INTEGRATING ARCHITECTURE IN RAINWATER HARVESTING FOR CLIMATE AND DISASTER RESILIENCE IN COASTAL CITIES: A CASE STUDY OF COX'S BAZAR

By

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A thesis submitted to the Department of Architecture in partial fulfillment of the requirements for the degree of Master in Disaster Management

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Declaration

It is hereby declared that

1. The thesis submitted is my own original work while completing 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 which 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 entire study was conducted with an ethical competence and integrity, taking into account social, economic, and ecological effects in addition to legal requirements when making decisions and acting responsibly. The first and foremost, consent was taken from each community and individuals in the survey the study areas while conducting surveys. Firstly, the purpose of the study was explained to the participants of the survey.

Secondly, other actions such as taking photographs, recording with the respondent's answers occurred with the permission from the concerned persons. Throughout the data analysis and findings, each respondent was given a unique identification number, maintaining their anonymity throughout the study. There was no activity in the study which have reasonably been expected to be uncomfortable or at risk for participants.

The entire research process, from formulating the research questions to arriving at the study conclusions, is carried out impartially. The overall research design, data analysis and representation are carried out notwithstanding any bias and inclination.

Abstract

Water scarcity is crucial global challenge due to rapid urbanization, population explosion, climate change and global warming. As a result, creative and sustainable methods of managing water resources are essential to ensure availability of sustainable, clean water sources and to create disaster resilient community. Cox's Bazar is a renowned tourist hotspot located in the southeastern region of Bangladesh.

The main sources of water in the region are groundwater and surface water, both of which are encountering escalating difficulties. The excessive extraction of groundwater and the invasion of seawater, worsened by the increase in sea levels, have led to a notable problem known as salinity intrusion. The growing tourism sector exacerbates the pressure on freshwater resources, as the need for drinkable water rises due to the influx of tourists. Additionally, Cox's Bazar is situated in an area prone to seismic activity, which has led to worries about the possible risks of earthquakes, especially since there are a lot of Forcibly Displaced Myanmar Nationals (FDMN) living in refugee camps. Rainwater harvesting (RWH) has become a viable approach and alternative way to mitigate water scarcity, lessen reliance on conventional water sources and reduces future water scarcity.

This study aims to find the prospective architectural design areas that can improve rainwater harvesting and build resilient communities to climate change and natural disasters. The research is based on a mixed method approach, including two phases. The first phase is to understand the vulnerable community responses with rainwater harvesting concept. And the second phase includes several architectural project analyses to find out the potentiality of integrating architecture with rainwater harvesting practices.

The findings present that integrating rainwater harvesting into architectural design not only lessen the water needs but also helps to maintain the balance in urban water management system. Additionally, the study shows the adaptive design sectors can create resilience by reducing vulnerability to climate-related disasters. To lessen the negative effects of climate change and make coastal cities more adaptable so that urban sustainability, new approaches must be implemented.

Keywords: Rainwater harvesting, climate change, architecture, disaster resilience, coastal cities.

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List of Acronyms

SDG	Sustainable Development Goals
FDMN	Forcibly Displaced Myanmar Nationals
IPCC	Intergovernmental Panel on Climate Change
UNESCO	United Nations Educational, Scientific and Cultural Organization
WWAP	World Water Assessment Programme
WMO	World Meteorological Organization
AWG)	Atmospheric Water Generator
EJF	Environmental Justice Foundation
WASA	Water Supply and Sewerage Authority.
RWHS	rainwater harvesting system
BUET	Bangladesh University of Engineering and Technology
BNBC	Bangladesh National Building Code
UNICEF	United Nations Children's Fund
WHO	World Health Organization
AHO	Africa Health Organization
KII	Key Informant Interview
FGD	Focus Group Discussion

CHAPTER ONE
Statement of Problem

1.1 Introduction

Climate change, rapid urbanization, and population expansion endanger global, regional, and local water shortage. (Zabidi HA, 2020). Since water is essential to human life and development, water security can be defined as safeguarding human societies against the negative impacts of both excess and scarcity of the resource (Aramillo & Nazemi, 2018). The disparity in precipitation between the wet and dry seasons has become increasingly pronounced as a result of climate change. The arid season is becoming increasingly dry while the rainy season is becoming more wet. Global warming has led to an increase in the precipitation of snow and rain in the northern high latitudes (Douville, 2021). Water scarcity raised the risk on number of sectors, including agriculture, forestry, domestic, livestock and energy. Therefore, to address these problems, the enhancement of climate resilience as a strategy to adapt to climate change and achieving of the Sustainable Development Goals (SDGs) have been made feasible.

As per the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the condition within coastal areas would decline due to the steady increase in sea-level and the potential increase in frequency and intensity of extreme events by 2100. By 2050, it is projected that the global urban population would reach 1.693–2.373 billion, and a significant increase from the 933 million urban dwellers, which constituted one third of the population in 2016. (He et al, 2021).

