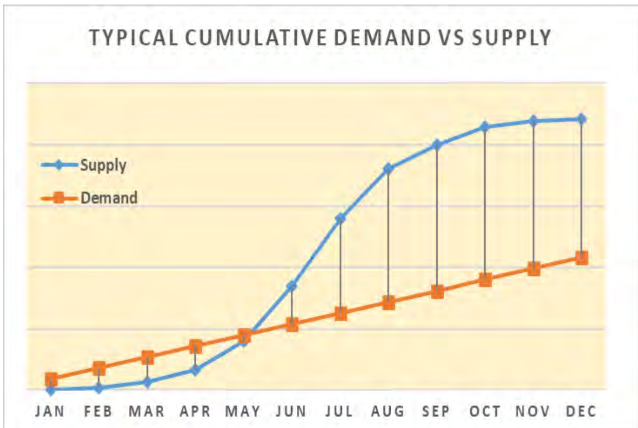


Figure 4: Typical cumulative demand vs supply

The reliability of a RWHS is a favourable combination of three factors: quantity of rainfall, water demand, and storage capacity. In most real-world cases, rainfall data and the water demand are not alterable where storage capacity can be adjusted based on the actual situation. This leads to a basic design problem on how to design a tank that can store adequate rainwater to meet the year-round demand, yet reasonability affordable, especially for the low-income population. Designing a rainwater tank is often limited to a certain capacity because of the economic feasibility reason. Hypothetically, beyond a certain capacity, the tank became economically impractical. However, the actual demand for water, especially during the dry season is often becoming a must-have survival need that goes beyond the usual economic feasibility framework. Yet, sizing for cost optimization has been found the most frequently used outcome indicator even though the system often failed to meet the primary objective which is supplying adequate water throughout the year (Semaan, et al., 2020).

Most of the studies conducted around the optimum volume of the RW tank have been used "dry period demand method" to calculate water demand and subsequently proposed the optimum size of the tank. However, the dry period method works when rainwater is used only as "supplementary" to the existing water supply system such as tube-well and PSF, not as a stand-alone system. But the harsh reality in the coastal area is that often rainwater is the only water source during the dry season. Other sources such as PSF, tube-well, and ponds either dry up (mainly because of water table depletion) or get heavily contaminated. Given this, using the "dry period" method may not be appropriate to calculate the optimum tank size which can meet the water demand throughout the year. In conventional RWHS, only a part of the roof (usually one or two sides of the roof) is used as a catchment area as the use of the gutter system is limited. This is because use of gutter system is considered as an additional cost to the system. Also, from a system optimization perspective, in most cases there is no need to use the whole roof as the reservoir tanks are usually smaller in size and cannot store water from the whole roof.

Use of a large volume rainwater reservoir is not a new discovery. People living in arid and semiarid regions have been using this option for ages mainly for agricultural purposes (Betasolo & Smith, 2020). However, the feasibility and the potential of the large-scale rainwater reservoir tank for drinking water have not been explored significantly. In Tokyo's Sumo Stadium a rainwater harvesting system with a large-scale underground reservoir became so successful that the city eventually built underground rainwater tanks for all new buildings (Espíndola & Sánchez, 2020). In 2016, under a pilot project titled "Rainwater4sale" Uganda Rainwater Association (URWA) constructed a 50 m^3 ferro cement tank to meet the water demand for agricultural production as well as for domestic use. This was done following the social enterprise business model through a microfinance grant. The users have paid back the loan in multiple installments. The RAiN forum has provided the capital investment as well as technical support including training for Operation & Maintenance (O&M) (Birungi, 2020).

In Bangladesh, Sky Water Harvesting Ltd (ISWH), a commercial rainwater business company in Bangladesh has come up with a solution where the main idea is to connect several small water tanks *(motka)* using "plug-in" method to satisfy the user needs. This provides users flexibility to choose the required volume based on their need. The company made a sale of 3600 such *motkas* at a rate of BDT 3,000 each (Murase, 2020). In 2013, Skywater Bangladesh Ltd (SBL), a sister concern of the ISWH produced and installed a 3 X 50 tons capacity underground concrete hollow block rainwater tank in Morrelganji Health Complex, Bagerhat. This was done in cooperation with JICA as an initiative to ensure adequate water supply in the health complex. As part of an emergency preparedness project, the company also installed a 50-ton capacity underground concrete hollow block tank in seven cyclone shelters in Chittagong City (Murase, 2020). Given the large dry spell in Bangladesh which is between 45-120 days (annual average), a number of studies including (Dakua, et al., 2013), (Islam, et al., 2013), (Islam, 2018), (Juliana, et al., 2016), (Khan, et al., 2017) have recommended for the large storage tank to be built. However, there has been very limited research done on the conceptualization and feasibility of adopting the large storage tank for RWHS.

Determining the "right" size of the tank required is not always as straightforward as it may look. In fact, there is no "right" size that fits everyone, because the "right" size depends on several factors including local climate, available roofing type & size, number of users, the intended use of water, and economic condition of the household among others (Thomas & Martinson, 2007). Also, in terms of industrially manufactured tanks, it is not possible to produce every size, every household needs for practical reasons. So, only a few standard sizes are available in the market. To some extent, any household that purchases such a tank from the market ends up buying either a smaller or bigger tank, not exactly what they need. The choice of tank always comes with a trade-off among multiple factors, especially the economic ability of the household and the compromised quantity of water use.

In addition to the other climatic factors, seasonality plays a critical role in the size of the tank needed. For example, when it comes to storing rainwater, during the rainy season a smaller tank is often enough to meet the water demand, whereas the same tank cannot store enough water needed for the dry season. This dilemma often leads to choosing an unsuitable tank size and thus leads to a number of negative coping strategies (which also comes with additional cost burden) such as using multiple sources, using contaminated sources, and or consuming not enough water.

Worldwide overwhelming pieces of literatures have been produced by Academia, Engineers, Practitioners, Architects, Scientists, Experts resulting in a variety of mathematical equations, models, methods, and theories around the right size of the rainwater storage tank. Most of these models, methods, and theories ended up proposing diverse sizes based on different success parameters. Identifying the right size, often characterized by reliability, performance, sustainability, the efficiency of the rainwater tank also has been a popular subject for hundreds, if not thousands of academic research such as (Khastagir & Jayasuriya, 2011); (Gurung, et al., 2012); (Karim, et al., 2013); (Hajani & Rahman, 2014); (Campisano & Modica, 2014); (Hanson & Vogel, 2014); (Vuong, et al., 2016); (Juliana, et al., 2016); (Khan, et al., 2017); (Imteaz, et al., 2017); (Islam, et al., 2020), just to mention a few. Nowadays even a whole online market of computerized calculators and apps (both free and paid form) are out there to solve this mysterious tank size problem, for example (Tank Depot, 2021); (Prestacrea, n.d.); (The Tank Factory, 2021); (Innovative Water Solutions LLC, 2021); and (Rainforum, 2010).

2.8 Sustainability of RWHS

There is no universally agreed definition of sustainability. However, according to the Brundtland Report, the definition of sustainability is “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (United Nations , 1987). Fundamental basis of the Sustainable Development Goals (SDG) is grounded on 5Ps which are People, Planet, Prosperity, Peace, and Partnership. The 17 Sustainable Development Goals (SDG) goals and its 169 unique indicators are primarily based on these five key thematic ideas (United Nations: Department of Economic and Social Affairs, 2015) and (United Nations System Staff College, n.d.).

(Karim, 2010) investigated 1,000 Rainwater Harvesting System (RWHS) located in Southwest coastal and arsenic affected 7 districts focused on assessing the different practices (type, coverage, financed by among others) around RWHS. This study found several interesting findings including the following:

- Of the 1,000 RWHS, 85.2% were household-based followed by 14.8% community-based.
- A total of 58.4% RWHS was financed by NGOs followed by 35.9% by the Government (DPHE 28.5% and LGED 7.4%) and 5.7% by individual initiatives.
- Most of the RWHS (93.6%) was constructed between 2000 and 2004 which shows the development of RWHS is still in the early stage.
- Only 19.8% of RWHS was capable of meeting water demand throughout the year and most of those are community-based systems having large storage tanks.

The performance of the RWHS is mainly described in terms of reliability. Reliability provides assurance that a given size of the tank can store and supply the required quantity of water to a specific number of people for a certain period. In 2020 Kareem Galal conducted a study (Galal, 2020) in the Lebanese Coastal Zone found that RWHS is effective for the given study area.

However, the demand for water can only be met for 5-7 months (during the rainy season). The author recommended a large-scale storage facility to make the system effective and efficient throughout the year. But given the socioeconomic condition of the community at large, having a large-scale tank itself is not easy and sometimes even not economically feasible and that is where the knowledge gap is. Hypothetically the ideal solution should be something that can make a good balance between the need and the feasibility.

(Staddon, et al., 2018) conducted a study in Uganda focusing on why some of the families do not practice RWS and found that adopting RWHS has a strong correlation not only with the financial affordability of a family but also other socioeconomic capabilities including level of awareness, age of the head of household (decision maker), level of education and Land tenure. An article published in 2018 by (Lani, et al., 2018) studied the prospects and challenges of RWHS for potable as well as non-potable water in Malaysia found that RWHS is highly feasible and can provide several benefits including long-term high ROI as to conventional centralized water supply system. However, the study also mentioned some challenges such as lack of public knowledge on the benefit of RWHS, needs for high capital investment, additional need for treatment facility (in case of potable use), and lack of effective policy.

Given the similar rainfall characteristics in Bangladesh as Malaysia, it can be safely assumed that the RWHS will be feasible for Bangladesh as well as sorting out the challenges mentioned above. A study conducted by (Hoque & Hope, 2019) in Dumuria and Batiaghata Upazilas found a 96% increase in the number of deep tube wells in a decade time. Of which 73% was directly financed by the Government with a small contribution (usually 5-7%) from the user community. The study also found a 94% increase in the number of privately funded shallow-tube wells which are mainly used for non-drinking purposes.

However, the study clearly articulated significant empirical evidence to support that the scope and extent of “affordability” go beyond the traditional definition of financial means to be able to pay for something. This was also resonated in a report by (Rogers, et al., 1998) where the authors illustrated that the economic value of water varies throughout a long spectrum of spatiality, quality, and reliability of services and intended use of water among others, and thus vary the definition of affordability.

Achieving SDG 6.1 certainly demands not only technological innovation but also new financial models and approaches that better fit the user’s needs and the context they are in. The same recommendation has been iterated in a recent technical paper by UNICEF where the affordability framework has been broken down into a number of workable components (Klawitter, 2019). The coping cost for water is often found higher for non-piped households living in relatively poor rural and peri-urban informal and slum settlements. (Amit & Sasidharan, 2019) found that coping costs can vary from 1-15% of the household income. A similar finding was also found by (Cook, et al., 2016) in a study conducted among 387 households in Kenya.

However, the coping cost in (Amit & Sasidharan, 2019) has not been examined throughout diffident seasons to find if there is any significant seasonal variation. Though the study revealed that the coping cost is higher for low-income households compared to high-income households. But (Cook, et al., 2016) made a different conclusion that the coping cost is high among larger and wealthier families. The finding in (Amit & Sasidharan, 2019) is not a surprise as many studies and reports conducted in different countries and contexts including (Meehan, et al., 2020); (UNESCO, 2019); (Mitlin, et al., 2019); (Andres, et al., 2019) and (Ruiz-Grossman, 2016) confirms the same that low-income segment of people pays more (and often for inferior quality water) for water than the high-income population.

This disparity forces people to come up with different negative coping strategies often self-financed, based on their situation and ability. Using the “water diary” methodology, (Hoque & Hope, 2019) contested the traditional belief that rural households do not pay for water by presenting concrete evidence of direct and indirect costs, trades-off costs, seasonality costs, and costs for the desired quality of water. The recent dramatic increase of the “water filter” market is another hard evidence of increased coping cost where between 2014-2019 the compound annual growth rate (CAGR) of the water filter industry increased 15% (Business Wire, Inc., 2020); (Market Data Forecast, 2019).

This leads to further exploration of a number of valid questions including investigation on how much actually is being paid for water and how affordable is this for the particular segment of the population, should the definition of affordability be a blanket threshold or be customized depending on the type of population and their trades-off costs as suggested by (Amit & Sasidharan, 2019). Answer to these questions may provide a clear, perhaps a new roadmap to avoid “one size fits all” approach rather than accept a more suitable customized subsidy approach that fits the context to be able to achieve the ambitious SGD Goal 6.1 “Universal and equitable access to safe and affordable drinking water for all by 2030" (United Nations Water, n.d.). However, when it comes to providing subsidies to cope with, often it comes in a blanket package which makes subsidies less effective than intended. Often this top-down subsidy approach insists people forcefully fit into the criteria set by the agencies to be eligible for subsidy where ideally it should be the other way around. A recent publication by Sanitation and Water for All (SWA) has provided a comprehensive framework for diffident successful financing models and subsidy approaches from different countries including Cambodia, Kiribati, the Philippines, Kenya, and Bangladesh (Fonseca, et al., 2020). It is very evident from this report that “one size does not fit all” is just not a coreless statement but has a very deep practical implication in terms of achieving SGD 6.1 by 2030.