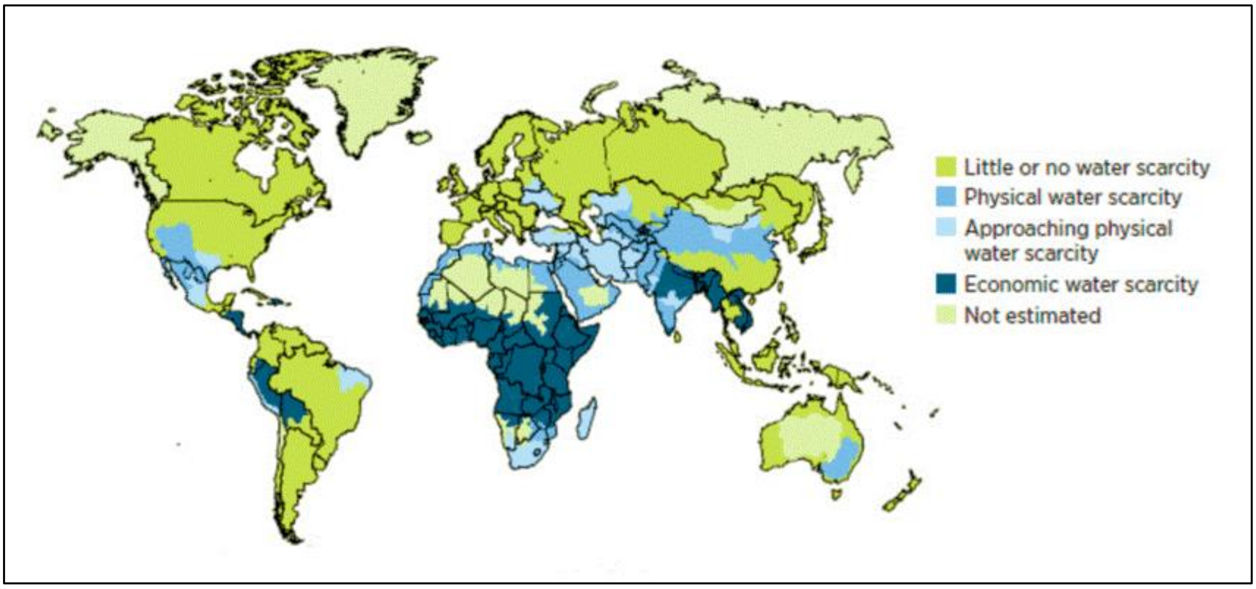


Figure 1: Water scarcity (World wide)

Source: World Water Development Report 4 (WWAP)

Less than 25% of freshwater supplies are used by people in many countries that don't have a water shortage, as shown in Figure 1. More than 75% of freshwater supplies are used for farming, manufacturing, and everyday living. (UNESCO, 2012). Therefore, it is urgent need to flourish good and sustainable practice in order to protect natural resources (Bini M, 2021). The lack of water continues to be a serious problem that affects millions of people worldwide, despite growing awareness of and adoption of sustainable practices worldwide.

Rainwater harvesting is one of the most effective and cost-effective method to address water scarcity in coastal cities (Zabidi HA, 2020). However, it is important to note that the vulnerabilities that arise are not just caused by climate change, but are also significantly impacted by the socioeconomic development and land management practices in urban areas. (Chen et al 2015; Hollis, 1975). Bangladesh is highly susceptible to the effects of climate change, mostly because of its geographical location, flat and low-lying terrain, dense population, high poverty rates, and inadequate health system infrastructure.

The Bangladesh Delta Plan 2100 (BDP 2100) categories 64 districts into six ecological zones according to their hydrological characteristics and vulnerability to climatic hazards. The primary objective of the Bangladesh Delta Plan 2100 is to tackle these difficulties by implementing sustainable water management practices, enhancing infrastructure development, and improving disaster preparedness measures in order to offset the adverse effects of salinity intrusion, water scarcity, and seismic events. There are two main areas of concern: urban areas with inadequate water, sanitation, and hygiene conditions, and coastal regions where the saline levels in natural drinking water sources are increasing (Raza, 2024).

1.2 Background

Water security is centered on protecting human societies against the negative impacts of both surplus and scarcity of water, given the importance of water to human existence and progress (Wheater and Gober, 2013, Wheater and Gober, 2015). The lack of safe drinking water affects more than 700 million people globally which is affecting more than 40% of people in the world. (Goals, 2022). Inadequate access to clean and dependable drinking water can result in desertification, compelled migration, starvation, illnesses, and internal or regional conflicts. According to World Meteorological Organization (WMO, 2021), Earth only has 0.5% usable and available water. However, climate change is affecting that supply. Extreme weather events are increasing the scarcity, unpredictability, and pollution of water.

According to climate scientists, Fluctuating temperatures can lead to increased flooding as the amount of rainfall exceeds the capacity of the soil and vegetation to absorb. Runoff, often known as surplus water, flows into nearby streams and transports pollution such as fertilizer and pesticide chemicals. Large water basins, such as lakes, estuaries, and the ocean, ultimately get an overflow of runoff, leading to water pollution and limited access for both ecosystems and individuals (Society, n.d.). The main contributors to water pollution in Cox's Bazar include untreated sewage and domestic waste, industrial effluents, agricultural runoff, and poorly managed solid waste. Furthermore, the pollution of local water bodies is greatly influenced by tourism activities, marine vessel emissions, building, and the existence of refugee camps. Substantial surface water is available for various purposes, reducing the need for underground water.

It is environmentally benign and does not produce pollutants. It is also cost effective and environment friendly because rainwater is largely devoid of salt and other impurities, it also contributes to the supply of drinkable water (Behzadian & Kapelan, 2015). Architecture has been always drawn attention to minimize the impact of human lives and properties in terms of developing strategies to design buildings and infrastructures. Starting from building materials and construction techniques, the location and elevation of a building and community planning, architecture plays crucial role to mitigate the disaster risk and vulnerabilities and to create a resilient city and community (Seo, 2023).

1.3 Water scarcity

The process of urbanization is rapidly increasing on a global scale. The global urban population increased from 0.8 billion (29.6%) in 1950 to 4.4 billion (56.2%) in 2020, and it is predictable to reach 6.7 billion (68.4%) by 2050, according to the United Nations (2018). (United Nations, 2018).

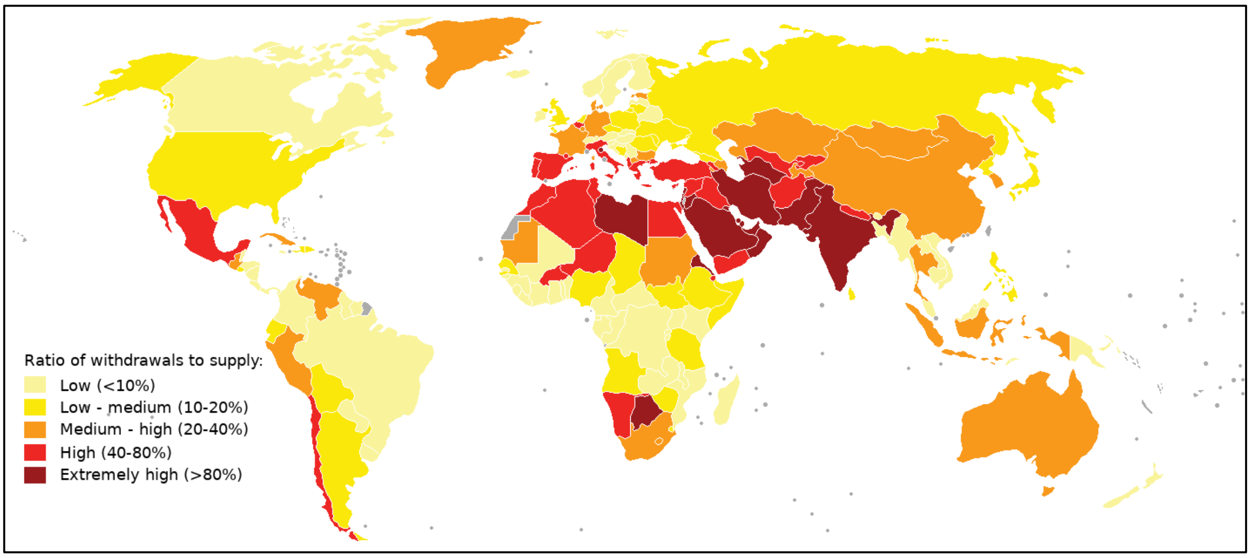


Figure 2: Water Stress by Country: 2040

Source: Kummu, M.; Guillaume, J. H. A.; de Moel, H.; Eisner, S.; Flörke, M.; Porkka, M.; Siebert, S.; Veldkamp, T. I. E.; Ward, P. J. (2016).

The term "water scarcity" refers to the situation in which there is not enough fresh water water resources available to satisfy the usual demand for water. This condition is strongly associated with water stress or crisis. There are various forms of water scarcity (Caretta, 2022). Physical water scarcity occurs when there is an insufficient amount of water to fulfil all demands, including the water necessary for ecosystems to operate. Arid areas, such as North Africa, West Asia, and Central Asia, often experience a scarcity of water (Rijsberman, 2006).

On the contrary, economic water scarcity arises due to insufficient financial resources for adopting the necessary technology or infrastructure to get water from aquifers, rivers, and other sources. Furthermore, this issue arises from our lack of capacity to satisfy the water demand (Caretta, 2022). In 2016, globally, 933 million urban dwellers, which accounted for 32.5% of the total, resided in places with limited water availability. Among them, 359 million (12.5%) experienced year-round water scarcity, while 573 million (20.0%) faced water scarcity during specific seasons (He et al, 2021).

1.4 Significance of research

Water availability is becoming more unpredictable in many areas. The scarcity of water due to droughts is having a negative impact on human health and productivity, putting biodiversity and sustainable development at risk on a worldwide scale. (UN, 2023).