2.9 Definitions and Concepts

(Laurence & Margolis, 1999) rightly said, “Concepts are the most fundamental constructs in theories of the mind”. The word concept generally refers to an idea or a notion, could be abstract or concrete. Some scholars argue that a concept can be an abstract mental representation (Carey, 2000), other scholars refer to it as an output of systematic and intended cognitive exercise (Wolff, 1939). (Wikipedia, n.d.) defines the concept as a product or output of a cognitive process and the fundamental building blocks of thoughts and beliefs. Despite differences in conceptualization, scholars in all disciplines use concepts as a linguistic expression of their ideas. Often, concepts developed in one discipline are used to explain problems and or phenomena in another disciple. It is common to see that the same concept and or theory has been used across many disciplines and domains of study. As many scholars argue that there should not be any problem with using the concept in multiple disciplines as long as the domain of application is clearly articulated, and people can differentiate them easily.

2.9.1 Rainwater Harvesting System (RWHS)

At fundamental level, a Rainwater Harvesting System (RWH) can be defined as a decentralized and independent process of directly capturing, collecting, storing, and using rainwater from a human-made catchment area such as roof and other forms of natural catchment surface area like rock surface. The system can be built at a small scale (household level) as well as a large scale (institution and or industry level). Though the primary purpose of the RWHS is to meet the domestic water needs, there is evidence of using RWHS for agricultural production as well as industrial use. RWHS come in different shapes and sizes, are made of a variety of materials, and of course have different capacities, especially the storage capacity. In this current study, the phrase “Rainwater Harvesting System (RWHS)” generally refers to the RWHS at the household level, predominantly used for potable water and where the existing roof is being used as a catchment area. RWHS refers to other types such as institutional level and or industrially used for all other purposes, but potable use has been mentioned explicitly.

2.9.2 Reliability and its Measures

The concept of reliability is based on the philosophy of "consistency of outcome" irrespective of frequency, number, location, etc. if the same test protocol and framework are used. In other words, reliability quantifies the degree of consistency (Analytics Simplified Pty Ltd, 2021). That means certain reliability of a system provides a certain level of confidence to its user. In the applied science fields such as Statistics and Engineering, the fundamental notion of reliability is the measurement of a gradual or sudden loss of "ability" of a system to operate (Encyclopedia of Mathematics, n.d.) and is expressed by various forms of mathematical models depending on the intended use and outcome (Singh & Ram, 2018).

In the case of determining the reliability of the RWHS, the reliability as to be broadly classified into two categories such as volumetric reliability and time-based reliability (Semaan, et al., 2020) where volumetric reliability is expressed in terms of the total supply (rainwater) divided by total demand (for water). On the other hand, time-based reliability is expressed as a fraction of time (day, month) when the user demand is adequately met. It turns out that most of the RWHS reliability studies are heavily focused on the optimization of system reliability in terms of tank size optimization (which is volumetric reliability). It may be because approx. 20-30% of the total cost of a RWHS is the tank, which means optimization of the tank would significantly reduce the overall cost.

However, in doing so, most of the proposed systems are found with increased volumetric reliability but completely ignored the time-based reliability aspect. As a result, the proposed systems may be "economic" but often not able to meet the demand, especially during the dry season when the need for water is paramount. But at the same time, a lot of rainwater is lost during the rainy season. The reliability determined based on volumetric calculation can only achieve a certain level, 11-16% (for HH level) and 3-17% (for community-scale) of reliability within the given economically feasible scale as stated by (Islam, et al., 2015). In other words, the reliability measured by volumetric reliability should be termed as "**seasonal reliability**". In addition, the optimum tank size proposed by the volumetric reliability is local in nature which may not work in other locations but in that particular study area and the settings. This is because the variables (rainfall data, catchment area, water use, seasonality) used in the process as these can vary largely from location to location.

Using the "Cluster Approach Tank Sharing Model" however, hypothetically it is possible to achieve both time-based reliabilities as well the maximum affordability as in this approach both the catchment area and the tank size have been optimized following the cost-sharing/ tank sharing approach. (Seo, et al., 2015) has provided strong evidence that tank-sharing can reduce the volume of the tank up to 61%, thus reducing the cost, but in contrast, it is also possible to construct a larger tank (using the savings from cost reduction) which increases time-based reliability. Using a similar approach (redistribution of surplus water within a cluster of buildings) (Nnaji, et al., 2017) reported increased reliability between 64% to 87% for basic water demand, though the author did not use the tank-sharing method directly. In this study, reliability mainly referred to the time-based reliability unless explicitly mentioned otherwise, the volumetric reliability is also part of this study.

2.9.3 Cluster Approach Tank Sharing Model

The core idea of the cluster approach tank sharing model is very similar to the popular contemporary "Sharing Economy" theory described in (Wikipedia, 2021), (Investopedia, 2020) where an individual person does not own a facility but, still gets the full benefit of the same facility build collectively with other users based on "resource-sharing" principle. Following the "Resource Sharing" model, a cluster of households having different roofing sizes and water demands but living in the same vicinity get together and construct a "common" large-scale underground RWH tank somewhere in their courtyard. A manual hand pump is then installed on the top slab of the underground tank to extract water. The idea of tank sharing is based on a very simple hypothesis which is to collect the rainwater from multiple household's roof and store that in a collectively built large tank that can provide adequate water for drinking throughout the year. This way, an individual household does not need to construct a large tank on their own, rather would join other nearby households and contribute to construct a large-scale tank to cover the water demand for the whole year. The bottom line is to collect the surplus water (during the rainy season) in a common storage tank built by sharing cost with others to be able to get enough water during off season.

There are only a handful of in-depth studies done to conceptualize the feasibility around using Cluster Scale Rainwater Harvesting Tank Design for household level (Gurung, et al., 2012). Among the few studies, (Cook, et al., 2012) conducted a study to investigate the performance of the cluster scale rainwater harvesting system in Australia engaging 46 households. In that study, the system was designed to supplement the main water supply system as and when required. The findings of this study have shown a promising result that the system was able to meet the water demand of the targeted households, but at the time it was found not an energy-efficient system as the system had to use a treatment plant (as well as pumping stations) to meet the required standards of potable water. Another study was done by (Huang, 2020) based on the idea of a decentralized water supply system for Sint Maarten Island also showed successful adaptation of the cluster scale design approach. However, rainwater harvesting was only a part of the integrated water management system where the author used the concept of a large-scale rainwater reservoir to meet the water demand of the targeted households. In addition, an overhead water supply system was used for the distribution of rainwater collected in the underground tank and that made it expensive for the low-income households. In addition, "sharing rainwater storage" concept was used in a study conducted by (Seo, et al., 2015) which showed a 61% reduction in storage volume yet achieved the targeted reliability.

Recommendation for increasing the tank size has been proposed by a number of studies using different models such as Water Balance Model (WBM), Reliability Index Model (RIM), Demand Satisfaction Model (DSM), Storage Reliability Yield (SRY) model, yield-after spillage (YAS) model, Mass Balance Model (MBM) across different countries including Uganda: (Kisakye, et al., 2018), Malaysia: (Lani, et al., 2018), Italy: (Campisano & Modica, 2014); (URSINO & GRISI, 2017), Australia: (Baek & Coles, 2011); (Imteaz, et al., 2017); (Rahman, et al., 2012), USA: (Hanson & Vogel, 2014), Tanzania: (Ndomba & Wambura, 2010), Mexico: (Nolan & Lartigue, 2017), Vietnam: (Vuong, et al., 2016) and Bangladesh: (Bashar, et al., 2018). Using long-term time series in the water balance model (Vuong, et al., 2016) conducted a study in 111 sites in Vietnam to evaluate the performance of rainwater harvesting as a primary source of drinking water. This study found that, under different tank sizes, roof areas, and monsoon patterns a range of 20–110 L/d daily water demand can be met with 95% reliability. The study also revealed that, after meeting the daily demand, an additional 50–400 litres of water per day is available during the rainy season.

A number of studies done on the reliability of RWHS have shown that it is almost impossible to design a rainwater storage tank that satisfies volumetric as well as time-based reliability. This is specifically true for the poor population segment like the population living in the coastal area of Bangladesh who has limited roof area to be used as a catchment. (Imteaz, et al., 2012) has claimed that, after a tank size of 5K-7K litres, reliability does not maintain corelation with the tank size anymore, meaning it becomes an independent variable. The author also claimed that for a smaller size roof, it is not possible to achieve 100% reliability, even with a 10,000 L tank.

However, as (Gires & Gouvello, 2009) rightly concluded that reliability is mainly defined by the authority, not by the end users. An RWHS might be labelled as “reliable” by the authority, but that does not mean it is also considered reliable by the end-users. This view has been found very evident in (Taffere, et al., 2016), a recent study done in Ethiopia. Because of the unreliable or less reliable RWHS, especially during dry season, people tend to go back to unsafe water sources or drink inadequate water. Sometimes, they also spend a significant amount of their income to buy safe water from water vendors or buy water filters. This leads to serious public health issues, sometimes turns into an outbreak of diseases (Paudel, et al., 2021); (Shammi, et al., 2019); (Nahian, et al., 2018); (Dasgupta, et al., 2015); (Khan, et al., 2011).

The main concept used in the “cluster approach tank sharing model” is similar to “system optimization by network connection” which has been used in other fields such as off-grid solar energy sharing systems (Elzinga, 2015); (Alotaibi, et al., 2020); (Roche & Blanchard, 2018); (Vand, et al., 2021); (Huang, et al., 2021). The evidence of using this concept has been also found in designing decentralized off-site sewage systems (Sharma, et al., 2012). Research done by (Noh, et al., 2015); (Lade & Oloke, 2020); (Nnaji, et al., 2017); (Jin, et al., 2018) has shown promising results including the potentiality of significant improvements including increasing of overall volumetric as well as time-based reliability.

The impact of using the tank-sharing model on costing has not been investigated in detail though, except a recently published thesis paper by (Semaan, 2020). The approach or the arrangement of sharing tank in my study is different from the one done by (Seo, et al., 2015) or (Semaan, 2020) as in those studies each individual family has its own tank, and on top of that, there was another “common” tank, which re-distribute the surplus from the overall system to the family whoever is in shortage. In addition, there were provisions kept for water treatment and pressured pumping (using electricity) for water distribution. However, unlike energy-sharing, there is no agent or platform (thus no exchange of money in any form) is present in this case. Also, unlike the smart energy sharing grid, the redistribution does not happen automatically. In this tank-sharing approach, the excessive runoff from one roof will get accumulated in the “common” tank that will provide benefit to other families who otherwise would not have adequate water. This approach is similar to off-grid smart solar system that works based on the “peer-to-peer energy-sharing” principle presented in (Vand, et al., 2021); (Sid Chi-Kin Chau, et al., 2019). In contrast, the current study is somehow close to the one done by (Hashim, et al., 2013), though it was done on a much larger scale for 200 families. In (Hashim, et al., 2013) it was also assumed that any deficit in water supply will be covered by the water utility company. But the most critical difference between (Hashim, et al., 2013) and my study is that (Hashim, et al., 2013) was for non-potable water mainly to be used for cleaning, gardening, and toilet flushing which is completely different in contrast to my study. The main idea of my study is to investigate whether the common denominators such as roofing area and

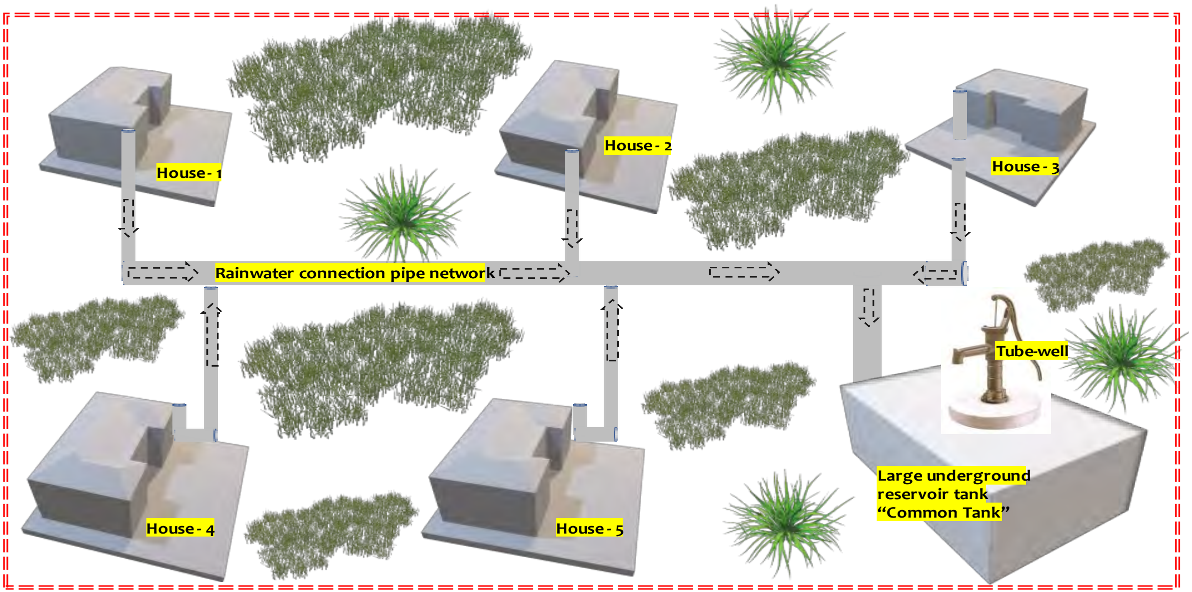


Figure 5: Cluster approach tank sharing model

water demand can make any difference on the storage capacity (thus on reliability) as well as the costing when roofing area of multiple families are combined and use instead of the roofing area of a single-family. The rainfall data has not been considered as variable here assuming that the families are living in the same vicinity thus share the same rainfall data.