The purpose of the research is to explore the potentiality of interacting architecture in rain water harvesting to ensure a climate and disaster resilient community of costal city. This study is conducted based on two perspectives:

- Climate and disaster resilient view and,
- Architectural design aesthetic view

Firstly, this study identifies the Potential of Rainwater Harvesting in unban coastal city context. Roughly 2.5 percent of the Earth's water resources consist of fresh water, despite the fact that global water consumption is growing at a rate twice due to population growth. Rainwater harvesting reduces rainwater runoff in highly urbanized areas also helps the demands on public water supply. Rainwater collection reduces costs associated with using urban water supply and promotes water conservation.

Secondly, the study reviews both international and local case studies focusing on rain water harvesting as a system to ensure integrating with architecture.

Therefore, the study can contribute to addressing Global Water Scarcity with achieving sustainable development goal (SDGs) no 6 and development goal no 11. Rainwater harvesting reduces rainwater runoff in highly urbanized areas also helps the demands on public water supply. Rainwater collection reduces costs associated with using urban water supply and promotes water conservation.

1. **Role of architecture in climate adaptation**

There various architectural contribution to climate adaptation reducing the negative effects from built environment and creating climate-responsive. There are options range from macro-level planning to detailed design of the building elements including building orientation, building form, roof shape, building elevation, building materials (Ahmed, 2009). Implementing rules and regulation on installing rainwater system by BNBC will advocate for the adoption of rainwater harvesting as a sustainable approach to water management ensuing that the design, construction, and maintenance of rainwater harvesting systems prioritize safety, efficacy, and environmental friendliness.

The Water Management Policy of Bangladesh highlights rainwater gathering as a viable and enduring water supply. It facilitates the adoption of systems in both urban and rural regions, incorporates systems into newly constructed structures, and provides support for retrofitting existing buildings. In general, the strategy aims to guarantee the long-term availability of water resources, tackle the problem of water scarcity, and respond effectively to the difficulties posed by climate change.

2. **Addressing for policy and practice**

The study will contribute to encourage climate-resilient, sustainable development in coastal cities by implementing urban planning and design policies, reviewing building codes and regulations that encourage the integration of rainwater harvesting systems into architectural designs and increasing capacity to assist legislators, urban planners, and architects in putting climate-resilient approaches into practice.

3. **Social and environmental impact**

The study's ultimate goal is to enhance the access to clean water supplies for coastal city individuals, minimizing the negative environmental effects of urbanization on coastal city and developing more inclusive, resilient urban communities for build back better (Sendai framework, 2015). Additionally, to emphasizes

1.5 Research questions

1. What is the place and importance of rainwater harvesting Bangladesh?
2. What is the acceptance rate among the local community people?
3. How can architectural design parameters can be effectively integrated to increase the potentially of rainwater harvesting capacity and adaptability in the coastal urban community to enhance resilience to climate change?

1.6 Research objectives

Objectives of this paper can be summarized as follow:

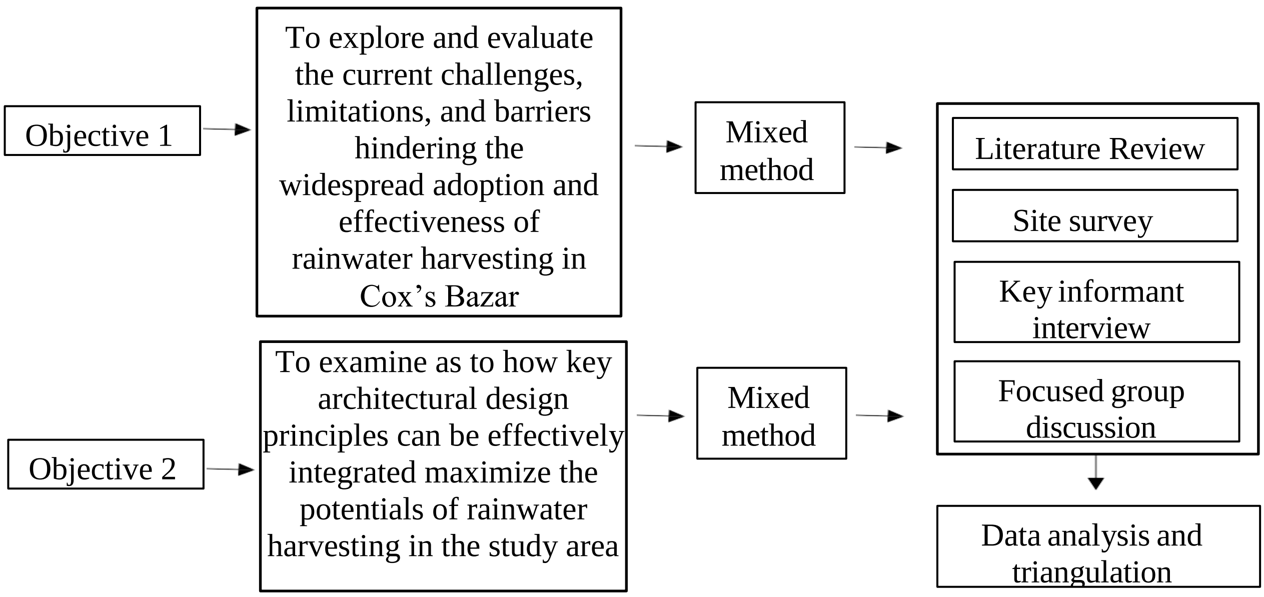
1. To explore and evaluate the current challenges, limitations, and barriers hindering the widespread adoption and effectiveness of rainwater harvesting in Cox's Bazar
2. To examine as to how key architectural design principles can be effectively integrated maximize the potentials of rainwater harvesting in the study area

1.7 Research methodology

This study is based on mixed-method approach including qualitative and quantitative techniques. The study is conducted by two phases. Firstly, analyzing of the architectural projects to find out the potentiality of interacting rainwater harvesting with architectural design by secondary data. Second phase carried out with quantitative data involved with field surveys and questionnaires focusing on acceptance rate of rainwater harvesting, implication feasibility, awareness rate among the locals and benefits of rainwater harvesting and qualitative data to draw general conclusions on existing buildings literatures survey which have integrated rainwater harvesting systems successfully. In-depth semi-structured interviews and Key Informant Interview (KII) is conducted using a close-ended questionnaire with architects and urban planners, and analysis of policy documents related to sustainable urban development and water management.

1.8 Study area

The study location is chosen at Cox's Bazar, which is located is sitting between 20°43' and 21°56' north latitudes and 91°50' and 92°23' east longitudes, one of the significant districts of 64 districts of Bangladesh. Its boundaries are the Naf River on the east, the Bay of Bengal on the west, the Bandarban District, Arakan (Myanmar), and the Chittagong District on the north, Bangladesh (Cox's Bazar District - Banglapedia. , (n.d.)).



According to the 2022 Bangladesh census, Cox's Bazar city had a population of 196,374. Nevertheless, Cox's Bazar has witnessed a substantial surge in tourism in recent years. Approximately 2 million tourists visit Cox's Bazar during the peak season, which lasts from October to April. It is projected that by the year 2030, the number of tourists visiting Cox's Bazar will reach a minimum of 15 million, according to the UDD 2011 report. The population of Cox's Bazar District itself consists of by internal residents who display diversity, comprising a significant number of indigenous Bangladeshis coexisting with the refugee community. The district of Cox's Bazar exhibits a combination of internal (local) and externals (migrant) inhabitants, both of whom play a role in shaping the area's population and economic characteristics. Here is a summary (United Nations Population Fund) (IFRC):

Internal residents		**External residents**
Bengali muslims	The majority of the people works in fishing, farming, tourism, and small businesses. There are many ways that Islamic traditions affect daily life and cultural activities.	Tourists
Indigenous communities	Rakhine are a minority group of people who have their own culture, language, and customs. In the past, they farmed, fished, and did some small-scale trade. The Chakma are another native group that lives mostly in the hills. They are known for their unique culture, which includes skills like weaving.	Rohingya Refugees
Local businesses and entrepreneurs	A significant number of residents operate hotels, restaurants, and retail establishments that specifically serve tourists. The fishing sector provides livelihoods for many families residing near the coastline.	Humanitarian Workers and NGOs

1.9 Rresearch design

Chapter one (Introduction): This chapter presents in-depth investigation of the global issue of water scarcity. Furthermore, it addressed the importance of the study and the objectives of the research.

Chapter two (Literature Review): A summary is done with related literature and the water resources study has been given. Then it talked about the gaps in knowledge on RWHS and its importance in the coastal cities. This chapter provided an organized investigating how architecture can be used as a tool to improve the use of rainwater harvesting systems. Furthermore, it has case studies from different sides of the world and standard guidelines.

Chapter three (Research Methodology): In Chapter 3, the research framework and methods are covered, along with the research questions, instruments and procedures, target population, sampling strategies, and criteria for choosing interview subjects. The chapter also gives an overview of the study area.

Chapter four (Findings and Analysis): Here, the main goal is to quickly present the most important results.

Chapter five (Discussion and Recommendation): This chapter discusses an overview of the findings of the study with major recommendations.

Chapter six - Conclusion: Finally, make the conclusion of the research.

CHAPTER TWO
Literature review

This this chapter will discuss about the definitions, methods and case studies of rainwater harvesting from a vast range of secondary sources- articles, studies and reports. The purpose of this chapter is to find out the knowledge of method of sustainable water practices through various context study. Furthermore, this chapter will discuss why sustainable water management has become important, and why coastal towns in particular need it. This chapter provides an organized framework for investigating how architecture might be used as a tool to improve the use of rainwater harvesting systems. In addition to discussing case studies, best practices, and recommendations for architects and urban planners.

2.1 Water resources and freshwater harvesting methods

Water is a renewable resource which is always present in the hydrologic cycle and constantly changing in quantity. Water is a fluid that encompasses 75% of the surface of Earth and is crucial on the origin, growth, prosperity, and propagation of all living organisms in the Biosphere. (Graham et al., 2010). Water serves various functions including drinking, cooking, food processing, industrial applications, agriculture, home uses, transportation, medicine, chemistry, heating and cooling, recreation, and fire suppression, among others. Ultimately, every item we consume, utilize, or generate requires the consumption of water.