Chapter Three

Geographical Context of the Study Area

3.1 The Study area and rationale for selection of the study area

The study has been conducted in Kamarkhola Union, Dacope Upazila under the Khulna district. The following factors have been considered in selecting this study area:

- This is one of the water-stressed areas in the coastal region
- The study area was severely affected by 2 recent major cyclones: SIDR and AILA
- It is one of the worst climate change and disaster-affected areas in the coastal area
- There is evidence of drinking water scarcity in the study area
- It is one of the Hard to Reach (HtR) area
- There are rainwater harvesting systems already in the study area

In addition, this study would be valuable for the communities having the situation such as significant rainfall but have limited roofing areas and storage tanks with limited capacity that results in a heavy overflow or waste of rainwater. Another aspect of this study is that it would investigate such a location where people are not connected to any public water supply network to compensate for their water demand, especially during the dry season. The study area which is Kamarkhola Union under Dacope Upazila of the Khulna District matches these criteria.

3.2 Geographical Context of the study area

The coastal areas of Bangladesh have unique geophysical as well as sociopolitical characteristics which are different from the rest of the country. The coastal ecosystem is a complex dynamic combination of a vast river network, plain islands, tidal flats, and offshore waters (Chowdhury & Chowdhury, 2007). This part of the country is the most vulnerable because of its geographical location and distribution of landscape. It receives at least seven cyclones and depressions every year of which at least one makes landfall (Masum, 2019). Floods, tropical cyclones, tornadoes and tidal surges, salinity intrusion, arsenic contamination, droughts, waterlogging, and riverbank erosion are the common hazards that made the coastal area vulnerable to frequent disasters.

The coastal area of Bangladesh represents 32 percent of the country's geographical area, wherein 28 percent of the country's total population lives. There are 19 districts (out of 64) that are considered coastal districts (Ahmad, 2019). There are certain areas in the coastal belt of Bangladesh, where both shallow and deep hand tube wells are not successful because suitable freshwater aquifers at reasonable depths are not available, and groundwater is saline within 200m-350m depth. Moreover, arsenic contamination in shallow aquifer water is more than the acceptable limit which recently become a major public health concern in many places of the coastal region. At least 59 districts, out of a total of 64 districts of Bangladesh have reported arsenic problems. Thousands of people have already been identified to be affected by arsenic poisoning, in addition to the millions potentially under threat from drinking arsenic-contaminated water (Alam, et al., 2002). By and large, the coastal region and offshore islands of Bangladesh are low-lying and flat terrain. The average height above the mean sea level of the coastal zone is less than 3 meters (Iftekhar & Islam, 2004). As per (BBS, 2015), massive inundation resulting from the storm surge has caused so far, the greatest damage in terms of death toll as well as economic loss in the coastal area of Bangladesh. The height of the storm surge could reach up to 10 meters even more if the timing of the cyclone coincides with the full-moon cycle. A hydrodynamic model developed by the World Bank used in the Bay of Bengal estimates that by 2050 the likelihood of cyclones to be increased by 26 percent (UNDP, Bangladesh, 2014). Currently, on average every year four cyclones make landfall in Bangladesh's coastal region which made it the most exposed country to tropical cyclones (Saha & Khan, 2014).

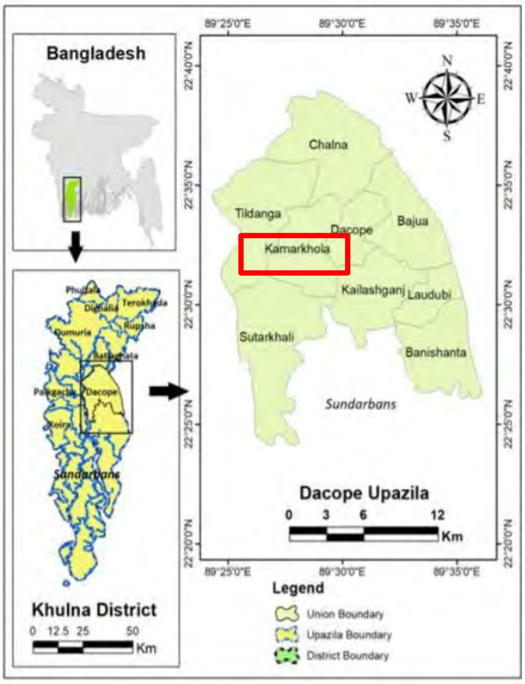


Figure 6: Study area map

Apart from causing hundreds of deaths and million-dollar worth of economic loss, the impact of the recurrent and frequent disasters is enormous, particularly on drinking water. Scarcity of drinking water becomes one of the urgent needs in any post-disaster period which often leads to severe public health emergencies. In the coastal region, lack of safe drinking water is also strongly linked with other geo-physical hazards including climate change impacts such as intrusion of saline water. Excessive level of arsenic in both shallow and deep tube-well creates an additional layer of vulnerability.

These challenges are particularly severe during the dry season when rainwater is not available of inadequate quality. Disasters like cyclone, floods, water logging coupled with other climate-induced hazards not only impact the groundwater source, but also contaminates the surface water bodies including ponds, canal, and rivers. The challenges with suitable water in the coastal region also adversely impact agricultural production thus often contributing to seasonal food insecurity. Studies show that in the last four decades, soil salinity in terms of intensity and coverage is on a rising curve. Only in Khulna and Barisal divisions, 1.05 million hectares of land has been affected by various degree of salinity (Salehin, et al., 2018); (Ahsan, 2010). Along with other hazards, this makes a major contribution to the significant shortage of safe drinking water in the coastal area which has severe repercussions on the health. In addition, un-planned and un-regulated shrimp farming simply make this situation worse as the intrusion of brackish water for shrimp farming seriously affects groundwater quality and thus increases the shortage of sweet water in the coastal region (Kabir & Eva, 2014); (Alam, et al., 2017).

3.3 Demography and climatic condition of the study area

The 19 coastal districts of Bangladesh are home to around 35 million people with an average population density of 743 per sq. km. These 35 million people living along the 710 km long coastline of the Bay of Bangle are exposed to frequent multi-hazard phenomena such as cyclones, tidal surges, floods, droughts, salinity intrusions, repeated waterlogging among others. In addition, arsenic contamination in groundwater stocks added a new layer of challenge. These hazards are not only responsible for killing people, but also affect local livelihoods, people, and environments of this region in many aspects.

In the coastal region, there are 60 islands and 127 char lands which experience these disasters multiple times a year. The western part of the coastal area is on average 0.9-1.2 meters above the mean sea level. Main livelihood options in this area include fishing, agriculture, shrimp farming, salt farming, and tourism (Islam & Haque, 2004). However, traditional livelihood options are being diversified where a significant percentage of the population have been engaged in the service sector. The Southwest part of the coastal region is surrounded by the Sundarbans mangrove forest which to some extent protects it from tidal surges and cyclones. In future, the region is likely to experience severe water scarcity due to the negative impacts of climate change (Abedin, et al., 2009).

Kamarkhola Union under Dacope Upazila of the Khulna District has been chosen for this study. This area is prone to multiple hazards and has been affected by a number of cyclones such as Sidr, Aila, and Mohasen. According to Population & Housing Census, 2011 (Bangladesh Bureau of Statistics, 2015), Khmarkhola Union has 14 villages (Governemnt of Bangladesh, 2022) and is located in LA: 22.601235, LO: 89.507287. It has an area of 10, 214 acres with a population of 13,897 living in 3,559 households of which 7,103 (51%) are male and 6,794 (49%) are female. Only 0.1% population has access to tap water, 97% population collects water from different types of tube-well, and 2.9% from other sources including 1% from rainwater harvesting system (Department of Public Health Engineering (DPHE), 2019). Because of weak tropical depressions that are brought from the Bay of Bengal into Bangladesh, more than 75% of rainfall occurs during the monsoon. Due to multiple factors including the climate change impact, average annual and pre-monsoon rainfall will significantly increase in the coming years. That means in the coming days, the number of wet months will increase, and the dry month will decrease (Shahid, 2010). The study area gets heavy rain with high frequency during monsoon but, no rain during the dry season. This phenomenon leads to the quest of designing a rainwater system that can meet the daily water demand during the monsoon as well as can store enough water for the dry spell.

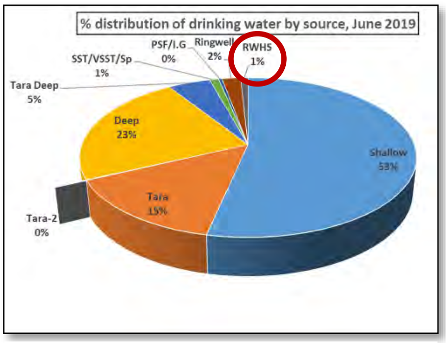


Figure 7: % distribution of drinking water by source

In the coastal region, traditionally, most houses are made of available natural materials and basic foreign materials. However, due to a progressive increase in income, the type and the pattern of the overall housing have changed in the last few years. In addition, more and more people started adopting durable and resilient housing to face the increasing adverse impact of disasters such as cyclones, tidal surges, and waterlogging (UNDP, Bangladesh, 2014). In the last few years, a remarkable change has been observed in terms of the use of more durable roofing materials such as corrugated galvanized iron (CGI). On average, 47% roof is made of Corrugated Galvanized Iron (CGI) sheets locally called “Tin”. Since 2000, the use of CGI sheets and concrete has increased twofold (World Bank, 2013).

A notable percentage of houses have a concrete roofing as well. Both the CGI sheet and the concrete roof are suitable to be used as a catchment for the RWHS. A small percentage of people use straw/ leaf for roofing which is not suitable as the catchment area for RWHS. However, with some modifications such as using the polyethylene sheet on top of the straw-made roof, it can also be used for RWHS to some extent (Islam, et al., 2014). According to the field survey conducted by (Islam, et al., 2014) in Satkhira district, it was found that most of the population (58%) have an average roof area between 25-50 sqm followed by a 22% having 9.5-25 sqm. About 20% of people have roof area > 100 sqm. (Karim, 2010) also confirmed similar findings for roofing size in a study assessing 1,000 RWHS in the coastal area of Bangladesh. This has an enormous impact on the type of rainwater system adopted over time given the increased roofing area to be used as rainwater catchment.

Chapter Four

Research Methodology

4.1 Research Question

This study has systematically explored the current state, issues, and possible alternative solutions around the reliability of the Rainwater Harvesting System in the coastal area of Bangladesh. Following are the specific questions this study investigated:

1. **Reliability**: What is the current state of reliability of the RWHS in the coastal area of Bangladesh?
2. **Perception:** What perceptions and lived experiences do different stakeholders (end-user, practitioner, expert) have about the reliability of the RWHS?
3. **Conceptual Model**: What changes in the current design may improve the reliability of the RWHS?

The above stated research questions were explored systematically following the research methodology and framework illustrated in the figure 4.