Food (per piece)	**Water (liter)**		**Drink (per Cup or Glass)**	**Water (liter)**
Potato	25		Tea	35
Bread	40		Beer	75
Egg	135		Coffee	140
Hamburger	2400		Milk	200

Table 1: How Much Water is needed to Produce?

Source: (Based on the data by Food and Agriculture Organization, 2009; Leahy, 2014)

Different countries use water in various manners, mostly because of their level of development. In countries with low or middle incomes, agriculture uses the most water. In high-income countries, however, industry uses more water than farmland. "Water resources" refers to the volume of water that can be used for human needs. While saltwater can be used for energy production and transportation, freshwater is needed drinking, cooking, and cleaning, which account for a large portion of daily human consumption. Freshwater resources support 7.5 billion people while making up only 2.5% of the planet's total water (NASA; UNPD, 2018).

Based on the water presence are on Earth, water resources can be categorized into three groups: surface, ground, and atmospheric water. "Groundwater" is the freshwater that flows via aquifers beneath the water table and is found in the subsurface. Surface water in rocks and soil is periodically depleted by processes such as evapotranspiration, groundwater recharge, ocean discharge, and evaporation. However, this lost water is replenished through precipitation. 1.3% of the total freshwater supply is comprised of atmospheric water, which refers to water vapor present in the form of fog or clouds, accounting for 0.22% of the total freshwater. (NASA 2). The terms "water harvesting methods" refer to the several processes used to collect water from air, surface, or groundwater. Considering individual requirements, the climate, and the geographic location, the majority of settlements employed many techniques for gathering water. For example, collecting rainwater or floodwater for irrigation, and using rooftop or water wells for drinking. Understanding water collection techniques helps architects better connect with their surroundings and people (Beckers et al., 2013; 145).

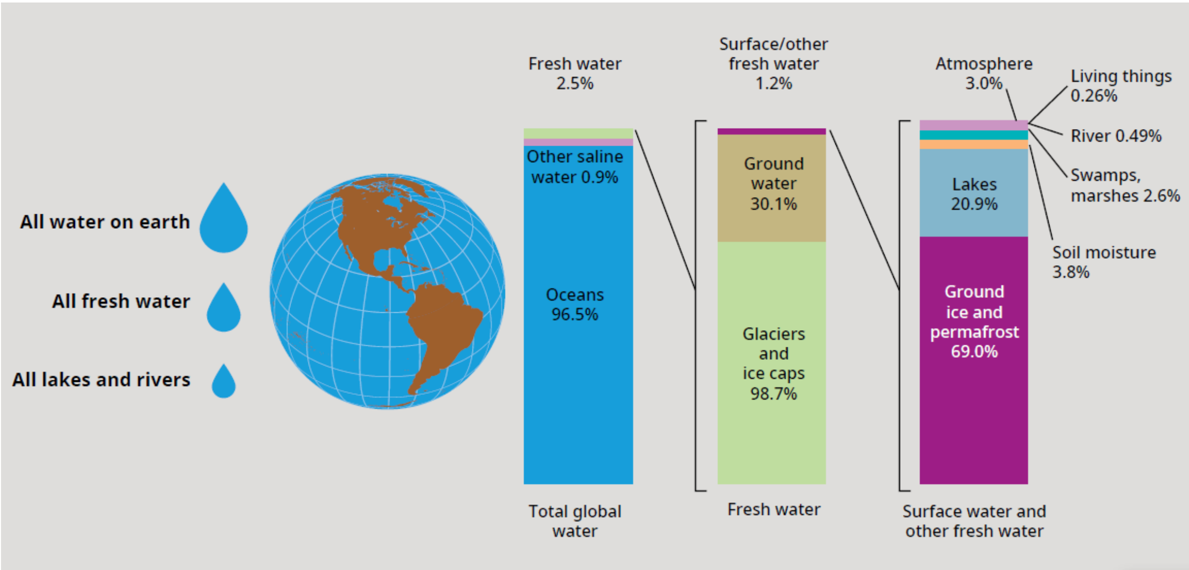


Figure 3: Distribution of Earth's Water

Source: https://www.usgs.gov

2.1.1 Groundwater harvesting

A water well is the type of structure that is the most fundamental and typical in terms of providing freshwater. The process of creating a well normally involves the following steps: (1) identifying the specific location of the water resource; (2) excavating the earth to reach the water level; (3) constructing supporting walls; and (4) pulling water with the assistance of devices that are placed on the top of the well. (Brikké and Bredero, 2003; 29-34). Another complex tunnel well system called "Qanat" which has a dense system of vertical tubes that link the underground system to the outer world. Qanats are found under different names but with the same principles of operation in Iran, Syria, Morocco, Spain, and Oman (Beckers et al., 2013; 149). The main method of accessing groundwater supplies in Cox's Bazar is through the use of tube wells and pump wells, which draw water from subsurface aquifers (UNDP).