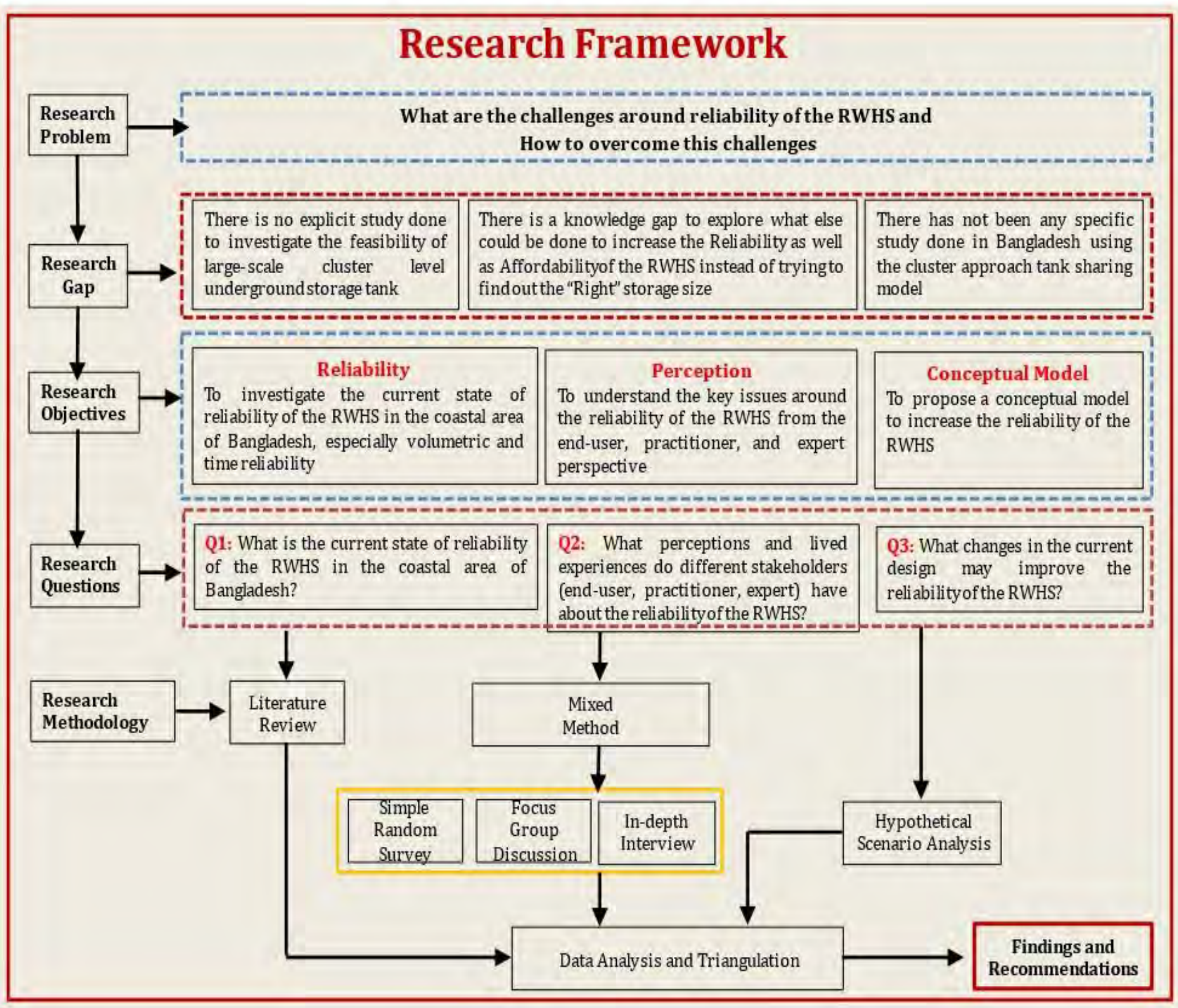


Figure 8: Research methodology framework

4.2 Tools and Techniques

The study employed a mixed-method approach consisting of literature review, Simple Random Survey (SRS), Focus Group Discussion (FGD), in-depth interviews, and hypothetical scenario analysis. The survey and the FGDs were conducted by self-developed guided questionnaires, the in-depth interviews were conducted following the Transcendental Phenomenological approach (TPh), and hypothetical scenario analysis was done using secondary data sources.

4.2.1 Simple Random Survey

Simple Random Sampling (SRS) methodology has been adopted for this study to conduct field survey. One of the reasons for adopting SRS is that the population were know and I was able to collect required secondary data to define population which is a pre-requisite for using SRS method. SRS is one of the probability sampling techniques widely used in the qualitative research field, especially found effective in social science spectrum (Singh, 2003), (Mitra & Pathak, 1984). In this study, population data has been collected from the Union Parishad for one of the villages (Joy Nagar) under Kamarkhola Union.

As per the data collected, Joy Nagar has a total of 126 families (population size) where each family has a unique household number (*Khana number*). The khana numbers in Joy Nagar stats from 418 and ends at 543 which gives 126 unique integer number. Using a widely used online-based random number generator program showing in this website (https://www.calculatorsoup.com), 67 random numbers corresponding to 67 households have been selected for the survey. The sample size of 67 has been calculated using an online sample size calculator available at (https://www.calculator.net/sample-size-calculator.html) where 95% Confidence Interval, 5% margin of error, 90% population proportion and population size of 126 were selected as input criteria. Necessary data was collected from these 67 households by using a self-developed questionnaire (annexed with this report as Appendix-A).

An online-based free mobile data collection platform called “KoBo Toolbox” was used to collect the data from the field. Data collection was done in July 2022 through two local volunteers from Joy Nagor, Dacope using the mobile version of the KoBo called “KoBo Collect”. KoBO Toolbox was developed by a group of humanitarian organizations in collaboration with Harvard Humanitarian Initiative and being widely used for surveys and data collection (UNOCHA, 2019), (UNHCR, 2016). Once the data collection is done, an auto generated analysis report can be extracted from KoBo which mainly provides basic analysis such as mean, median and frequency. However, collected data in KoBo can also be extracted in different formats including MS Excel and customized analysis can be done thereafter. For this study, in addition to the auto generated analysis, I have extracted data into MS Excel and analysed further as it was needed for the report.

4.2.2 Focus Group Discussion (FGD)

FGD is one of the most frequently used methods in qualitative research in almost across all disciplines, especially in social science. Because of its simplicity yet high effectiveness as a data collection method, especially when the researcher needs to gather information on experience and opinions on a particular topic from a large group of people (Kitzinger, 1995). In this study, 3 FGD were conducted between Jan-March 2022 in the research area (Kamarkhola

Figure 9:FGD in Choto Kali Nogar

Figure 10: FGD in Sarabad

union, Dacope) each consisting of 7 participants.

Because of the limited resource, time, and workforce, the participants were selected following the purposive sampling technique only from the 3 nearby villages. However, the participants were selected from 3 villages (Choto Kali Nogor, Kali Nogor and Sarabad) in this study area who are regular users of RWHS and are well-informed about the RWHS. Figure 7 and Figure 8 shows the FGD sessions in Choto Kali Nogar and Sarabad.

4.2.3 In-depth Interview

In addition, six in-depth interviews were conducted with three different groups of participants followed by the purposive sampling technique described in (Patton, 2014). Two of the interviews were with end-users (who use the RWHS), two with the field practitioners (who help with the design and construction), and two with the academia/experts (who deal with relevant policies and strategies). All the interviews were conducted between Oct 2021 to Dec 2021. Of the six interviews, four were conducted through mobile phone (user-group and practitioner groups) and two (expert group) were face-to-face. The number of interviews was aligned with the recommendation made by (Creswell, 2013); (Cordes, 2014) and (Polkinghorne, 1989). This was also in line with the recommendations by (Canfield, 2013); (Howard, 2008) and (Howard & Whitaker, 2011). These in-depth interviews were done following Transcendental Phenomenological Methodology (TPh) approach, sometimes also conceived as descriptive phenomenology. To fully grasp people's "first-person" or undistorted experience around the core concept of this research, it was needed the fullest understanding of what has been the experience of the participants who have dealt with the RWHS as parts and parcel of their regular life. For this obvious reason to "describe" rather than "explain", Phenomenological Methodology (TPh) was chosen as of the tools used for this research.

4.2.4 Hypothetical scenario analysis

Hypothetical scenario analysis was conducted using the secondary data collected from the (Bangladesh Meteorological Department (BMD), 2021). The monthly average rainfall data of the Khulna district was obtained from BMD. Using this data two hypothetical scenarios were developed. In scenario – 1, to capture the full amount of rainfall, the monthly average required roofing area was calculated using monthly rainfall data, and the monthly average water demand for a family of 5 people. A frequency table was then developed using the monthly average required roofing area with a class interval of 10. Finally, keeping the same rainfall data, water demand, and population size, this frequency table was recalculated for 5 families or 25 people together (labelled as "cluster") at an interval of 50.

The comparative result of these two has been presented in Figure 4. In addition, given the water demand, separate tank size for an individual family (HH level) and the tank size for a cluster scale (for 5 HHs) were calculated using the mass balance equation adopted from (Islam, et al., 2020) which can be mathematically expressed as $0 \le V_t = V_{t-1} + Q_t - D_t \le V_s$. This mass balance equation method is widely used by other researchers including (Rahman, et al., 2012); (Imteaz, et al., 2017); (Lani, et al., 2018); (Vuong, et al., 2016); (Karim, et al., 2014) among others. The construction cost (excluding O&M cost) of these two types of tanks was then compared to see if there is any significant difference in terms of cost. The costs have been estimated based on the pricing information presented in the 3 studies: (WaterAid Bangladesh, 2006); (Karim, 2010) and (Murase, 2020). This is because, among the available studies explicitly done for the coastal area of Bangladesh, these three studies are found with enriched data around the cost of the RWHS. Though the study conducted by WaterAid was done in 2006 and some of the costing information may have changed by now, still it provides a good understanding of the costing of the RWHS. However, for this study, the price information has been adjusted for cumulative inflation using two (Bangladesh specific) online calculators from (World Data, 2021) and (Creatifwerks, 2021).

4.3 Participants Selection

As described in section 4.2.2, in addition to simple random survey (section 2.4.1), the study employed 3 Focus Group Discussion (FGD) as one of the data collection tools. There were 7 participants in each of the FGDs and they were purposively selected from 3 different villages (Choto Kali Nogor, Kali Nogor, Sarabad) in the study area. I engaged 2 local volunteers to organize the FGDs. The volunteers communicated with the people living in these 3 targeted villages and then identified the participants based on their willingness for volunteer participation and availability of time. Gender, age, and occupation diversity were also carefully considered in participant selection. The six participants for in-depth interview were selected following the purposive sampling technique but based on several criteria as illustrated below:

Table 2: Interview Participants Selection Criteria

Category	Criteria
End-user (2)	- Have been living in the study area - Have been using HH RWHS
	- Have been living in the study area - Does not own and currently not using HH RWHS
Practitioner (2)	- Have been working (or have worked) in the study area and involved with RWHS construction project - Has a technical background in civil engineering, or architecture
	- Have been working (or have worked) in the study area and involved with Water, Sanitation and Hygiene (WASH) projects - Preferably, working with Non-government Organization (NGO) - Has a non-technical background in social science, anthropology etc.
Expert (2)	- Have been involved with RWHS strategy and policy level issues
	- Have been working (or have worked) as a senior-level official (preferably in NGO, research institute, water-sector business) and involved in RWHS strategy and policy level issues

As mentioned in section 2.2.3 the research design employed Transcendental Phenomenological Methodology for in-depth interviews to understand and capture people's living experiences around RWHS. The target participants were carefully identified using the criterion above in order to capture diverse experiences from a wider category of people closely involved with RWHS. At first, participants were classified into three categories: End-user, Practitioner, and Expert. This was purposely done to capture the living experience of different stakeholders working at different levels and understand what their experience is and what they think should be the solution to the problem.

Also, what do they think about the proposed solution in this study? Between the two participants in the **end-user group**, even though both are from the study area, one has experience in using RWHS and another does not. This is to get a comparative experience in contrast to one another. Two participants of the **practitioner group** were selected based on their involvement with two major service providers /stakeholders (the government and the NGO). Their experience in two different academic disciplines i.e., civil engineering (technical) and social science or anthropology (non-engineering) was also selected consciously to grasp their living experience from different perspectives. Finally, the participants of the **expert group** were selected based on their expertise and type of contribution to the body of knowledge i.e., RWHS. The academic expert's experience is more like theoretical knowledge in contrast to the other participants who came more with practical experience.

4.4 Data collection and analysis

As mentioned in section 4.2.1, that survey data was collected from 67 households (33 data points X 67 households = 2,211 data points) and then analysed using **MS Excel**. The analysis report has been presented in section 5.2 following descriptive methodology. The discussion in the FGDs was framed around five self-developed qualitative open-ended questions. During the FGD sessions, two local volunteers (recruited by me) took note while I moderated the discussion.

I also took notes on important discussion points, opinions, and ideas expressed by the participants. The collected notes were then analysed using the **Content Analysis Method** guided by the six self-developed questions. The Content Analysis Method is one of the well-recognized and widely used methods in the qualitative research approach (Mishra, 2016). **Microsoft Word** and **Excel** have been used in this study to analyse and synthesize both FGD data and in-depth interview data. During the in-depth interview, answers were written down in the notebook for further analysis.

Because of the nature of the research, semi-structured and in-depth interviews are the most common type used in the Phenomenology approach (Tanwir, et al., 2021). Although for the in-depth interview, it is not mandatory to develop predetermined interview questions, I developed a few broad and open-ended questions only to lead the conversation. Since the core idea of this study is to understand people's lived experiences around RWHS and critically look at the reliability of the RWHS, the broad questions were based on the sustainability criteria and their indicators following the FIETS model.

FIETS model uses 5 sustainability principles to assess the sustainability of any intervention (WAI, 2018); (IRC, 2014). It has been widely used by many agencies to assess the sustainability of their interventions (Dutch WASH Alliance, 2014); (Lilian & Soelen, 2018). The data collected from the in-depth interviews were then analysed and presented following the **Thematic Analysis Framework** which is one of the widely used data analysis methods in the field of qualitative research (Sundler, et al., 2019). Hypothetical scenario analysis was done based on the secondary data collected from (Bangladesh Meteorological Department (BMD), 2021). These secondary data were then organized and analysed using **Excel** and presented in the form of graphs and tables.