2.1.2 Surface water

Surface rivers, streams, lakes, haors, natural fountains (chora), beels, and ponds comprise the water body (Banglapedia, n.d.).When the majority of precipitation that falls on populated areas either evapotranspiration into the sky or flows into rivers far from towns before it can be utilized. Rainwater may significantly increase the amount of freshwater that is accessible for human consumption if it is collected using the right infrastructure which is especially important in dry and semi-arid areas, where the little rainfall that does fall is typically quite heavy and irregular. Rainwater is gathered, accumulated, treated or purified, and stored for potential future use in surface runoff water harvesting. Other catchment areas from man-made surfaces, such roadways, or other urban settings, like parks, gardens, and sports grounds, may also be included. (Elliot et al 2011).

2.1.3 Atmospheric water

An atmospheric water generator (AWG) is a machine that creates drinkable water by drawing moisture out of humid surrounding air (Rao, Fix, Yang, & Warsinger, 2022). Water vapor from the atmosphere condenses on cold surfaces and reflect heat upwards to cool and condense into droplets of water known as dew. It is easily observable with thin or flat items. In a similar manner, fog—which is likewise composed of frozen or condensed water vapor—can be gathered using sizable vertical canvas pieces. The 2016 United Nations "Momentum for Change" award-winning project which gathers water from fog clouds for 140 days a year. It was launched in 2015 in Morocco, the pilot fog collection project collects 6000 liters of water per day to supply 500 people in five communities eight km distant with safe drinking water.

2.2 Water scarcity and impacts

2.2.1 Impacts on public health

The worldwide distribution of water-borne and water-related diseases is significant, resulting in a large number of annual deaths, particularly among children aged 5 and above. Bangladesh is similarly afflicted by these diseases, particularly in its coastal regions. Malnutrition, cholera, diarrhoea, organ damage and other water-borne illnesses can result from both insufficient and unsafe drinking water (Khan, et al., 2011).

2.2.2 Impacts on food security

In Bangladesh, 80% of freshwater is used for agriculture. Only 2% of the demand is currently met by the industrial and service sectors; that percentage is predicted to reach 40% by 2050. However, the amount of freshwater required for households now only makes up 10% of the total. Urbanization and population growth will lead to a projected 200% increase by 2050 (World Bank, 2020). According to the World Bank Group (2000), the groundwater table is shrinking constantly, as result it will also increase the food cost proportionately. Therefore, utilizing alternate water sources like rainwater for non-agricultural purposes, including drinking, will alleviate the strain on groundwater.

2.2.3 Impacts on migration

Climate change factors are expected to cause the migration of around 200 million people worldwide by the year 2050 (Mcdonnell, 2019). By 2050, one in seven Bangladeshis will be relocated by climate change in a matter of years, predicts EJF. Furthermore, 18 million people might face displacement as a result of sea level rise alone. Coastal communities are particularly susceptible, as they are subject to a variety of multi-hazard climate change phenomena. According to Environmental Justice Foundation (EJF, n.d.), the primary cause of this type of displacement is, among other things, the shortage of water for agriculture and drinking. Due to the dislocation caused by this climate, women and children are more vulnerable.

2.3 Rainwater harvesting system

Rainwater harvesting refers to the process of gathering and storing rainwater either on the surface or underground, in the soil or in reservoirs, for a variety of purposes and the water is consumed for drinking purposes and also utilized for watering plants in household and agricultural settings. Water catchment areas are typically categorized into four categories based on their size: farm systems (microsystems), roof systems (microsystems), valley floor systems (macro systems), and non-valley systems (microsystems) (Yetik & Şen, 2020). A suitable system is chosen depending on local water demand and climate. However, several studies show that roof rainwater collection is the most popular option (Yeniçeri, 2018) (Richards, et al., 2021) (Üstün, Can, & Küçük, 2020) (Eren, Aygün, Likos, & Dama, 2016).

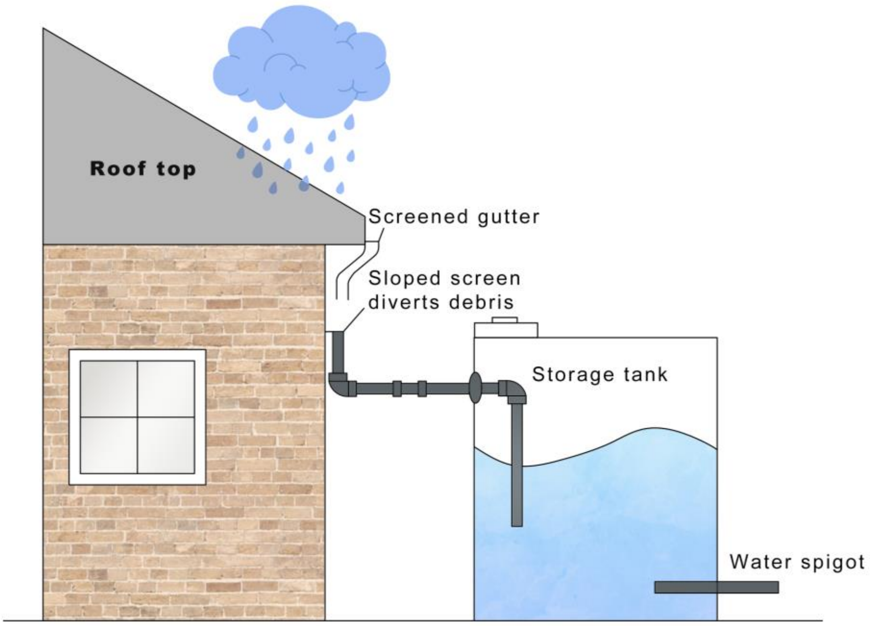


Figure 4: Rainwater Harvesting System

Source: Author (redraw)