4.5 Limitations of the study

The study has been conducted at Dacope Upazila, Khulna district. The people of Khulna district suffer much more in water poverty than other geographic regions of the country due to excessive salinity and arsenic contamination in their main drinking water source i.e., tube-well. If other coastal districts were part of the study, then it may have been possible to get an overall idea of the cyclone-affected coastal area of Bangladesh.

The idea of tank sharing is relatively new in the RWHS field and was studied only by a handful of researchers including (Seo, et al., 2015); (Hashim, et al., 2013); (Semaan, 2020); (Noh, et al., 2015); (Lade & Oloke, 2020); (Nnaji, et al., 2017); (Jin, et al., 2018); (Sharma, et al., 2012).

Figure 12: Existing RWHS in Sarabad

Figure 11: FGD in Kali Nogar

However, all these studies were done in different settings, targeting different objectives, using different data sources and none of them was in Bangladesh. Another aspect is that there has not been any specific study done in Bangladesh using this cluster approach tank sharing model. In that context, it needs further in-detail research to be able to truly claim the positive contribution of the Cluster Approach Tank Sharing model presented in this study. Figure 9 shows a FGD session in Kali Nogar and Figure 10 shows an existing RWHS in Sarabad village. In addition, due to the time and resource limitations, it was not possible to conduct a practical demonstration (construction) of the RWHS following the cluster approach tank sharing model which might have revealed different results in contrast to the hypothetical model presented in this study.

Chapter Five

Findings and Discussion

5.1 Introduction

As stated in section 4.1, the key questions this study seeks to answer are:

1) **Reliability**: what is the current state of reliability of the RWHS in the coastal area of Bangladesh?
2) **Perception:** What perceptions and lived experiences do different stakeholders have about the reliability of the RWHS?
3) **Conceptual Model**: What changes in the current design may improve the reliability of the RWHS?

To answer these questions, the study collected data through 67 Sample Survey, 3 FGDs and 6 in-depth interviews. In addition, the study also developed a hypothetical scenario and tested the reliability of the proposed Tank Sharing Model using secondary data. The observations and findings from these have been presented in this chapter.

5.2 Findings and discussion: Field Survey

As described in section 4.2.1, a total of 67 surveys conducted in Joy Nagar, Kamarkhola union under Dacope Upazila, Khulna.

Table 3: Sociodemographic status of the studied area

SL	Aspects		Frequency	Percentage (%)
1	Gender	Male	48	72
		Female	19	28
2	Age (years)	18-30	20	30
		31-40	9	13
		41-50	14	21
		51-60	6	9
		61-70	16	24
		71-80	2	3
3	Annual family income (BDT)	< 3,000	7	10
		3,001-5,000	21	31
		5,001-10,000	25	37
		>10,000	14	21

Question: What is the capacity of the RWH storage? In the study area, 97% of the surveyed population responded that they own RWHS of different types and capacities. Of the population who have RWHS, 6% reported to have a tank capacity <500 L and none reported to have a tank >10,000 L. Total 68% of the population reported using 2 most frequently used tank sizes: 1,000-3000 L (31%) and 3,000-5000 L (37%).

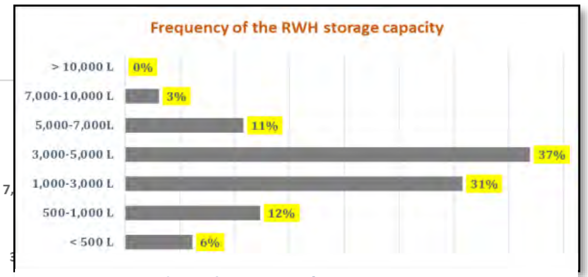
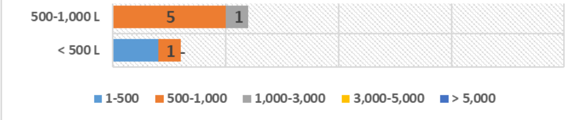


Figure 13: % distribution of RWHS storage capacity



Question: Do you need to buy drinking water? If yes, how much do you spend in a year for buying drinking water? Of the surveyed population, 79% buy water mainly from local vendors. However, of the 79% significant percentage (66%) responded that they only buy water "sometimes". The study then looked at the corelation between the purchase of water and the annual income and found that only 9% of the lowest income group (BDT 1-3,000) spend money for buying water in contrast to 91% having an income range between 3,000- 10,000 BDT. When it was asked how much they spend on buying water, the most frequent response was 5-10 K BDT (40%), followed by 3-5 K BDT (32%) and > 10 K BDT (19%). It was found that 75% of the population who buy water owns a RWHS having a capacity of 1,000- 3,000 L (37%) and 3,000-5000 L (37%). Interestingly, only 6% of the population having a tank capacity < 500 L spend money for buying water (Figure 8).

Figure 14: Storage capacity vs money spend to buy water

Question: What is your average annual income? This leads to a query on what do this group of people do to cope up with the problem. The most obvious answer is adopting "Negative coping mechanisms" such as inadequate consumption, using contaminated sources, compromise health care & education cost, purchasing water from local vendors, and investing on technologies

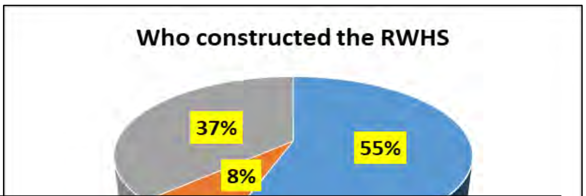


Figure 15: % of RWHS supported by stakeholders

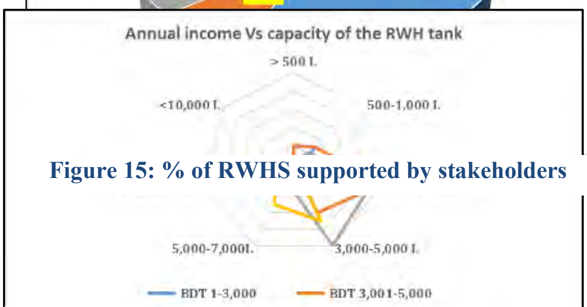


Figure 16:Annual income Vs RWHS storage capacity

including water filter and other water treatment chemicals. Most of these negative coping mechanisms if not all can be eliminated just by increasing tank capacity to a reliable level to ensure adequate supply throughout the year. The study also found a fairly strong corelation between the annual income and the capacity of the RWHS. As shown in the figure 9 that, higher annual income clearly corresponds to bigger tank size. This is an indication of "willingness to pay" for the RWHS if income is sufficient.

Question: Who constructed RWHS for you? If self, how much did you spend? How many months it can provide enough water for your family? What is the main challenge about the RWHS you own? What suggestion do you have to overcome the challenge?

Of the surveyed population 97% reported having different types and capacities of RWHS. When it was asked whether the system was constructed by themselves or someone else, the response was that staggering 55% was self-constructed, followed by 37% supported by NGO and only 8% by the Government (figure 7). This indicates inadequate government investment on RWHS, but at the same time people's willingness to invest on the system as access to adequate water is a "must-have" survival issue for them. However, even though 97% of the population have a RWHS, but 90%, 60 (out of 67) responded that the "storage is not enough" to meet their water demand where only 9% said that "catchment area is not enough" (figure 10). In fact, when it was asked "how many months the current RWHS provide adequate water", 60% responded "1-2 months", followed by 32% "2-3 months" and 8% "3-4 months".

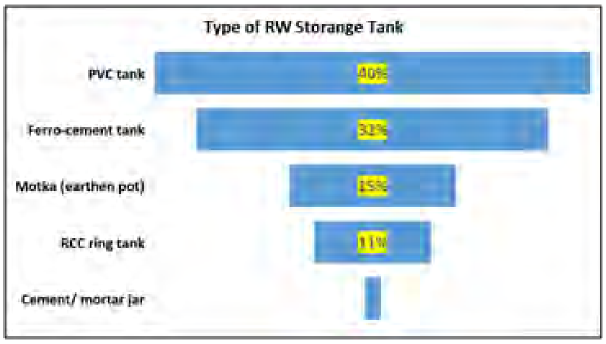


Figure 17: Types of different storage tanks

When the participants were asked for recommendation to overcome this challenge, 85% recommended to "increase the storage capacity" followed by 9% "increase alternative options" and 6% recommended to "increase catchment area". However, the critical aspect here is that only increasing the "storage capacity" will not solve the problem as without having required catchment area it is impossible to collect sufficient rainwater.

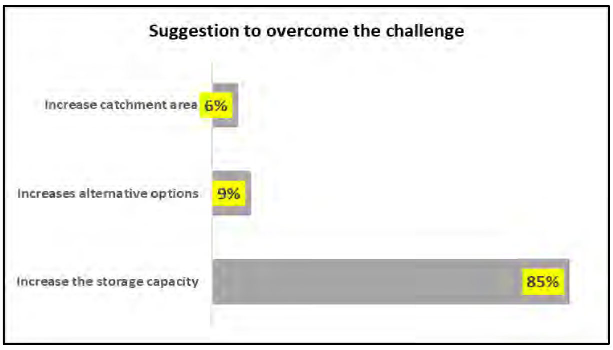


Figure 18: Suggestions to overcome the challenges

This situation demands a solution which will not only increase the storage capacity, but also increase the catchment area as well. The proposed "Cluster approach tank sharing" model where it is recommended that multiple families to construct a large capacity "common" tank instead of small capacity individual tanks would solve the "storage capacity" problem. In addition, to solve the "catchment area" problem, the study recommended to use "catchment area" as a variable and carefully grouping the families in a way that the catchment areas of the individual families will complement each other.

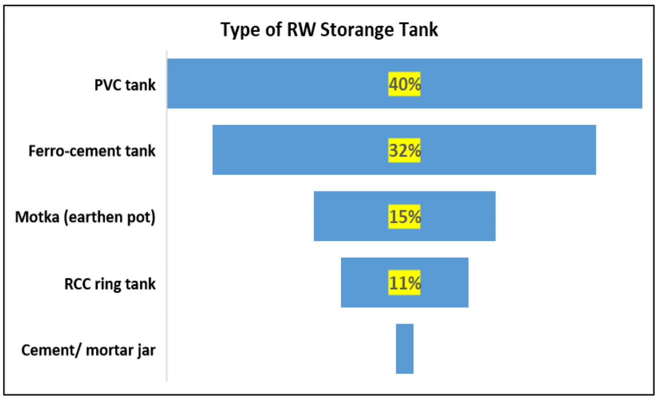


Figure 19: Different types of storage tanks

Question: What type of RWHS Storage Tank do you have? The study found one emerging trend in terms of the "type of RWHS" which is frequent use of "PVC tank" as a means of storing rainwater. Of the surveyed population, 40% reported to use PVC tank, followed by 32% ferro-cement tank, 15% earthen *Motka* ,11% RCC ring tank and 2% cement-mortar jar (figure 11). When corelation was drawn (figure 12) between type of tank vs annual income, it was found that of the 40% who use PVC tank are in the annual income range of BDT 3,000 to 10,000. None was found in the income range of 1,000-3,000 BDT. Out of total number (26) of PVC tanks, 20 of them (77%) have been self-constructed and 6 were supported by NGO. None of the PVC tank was found supported by government. Of the total government supported 6 RWHS 5 was "Ferro-cement" tank and 1 was RCC ring tank.

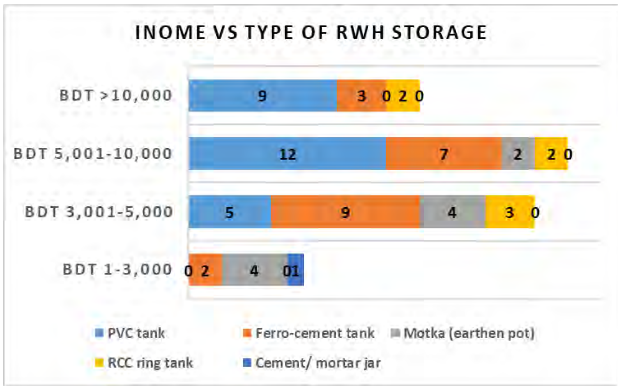


Figure 20: Income Vs types of RW storage tanks

Question: What is your primary source for drinking water? Do your family have access to adequate drinking water throughout the year? Of the total 67 participants, 65 (97%) responded having RWHS of different types and capacities. However, of the 65 participants (who have RWHS), 92% responded that they do not have access to adequate water throughout the year. But 63% of the total population reported "tube-well" as their "primary source of drinking water" followed by 20 (33%) using "multiple sources". This indicates, that having a tube-well is not a "magical" solution, especially in the

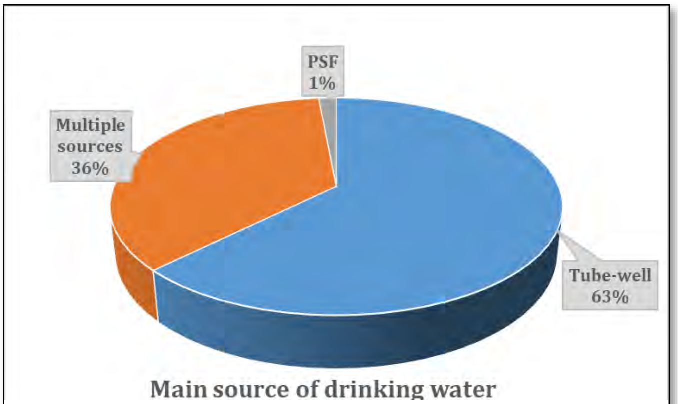


Figure 21: Main sources of drinking water

coastal region where tube-wells are very much vulnerable to many geo-physical and climate change related factors including arsenic contamination, water table depletion, high salinity, and frequent and intense hazards such as cyclones and floods. On contrary, it also demands quest for reliable alternative solutions including systematic and increased investment of RWHS.

5.3 Findings and discussion: Focus Group Discussion (FGD)

As mentioned in section 4.2.2 that 3 FGDs were conducted in the study area (Kamarkhola, Dacope) to collect the necessary information. A total of 21 people participated in these 3 FGDs of which 43% were female and 57% were male. More detail on the location-wise participant number is shown in figure 14. Average age of the male participants was 51 years whereas the same for the female was 43 years. The participants were from diverse occupations dominated by housewife (35%) followed by 30% fishermen. Also, a significant percentage (15%) of the participants were shopkeepers from the three study locations (village). Of the participants 29% were Hindu and 71% were Muslim. A detail of the participants occupation is presented in figure 15. In general, all three villages (Choto Kali Nogor, Kali Nogor and Sarabad) are water -stressed where tube-well is still the dominant water source followed by RWHS which is used for 3-4 months during the rainy season.

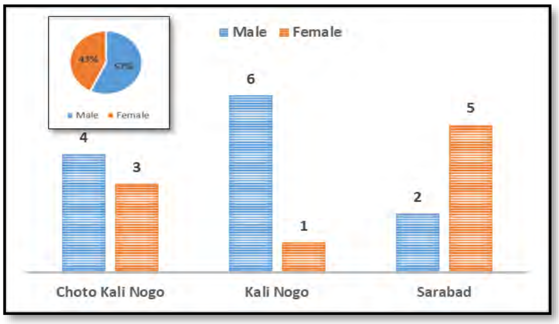


Figure 22: # of participants by FGD groups

The findings reported in this study should be considered as "group" findings rather than the "individual" opinion of any participant. I followed the steps: "description", "interpretation" and "recommendation" to present the FGD findings for each of the questions asked as suggested by (Negr & Thomas, 2003). Most of the participants either own a household level RWHS or have access to a RWHS (either community RWHS and or HH level RWHS owned by another person). The bale below shows the key findings and the discussions from the three FGDs conducted in the study area.

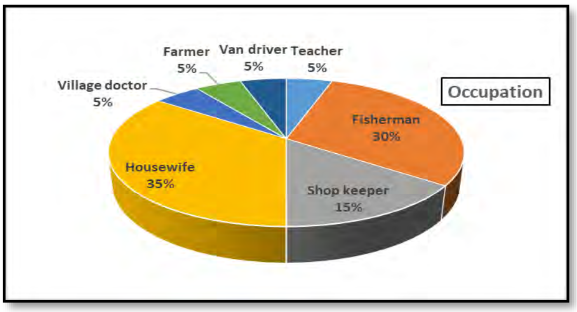


Figure 23: Occupations of the participants

Table 4: FGD Findings

	FGD Sessions		
	FGD-1: Choto Kali Nogor	FGD-2: Kali Nogor	FGD-3: Sarabad
Introduction and organization of the session	Participants were welcomed and introduced. The researcher and two local volunteers were also introduced to the groups. Because of my previous experience of working in the same area, I was already known to some of the participants. However, given my limited knowledge of		

	the local language, one of the facilitated the discussion in coordination with me. I took note of the main discussion points asked the follow-up questions and clarifications. Another also took note of the discussion points, opinions, and clarifications provided by the groups. These notes were used to triangulate and interpret the information collected from the FGDs.
Explain the research and why FGD	The purpose of the research was clearly explained to the groups including the intended use of the information collected from the FGDs. Verbal consents were also obtained from the groups regarding notetaking and the use of information.
Q1: Do you own a RWHS	Almost all participants in all groups responded that they own RWHS of different types and sizes, mainly made of the earthen pot (*motka*) and PVC tank connected to the roof. The capacity of these tanks ranged between 300 L – 2,000 L which almost always does not meet their water storage demand. As a result, they use multiple water sources including tube-wells, communal RWHS, Pond Sand Filter (PSF), river/ pond water, and Water Vendors. It was very clear from the discussion that the RWHS in this area is perceived as a "supplementary" source only to be used during the rainy season (June-Oct). Some participants reported that in some cases, even during the peak rainy season they need to collect water from other sources as the capacity of the storage tank is very small. A few participants reported use of surface water which are often contaminated with Fecal matters. This leads to a huge hike in water-borne diseases including cholera, diarrhoea, and typhoid, and increases their medical expenses. Due to this, some people started buying water filters that promise to provide safe water.
Q2: If not, do you have access to other RWHS	Some participants reported that they have access to other RWHS either owned by someone else or community level RWHS. Usually, the capacity of the community level RWHS is within a range of 5,000 L – 15,000 L. Most of these community-level RWHSs are constructed by different NGOs and govt. agency such as DPHE. There is no uniform design or size of these RWHSs. Each of them is different in size, shape and capacity which is expressed as a challenge by the participants as it is difficult to replicate.

	Even though most participants reported there are no issues around accessing this community-level RWHS, the functionality of these systems has been a serious issue. Also, some participants reported that they need to pay a certain amount of money (BDT 3-10 per *Kolisi*) to collect water from these systems. However, most of these committees lack transparency and accountability. It was also shared by some participants that because of the smaller size, often the catchment area (roof) is not able to collect enough water, especially when there is intense rain. However, most of the participants said that they have a roof area between 120-300 sft of which only a small portion is being used to collect rainwater.
Q3: How many months can you collect and use rainwater with the current storage tank	It was reported by almost all participants that with their household-level RWHS, they can collect water for 3-5 months. However, the challenge is because of the small storage capacity it's never enough to meet their demand. The way it works is that they collect and use, never collect then store then use. This is because the supply and the demand of rainwater does not correspond. Since there is no provision for "storage", a significant quantity of rainwater goes back to earth without use. But, at the same time, when there is no rain, people are forced to drink inadequate and inferior quality water often from different contaminated sources. Some financially better people buy water from local vendors or buy a water filter. Participants stated that if they had a larger storage tank, they could use the full roof to collect more water. However, some were skeptical about the sufficiency of the roof area to be able to collect adequate water within the 3-5 months of the rainy season because the collection and the consumption will take place simultaneously, not in a linear fashion.
Q4: What are the main challenges of the current RWHS	Many participants mentioned that, while the rainfall occurs only for a few months, the demand remains the same throughout the year. That means the demand does not correspond to the supply even though the cumulative quantity of rainfall in a given year is sufficient to meet the demand. The biggest challenge is that rainfall occurs in a short period

	of time with high intensity and there is not large enough storage capacity to collect water for the whole year. Another challenge expressed by the participants was that because of the low storage capacity of the existing RWHS, it is not reliable. Therefore, people always need to use multiple water sources as a coping mechanism to meet their water demands. In most cases, these sources are often unsafe (such as surface water and or arsenic comminated water from the tube-wells) or expensive such as using water filters or water treatment chemicals. Participants also reported that in most of the cases, only a portion of the roof is being used as a catchment as it is not needed to use the whole roof while the capacity of the storage tank is very much limited. Some also mentioned that as most of the current RWHS systems have a small storage tank and can only be used for a few months, the rest of the time of the year it is not in use. This enables the incubation of different harmful fungi and bacteria inside the storage tank. Some participants expressed their strong view that, instead of providing a sustainable solution, there are some people who take advantage of this situation and try to promote expensive and unsustainable technologies such as water filters, desalination plants, and different water treatment chemicals. Some also promote the "commercialization" of water by setting up water treatment plants and selling water in this area.
Q5: What are your suggestions to overcome these challenges	Most participants said that to some extent they are aware of the problem around the limited capacity of the RWHS storage tank. But at the same time, they said until the following few challenges are solved, the problem will persist: - **Increase catchment area** (individual household level): Given the limited storage capacity (300 L -2,000 L) of the current RWHS at the household level, it is sufficient to use only a portion of the roof. However, as already mentioned earlier, this storage is not enough for them to meet the demand. But at the same time, simply

	increasing the storage capacity alone will not solve the problem either, unless the catchment area (roof) is also increased proportionally. But given the housing pattern, each individual household constructs the house as per their needs and financial capacity, not based on how much roofing area is needed for RWHS. It is almost impossible to change the size of the house (and thus the roofing area) only to increase the catchment area for RWHS to collect water from. Some participants suggest that as an alternative, it is possible to combine the roofing area of a few houses living close by and thus achieve the required catchment area needed for a large RWHS storage tank. But, in this case, the families need to come together with full cooperation and to be agreed on this arrangement. Participants also suggested using the roof of different public institutes such as schools, clinics, cyclone shelters, mosques etc. for this purpose. - **Limited financial capacity:** Even though the problem around the catchment area is solved, people need a huge amount of money to construct a large enough underground water reservoir to store adequate water for the full dry season. In addition, money will be also needed to set up the system i. e. to connect rainwater inlet pipes to different roofs of different houses. On top of that, they also need to buy a hand pump to be able to draw rainwater from the underground reservoir. They estimated that all together one such system would need around BDT 70-80 thousand ($ 800-950) which is not within their affordability. However, given that water became a "survival issue," they expect some people (a few) will be able to do it by themselves while the majority would need external support, especially from the Govt. and NGOs. Participants also suggested that the govt. should provide subsidies on such RWHS as they do it for deep tube-wells, solar, and biogas.
Q6: What is your opinion on the "Tank Sharing Model"	A 3D design of the proposed tank sharing model was presented and explained to the groups. Then the participants were asked to provide their opinion from the end user perspective. Mixed opinions were noted from all 3 groups. Most of the participants provided an opinion

	on the proposed design that in comparison to traditional design, it would certainly improve the reliability and thus covers additional time. However, some participants also raised concerns around the cost implication that it would be expensive for them and only a few families in a village would be able to afford it. But others pointed out that, since this model could potentially serve them adequate safe drinking throughout the year just like a tube-well, the govt. and the NGOs should be able to support them on this by providing subsidies. Most participants agreed that the proposed design and the construction technology would not be difficult to follow as the required technical skill and the materials required are available in the local market. Some participants also expressed their concern about the potential contamination (by bacteria and other pathogens) of the water as the water would be stored for a long time in the underground tank. But it also discussed and agreed that with regular cleaning and disinfection (by chlorine), this potential contamination problem can be tackled. Currently, there is no such RWHS design that has a large underground storage tank and handpump attached on top of the tank to extract water. Most of the participants liked this idea as they said that it would provide a phycological satisfaction around the water safety as tube well is a well-known technology in the community. Participants also said that the top slab of the tank can also be used as a platform (just like the traditional tube-well) for bathing and washing space, though that is not the intended use proposed in this study. Participants also stated that they are very happy to see that this model will be run by gravity only which means literally “zero” power, not even solar.

5.4 Findings and discussion: Hypothetical scenario analysis

As described in section 3.3, monthly average rainfall data of the Khulna (Figure-16) district was obtained from (Bangladesh Meteorological Department (BMD), 2021). This graph shows that the maximum amount of rainfall occurs during the monsoon season (Jun-Sept) whereas minimum rainfall occurs during winter and summary.

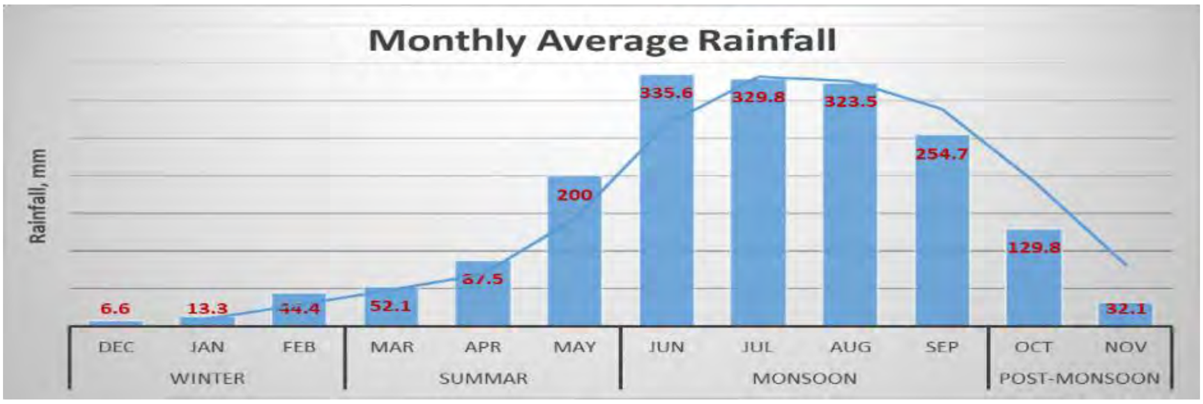


Figure 24: Monthly average rainfall data, Khulna

Following the two hypothetical scenarios described in section 4.2.4, Figure 17 shows that following the Cluster approach tank sharing model and adding a small roofing area, more time coverage (month) can be achieved. The additional area required has been presented in Figure-17. That means, keeping the same water demand if a number of HHs build a large common tank and add a small catchment area, the total system becomes more reliable. For example: when an individual HHs has a roofing area (catchment) of 10 sqm in contrast to this, adding only 20 sqm of catchment area to the total area (5 X 10 sqm + 20 sqm), if 5 of these HHs build a common RWH tank that can meet the water demand for 6 months instead of 5. Similarly, 5 HHs (each having 20 sqm of catchment area) if 75 sqm added to this and they build a common tank, the system can meet the water demand for 9 months instead of 7 months and so on (figure 17 and 18). The result presented in the Figure-17 and 18 shows a promising outcome of increased reliability using the "Cluster Approach Tank Sharing Model". It should be noted here though that the outcome presented here was based on two hypothetical scenarios. The result may vary depending on the hypothetical assumption and secondary data; however, it is fair to claim that as long as the hypothetical (input) data remain same, the result will always be consistent and

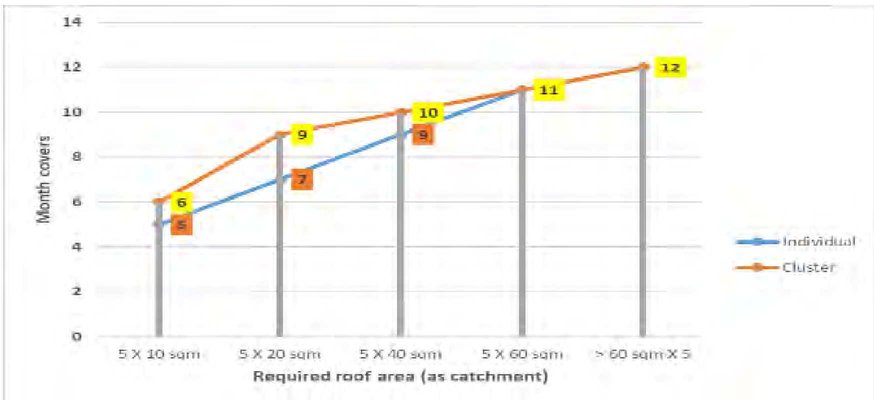


Figure 25: Required roof area for individual vs cluster

will be supporting the claim that, the proposed cluster approach tank sharing model RWHS system is more reliable than the conventional RWHS system.

As stated in section 4.2.4, the widely used mass balance equation has been used to calculate the optimum tank size for two separate hypothetical scenarios (refer to section 4.2.4). Under the first scenario, the result shows that for individual HH scenario with a population of 5 and average water demand of 10 lpcd throughout the year, the optimum tank size was found 6,130 L which has been rounded up to 6,500 L in this study. On the other hand, under the second scenario with a population of 25 (cluster = 5 HHs together) and average demand of 10 lpcd throughout the year, the optimum size was found 58,637 L which has been rounded up to 60,000 L. In both cases, the same rainfall data has been used as presented in Figure 10. In terms of roof area, average (10 sqm X 5 HH) = 50 sqm has been assumed for the first scenario whereas under the second scenario roof area has been calculated by: [(5 HHs X 10 sqm) + 20 sqm] = 70 sqm. The rationale and objective of adding this 20 sqm were to create the hypothetical scenario which has been explained under section 4.2.4.

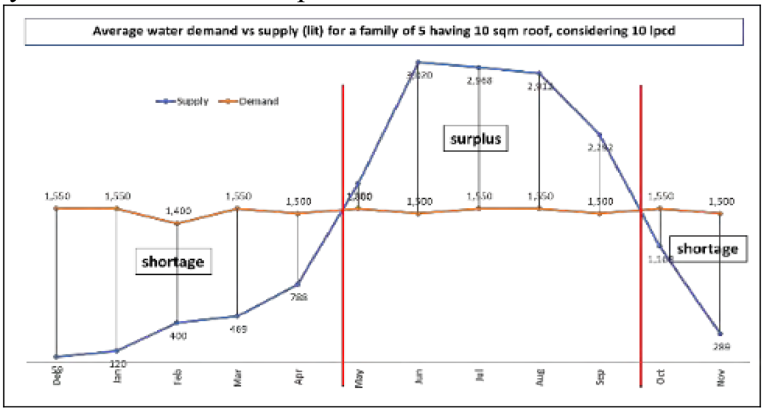


Figure 26: Average demand vs supply for a family of 5

As mentioned in section 4.2.4 the costing comparison presented in this study is based on the information from these 3 studies: (WaterAid Bangladesh, 2006); (Karim, 2010) and (Murase, 2020). The following table (Table-4) shows the costing information obtained from (WaterAid Bangladesh, 2006). As mentioned in section 3.3, the cost has been adjusted for cumulative inflation (2006-2020) using online inflation calculators from these websites: (Creatifwerks, 2021) and (World Data, 2021).

Table 5: Cost comparison

Type of RWHS	Capacity (L)	# of people served	Cost in BDT (2006)	Adjusted cost, BDT (2020)	Approx. adjusted cost ($)	Comment
Cement/ mortar jar	3,000	7-8	5,500	14,290- 15,103	167-176	HH level
Ferro-cement tank	3,200	9-10	6,500	16,888 -17,849	197-208	
Ferro-cement tank	4,600	13-14	9,300	24,163- 25,538	282-298	
RCC ring tank	2,500	6-7	4,800	12,471- 13,181	145-154	
Motka (earthen pot)	1,000	No info	600	1,559-1,648	18-19	
Underground RCC tank	10,000	30-35	20,000	51,963- 54,920	606-640	Community Level
Underground RCC tank	50,000	95-100	72,500	188,367- 199,085	2,196-2,321	

The costing information presented in Table-5 clearly shows that a 2,500 L RCC ring tank that can meet the demand of 6-7 people or close to 2 HHs would cost BDT 12-13 thousand which clearly projects that the optimum tank size identified in section 3.3 (6,500 L) would cost around BDT 20-22 thousand. If 5 separate HHs construct 5 separate tanks, the total cost would be close to BDT 100-120 thousand. However, this tank can provide water only for 2-3 months which makes this an unreliable and thus unpopular option, especially for the low-income group.

Table 5 also shows that a 50 thousand capacity underground tank would cost around 2 lac BDT which means if 5 HHs want to build this tank, they have to invest BDT 40 thousand each which is a better deal compared to constructing 5 separate tanks which would meet year-round water demand. An upfront investment of 40K BDT would be difficult for most low-income people. However, the government can provide different forms of subsidy in this case as they do for the tube-well. In addition, various social business models including long-term microfinance schemes, soft loans specific for constructing this type of large tank can be provided by the government as well as NGOs and private sector investors. Various types of loans and or direct and cross-subsidy options are already present in Bangladesh for other sectors such as solar electrification, biogas, improved cooking stove, and rural sanitation projects among others.

5.5 Findings and discussion: In-depth interview

As mentioned in section 4.2.3, a thematic analysis framework has been used to analyse the data obtained from the 6 in-depth interviews conducted with three categories of participants (detail in section 4.3). As clearly described in (Maguire & Delahunt, 2017) a theme grasps a common and recurring pattern that emerged across a large dataset that is clustered around the main concept. Thematic analysis is one of the widely used processes for data analysis and reporting within the qualitative research methodological spectrum (Braun & Clarke, 2006).

This is particularly useful to be used in the phenomenological research stream as this process provides enough flexibility to the researcher to present the participant's lived experience in recurrent patterns emerging from the in-depth interview (Cassol, et al., 2018). This process also provides room to present key concepts derived from the main themes as well as to show the similarities and relationships between and or among themes. In this study, the information obtained from the 6 in-depth interviews has been presented in Table-6 under 5 key categories (Financial, Institutional, Environmental, Technological, Social). Deductive data analysis (Kyngäs, et al., 2020) approach has been used in this case.

Table 6: Key Themes

Category	Themes and associated sub-themes	Discussion
Financial	Coping cost, poor pays more, limited financial support, capital investment, microfinance, cooperatives	"Coping cost" or cost of dealing with the adverse impacts of water scarcity (exp: buying water)/poor quality of water (exp: medical cost) is one of the frequently mentioned lived experiences shared by the participants. When asked what prevents people to eliminate coping costs, "high capital cost" was the most cited answer. All three stakeholder groups expressed their high interest in the "cluster approach design". However, the concern is also raised around "social cooperation and mindset" as this is the challenging part yet a must-have prerequisite for the success of cluster approach tank sharing model. Participants also frequently mentioned, "redirecting" resources from "tube-well" to "RWHS", especially by govt and NGOs. One of the participants said that "the cost of one deep tube-well is approx. 100 K BDT, yet it often does not provide adequate and good quality water throughout the year, and on top of this the risk of arsenic is there. I do not understand why Govt, and NGOs do not invest the same amount on cluster approach tank sharing RWHS which seems more reliable and safer".
Institutional	Lack of knowledge, lack of govt-support, strategic priority, lack of research, NGO support, Union Parishad, local government, long-term	Four out of six participants mentioned that RWHS has not been emphasized enough in the strategic and policy documents. Participants said that there is a huge gap in knowledge and acceptancy of RWHS in the govt. departments. It was also mentioned that some of these gaps may be a result of a system-wide "un-willing to promote RWHS" as it might pose a threat to the

Category	Themes and associated sub-themes	Discussion
		traditional water supply system. It was suggested that NGOs, local govt, and development partners should increase investment in RWHS, especially in R&D where different models can be developed and tested including the proposed "cluster approach tank sharing model".
Environmental	High and low rainfall, limited storage, saline water, cyclone, arsenic, diseases, women and girls, children, school, arsenic	All six participants contrasted the proposed "cluster approach tank sharing model" with other water supply systems, especially with the most common option i.e., tube-well. They have shared experiences that, given the presence of natural hazards and geophysical conditions (arsenic, salinity, etc) in the coastal area, a cluster approach tank sharing model would be a high potential alternative. However, the proposed model needs to be tested in different settings to understand it better. They also said that if successful, there will be a huge benefit, especially for women and girls that includes less water collection time and thus spending more time for other productive purposes. Guarantee for a year-round drinking water from RWHS will significantly reduce dependency on tube-wells and thus contributes to resolving arsenic-related hazards.
Technological	New technology, off-grid system, decentralized, tube-well, large tank, demo	Participants mentioned cluster approach tank sharing model RWHS as a promising alternative option in contrast to other traditional water supply systems. However, it needs piloting in different social settings before scaling up. This system also has a huge potential for building a completely off-grid water supply system like off-grid solar. Some participants expressed skepticism around the risk

Category	Themes and associated sub-themes	Discussion
		of water contamination because of the potential growth of bacteria inside the underground tank. "It's easy to clean small size aboveground tank but would be difficult to clean huge underground tank". Though they said this problem can be solved by providing necessary O&M training.
Social	Cooperation, relatives, tolerance, helping each other, poor people, social business, profit-making	"Though the proposed cluster approach tank sharing model RWHS system has a potential, it needs full social cooperation from the targeted people to be able to build and run this massive system". As the idea is new, it would also need a lot of investment to create social awareness. Though the idea of "social-business/ cooperatives" etc. is not new but using the same idea for building cluster approach tank sharing model RWHS would take a lot of resources. A recommendation made by a participant was to use existing organized groups such as microcredit groups, women groups, etc to test this concept for better understanding.

Chapter Six

Recommendations and Conclusion

6.1 Recommendations overview

Bangladesh has tremendous potential for scaling up the Rainwater Harvesting System given the average 2400-2600 mm annual rainfall. In general, at the community level, especially in the coastal region of Bangladesh people has good experience of using RWHS. Given the multiple extreme socioeconomic vulnerabilities, geophysical conditions, and muti-hazard disaster profiles, the coastal population is more susceptible to water scarcity. To deal with this water scarcity Rainwater Harvesting could be the best option in contrast to other traditional options. However, inadequate storage, mismanagement, lack of consistent and well-thought investment and promotion, technical issues such as water quality add significant limitations to the current state of rainwater harvesting in the coastal area. In addition, due to climatic and seasonal reasons, the rainfall is not equally distributed over all the months in a year. This creates a phenomenon i.e., "**too much and or too little rainfall".** That means, we need a RWHS which can store enough water when too much rain for the time when there is little to no rain.

"**Coping cost**" could reach up to 15% of the household's income (Amit & Sasidharan, 2019). Several studies in multiples countries including Bangladesh have clearly shown that the coping cost is much higher for non-piped water supply systems, especially for the low-income people living in informal settings like slums and rural areas where government-supported pipe water supply systems are not available. Coping cost varies across different seasons as claimed by several studies. It shows that coping cost is much higher during the dry season in contrast to the rainy season, which makes sense as during the rainy season people can use rainwater to some extent to cope with the shortage of water. Given this, it would be beneficial, especially for low-income communities living in multi-hazard prone settings to maximize the use of rainwater as much as possible. To do so, the proposed cluster approach tank sharing model can make a significant difference.

In the last few years, Bangladesh made tremendous progress in providing overall 97.4% access to drinking water. However, of which only 52.78% are classified as "Safely managed" and 44.62% under "Basic" as per the Joint Monitoring Program (JMP) definition (WHO and UNICEF, 2019). As per the JMP service ladder for drinking water, a source must be accessible on-premises, available when needed, and free from contamination to qualify as an "improved" source (UNICEF, 2020). Though by and large, the traditional RWHS meets "accessible on-premises” and “free from contamination” criteria, it does not meet the criteria for “available when needed” as the current design of the RWHS fails to provide adequate water for the year-round demand. In this context, a RWHS system with a large shared underground tank as proposed in this study will significantly increase its reliability to provide required water for a longer period of time, hence this type of RWHS can be classified as an “improved” source. Therefore, mass adoption of Cluster Approach Tank Sharing Model will significantly contribute to increasing the national share of “improved” drinking water sources and achieve SDG 6.1 target.

6.2 Specific recommendations

a) **Change in policy and regulatory level:** Given the findings from six in-depth interviews, it can be claimed with confidence that RWHS is still seen as a “seasonal” water supply option. This is further confirmed by the strategic document analysis done under section 2.1 (table 1) where it is found that RWHS is rarely mentioned in the strategic and policy documents. One of the reasons mentioned by the participants is that water supply in Bangladesh is still very much a centralized system dominated by traditional pipe water distribution network systems (in the urban) and tube-well (in the rural area). In fact, all our infrastructures, as well as the skill and knowledge base have been developed around the pipe water distribution network system and tube-well.

   However, given the huge gap in demand and supply as well as the gradual failure of tube-well, it’s time to change attitude towards rainwater. This process can start by incorporating and emphasizing use of rainwater at the Policy and Regulatory Level. In addition, a significant investment must be ensured for R&D on RWHS including the Cluster-based Design Approach.

b) **Change attitude towards rainwater:** Historically, tube-well has been glamorized as the “**magical solution**” for safe drinking water. This has shaped our perception and narratives only around tube-well. Contribution made by the tube-well technology in terms of providing critical access to safe drinking water is significant. However, eventually, it turned out to be not so “magical solution” since the discovery of arsenic contamination, water table depletion and salinity issue. Today the presence of excessive levels of arsenic and sodium is not only in the tube-well water but also entered the larger food chain system which is creating a serious public health issue. Because of over representation of tube-well and the easiness of the technology, other safe drinking water options such as Rainwater remain unexplored or did not get enough attention in the public domain. This attitude is clearly visible both in the government and the private sector practitioners as well as in the policy and strategic documents. Given this, it is very much important to change people's attitude and perception towards rainwater as an alternative. Both the government and the NGO and private sector practitioners should play critical role in reshaping public perception by investing in awareness and training at scale. Finally, both the electronic and print media also need to present rainwater as safe as tube-well water if not better in the contents they present related to safe drinking water.

c) **Increase investment in RWHS:** In FY 2017-2018, the GoB spent $ 0.8 billion in the Water and Sanitation sector of which 50% was public funding. The budget for FY 2020-2021 is estimated at $ 1.44 billion due to steady economic growth (Government of Bangladesh (GoB), 2020). Proper use and management of rainwater can save a huge amount of this national budget from the water supply-related expenditure. However, as the traditional pipe water and tube-well are the dominating options and all the water supply system infrastructures, skills, and workforce, especially in the government section have been built up around these options, promotion of RWHS may be seen as a barrier to this business as usual. To promote RWHS on a large scale, it is needed to have a dedicated policy, skilled workforce, implementation plan, and adequate resources.

In this situation, the Government may link up the promotion of RWHS to different climate change mitigation funding sources such as the Climate Change Trust Fund, and Bangladesh Climate Change Resilience Fund (BCCRF) among others. At the same time, it is also needed to increase investment at the household level for RWHS by providing subsidies in different forms (full, partial, cross, etc.) just like it is provided for tube-well installation, solar panel, and biogas plants. Investment in green and sustainable technology such as Rainwater will not only improve access to water but also will have a significant cross-sectoral impact on public health, food security, disaster preparedness, and community resilience.

d) **Institutionalize, Empower and Equip Rainwater Promotion Platforms:** In general, the awareness about rainwater in the public domain is limited. This is even worse among the young generation including students. A study done on 1,075 college students in Malaysia shows a low-level awareness score 3.28 out of 5) about the importance and use of rainwater in general (Tan, et al., 2017). The situation in Bangladesh is not much different than in Malaysia. However, a little has been done to improve this situation. WaterAid Bangladesh

(WAB) is one of the pioneers in promoting Rainwater in an organized and systematic way. This was done mainly by organizing and supporting various rainwater related training and seminars for practitioners in collaboration with the Institution of Engineers Bangladesh (IEB), Institute of Architects Bangladesh (IAB), Bangladesh Institute of Planners (BIP), Institute of Water Modeling (IWM) and International Training Network (ITN-BUET) (Hassan, et al., 2010). As a result of WAB's various initiatives over the last few years, a few key milestones were achieved including training to 142 professionals (between 2010-2014), construction of a number of demo RWHS in different Universities, and govt. premises, the establishment of RAiN Forum, Bangladesh, organizing a number of National Convention on Rainwater Harvesting (WaterAid, 2019), and influencing inclusion of a designated chapter in the Bangladesh National Building Code (BNBC) among others (Hassan, et al., 2010).

sHowever, for a good reason, most of these initiatives targeted and engaged a particular segment of the population who are academics, professionals, and practitioners from different NGOs and engineering institutes. This segment mainly acts on the supply side of the equation. Engagement of the mass population, especially children and youth including students is largely missing. It is highly recommended to expand and scale-up initiatives like the one by WAB to act on the demand side i.e., to create more demand for rainwater harvesting systems through mass awareness and engagement. In addition, a platform like RAiN Forum should be supported (both technical and financial) by the government with a vision to expand its activities at the grassroots level, especially targeting the mass population in the water-stressed areas such as the coastal belt.

e) **Increase Private Sector Investment in RWHS:** Between 2003-2018, 20 million people obtained connections from the Bangladesh Solar Home Systems (SHS) Program (Cabraal, et al., 2021). This project was led by IDCOL in partnership with the Bangladesh Rural Electrification Board (BREB) and 54 Partner Organizations including NGOs and Microfinance Institutions (MFIs). The project was able to connect 14% of the total population to the solar off-grid system. In addition, the government also achieved a national priority of replacing a substantial number of LED lights with more energy-efficient Compact Fluorescent Lights (CFLs). This is not the only success story of an off-grid system implemented in Bangladesh. There are many similar types of projects are being implemented mainly in the energy sector, particularly around solar, biogas improved cooking stoves which used different levels of cross-subsidy approach to promoting the technology. Unfortunately, there is no explicit and organized large-scale initiative taken for RWHS either by the government, private sector, or NGOs. Rather every year hundreds of millions are pouring into the traditional water resource management system which promotes groundwater-based centralized pipe water supply system. The promotion of technology such as solar, biogas and, Water Filter has been very successfully run by many NGOs, Social Enterprises, and Startups under the broader framework of the Social Business Model. Many of these are directly or indirectly subsidized by the government and development partners. In this context, it is strongly recommended to adopt the same social business model for promoting RWHS including Cluster Approach Tank Sharing Model at scale, especially in the coastal area where access to safe and adequate drinking water is a basic survival issue.

6.3 Further study

The proposed Cluster Approach Tank Sharing Model solution is global in nature. That means this approach can be adopted anywhere where there is adequate annual rainfall to meet the annual drinking water demand. In this context, it is highly replicable anywhere in the world. However, the idea of constructing a large underground common RW water tank following the "tank-sharing" approach or in other words adopting the cluster approach design is relatively new in the sector, especially in Bangladesh. This needs further in-depth study based on the actual model constructed, to be able to demonstrate whether it works in the real-world situation. If so, how much contribution this can make in terms of increasing reliability of the RWHS, and finally if this can be replicated at scale.

6.4 Conclusion

In recent years, Bangladesh is considered one of the fastest and most consistently growing economies in the Global South. In fact, in the last 10 years (2010-2020) GDP per capita has grown 2.5 folds from $ 781.15 to $ 1,961.61 (World Bank, 2022). However, this huge economic development comes with a huge toll, especially on ecological and natural resource bases such as the water resource. Even though the current household water demand is only 10% of the total freshwater demand, this is expected to dramatically increase by 200% by 2050 mainly because of economic growth spread across agriculture, service sector, and industrial sector (World Bank, 2020). To be able to cope with this demand it is paramount to look at this challenge carefully and find out more localized and context-specific ecologically and economically viable solutions such as increasing and optimizing the use of rainwater. This is particularly critical for the coastal belt given the existing socioeconomic and climatic vulnerabilities. It is estimated that half of the coastal population is already drinking water with an unacceptable level of salinity which creates serious public health concerns (Galiulin, et al., 2001); (Shammi, et al., 2019). Bangladesh is one of the top ten high rainfall receiving countries in the world receiving an average of 2400mm- 2600mm rainfall per year (CountryDetail.com, 2017) . This quantifies to approx. 200-250 billion m^3 per year where the annual basic water requirement for consumption is 160 billion m^3 (Amin, 2019). However, a significant portion of this rainfall goes back to the hydrological cycle. In this context, it's time to explore more ecologically and economically viable alternative approaches such as Cluster Approach Tank Sharing Model RWHS design that will free the water resource from its groundwater dependency and reduce national expenditure on water supply.

Given the population density, housing pattern, social cohesion, and cooperative mindset, Cluster Approach Tank Sharing Model will be an economically feasible, socially acceptable, and saleable solution, especially for the rural settings. It also fits the localities where there is no reliable energy source available as the system functions by gravity without any electricity of any kind. In addition to building the new RWHS, the proposed concept can also be used to modify the existing RWHS without much investment as the concept is very simple and does not need any complex mechanism to build. All the necessary accessories, fittings, and fixtures (PVC pipe, concrete, hand pump, etc) are very much available even in the remote communities in the coastal area. Also, the Operation & Maintenance (O&M) part of the system can be done by the local communities without requiring any skilled labour which ensures the long-term sustainability of the system.

The proposed Cluster Approach Tank Sharing Model also has the potential to be scaled up at a very large scale by building a local network of shared tanks in an off-grid fashion that can cover a large geographical area depending on the land terrain, closeness of the houses, and people's cooperative mindset. However, to be able to set up this kind of network, a skilled workforce may be needed as maintaining the gradient in the long connection network will be critical.

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Appendix-A: Questionnaire Simple Random Sampling Survey

Simple Random Sampling Survey

Khana Number

____

Name of HH Head

____

Husband/ Father Name

____

Family size

____

Age

____

Gender

- ◯ Male
- ◯ Female

Average monthly income range

- ◯ BDT 1-3000
- ◯ BDT 3001-5000
- ◯ BDT 5001-10000
- ◯ BDT 10001 & above

Do your family have access to adequate drinking water throughout the year?

- ◯ Yes
- ◯ No

What is your primary source for drinking water?

- ◯ Tube-well
- ◯ Pond, River, Canal
- ◯ RWHS
- ◯ PSF
- ◯ Bottled water
- ◯ Buy water from vendor
- ◯ Combination of multiple sources

If it is TW, has it been tested for arsenic?

- ◯ Yes
- ◯ No

Do you have a RWHS?

- ◯ Yes
- ◯ No

What type of RWHS Storage Tank do you have?

- ◯ Cement/ mortar jar
- ◯ Ferro-cement tank
- ◯ RCC ring tank
- ◯ Motka (earthen pot)
- ◯ Underground RCC tank
- ◯ PVC tank

Was your RWHS constructed by you?

- ◯ Yes
- ◯ No

If yes, how much did you spend for it?

- ◯ BDT 1-2000
- ◯ BDT 2001-5000
- ◯ BDT 5001-10000
- ◯ BDT more than 10000

If not, who constructed it?

- ◯ NGO
- ◯ Government
- ◯ Others

How many months it can provide enough water for your family?

- ◯ 1-2
- ◯ 2-3
- ◯ 3-4
- ◯ 4-5
- ◯ 5-6
- ◯ more than 6 months

What is the capacity of the RWH storage?

- ◯ Less than 500 L
- ◯ 500-1000 L
- ◯ 1000-3000 L
- ◯ 3000-5000 L
- ◯ 5000-7000L
- ◯ 7000-10000 L
- ◯ More than 10000 L

What is the main challenge about the RWHS you own?

- ◯ Maintenance is costly
- ◯ Storage is not enough
- ◯ Catchment area is not enough
- ◯ No challenge

What suggestion do you have to overcome the challenge?

- ◯ Increases alternative options: Tube-well, PSF, Pond etc
- ◯ Increase the storage capacity of the RWHS
- ◯ Increase catchment area

Do you need to buy drinking water?

- ◯ Yes
- ◯ No
- ◯ Sometime

If yes, how much do you spend in a year for buying drinking water?

- ◯ BDT 1-500
- ◯ BDT 500-1000
- ◯ BDT 1000-3000
- ◯ BDT 3000-5000
- ◯ BDT more than 5000

What is main challenge with your drinking water?

- ◯ Quality
- ◯ Quantity
- ◯ Both
- ◯ None