In these systems, gutters help collect and move rainwater that falls on the roof's surface to water storage spaces. Rainwater is collected using two different techniques: underground storage and surface-level storage. Ground-level storage areas are elements like tanks, reservoirs, and ponds. For underground storing of collected water, soil and cisterns are used (Hacisalihoğlu, 2022).

2.3.1 Advantages of rainwater harvesting

There are many advantages of Rain harvesting. These advantages are as follows (Yeniçeri, 2018) (Richards, et al., 2021) (Üstün, Can, & Küçük, 2020) (Eren, Aygün, Likos, & Dama, 2016) :

1	Utilized as a supplementary water resource in areas with limited water availability and high demand.

2	Ensures the preservation and safeguarding of water resources.
3	Pure water for drinking.
4	Planting and landscape irrigation
5	Simple technology and inexpensive maintenance make it a cheap water management system.
6	Diminishes the need for both surface water and groundwater.
7	Installation can be situated in any location, irrespective of the topography, geology, or plans for managing infrastructure.
8	Prevents the negative impacts caused by infrastructure problems, such as drainage and flooding during heavy rainfall in urban areas.
9	Source for domestic use.
10	Flood mitigation during occasions of intense precipitation.

2.1.1 Rainwater harvesting goals

I. Prevent overuse of underground water

A community's need for water rises in tandem with its population. Water from below is used at this time. This is the reason why the subsurface water level is dropping quickly. Utilizing rainfall lessens the need for groundwater.

II. Increase the size of bodies of water

There are two distinct seasons, such as the wet and dry seasons, in many places of the world. There is either extremely little or no rain throughout the dry season. Ponds, rivers, and other bodies of water are dried up as a result. These approaches facilitate regeneration and development of water bodies (RK.Rourkela, 2010).

III. Minimizing soil erosion and flood

Rainfall is stored, which lessens surface runoff. This lowers the erosion of the surface. Flooding during heavy downpours is also lessened by collecting rainwater in reservoirs.

IV. Saving money

Underground water pumping is far more expensive than rainwater collection.

2.1.2 Design consideration of rainwater harvesting

In order to optimize the advantages of rainwater harvesting, the following considerations must be made before designing:

Rainfall: The planning and installation of the rainwater collecting system must take into account factors such as the rainfall patterns and the average annual precipitation rate in the specific geographical location of the building. A minimum average annual rainfall of 24 inches (600 mm) is necessary for rainwater to serve as the primary water source (Siegel, 2015).

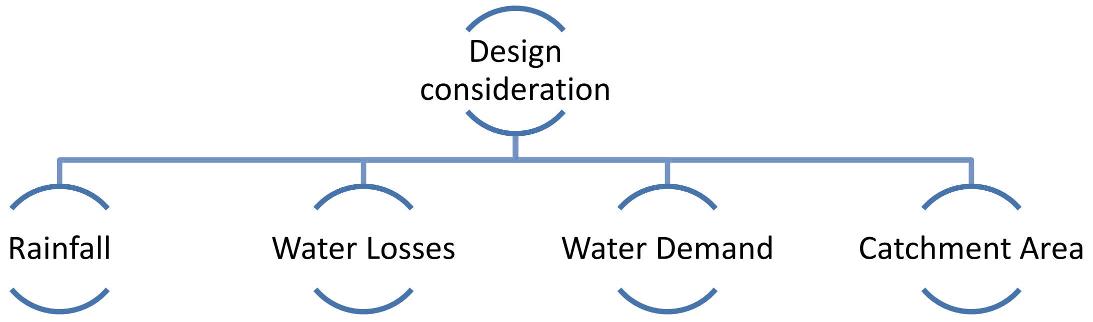


Figure 5: Design consideration of rain water harvesting

Water losses: In order to determine the quantity of water that can be collected, it is essential to calculate the losses generated due to evaporation and leaks across the entire system.

Water demand: The widely acknowledged average daily water demand per person is 190 liters, although it can range from 95 to 190 liters per day per person (Siegel, 2015).

Catchment area: The surface area of the roof that is immediately exposed to rainfall is crucial in order to get an appropriate size for efficient water collecting (Siegel, 2015).

2.2 History of rain harvesting

The practice of collecting and storing water has been practiced since ancient times in many parts of the world (Oweis, Prinz, & Hachum, 2001). The earliest known evidence indicates that Egypt has been using 200–2000 m3 tanks continuously for approximately 2000 years. Asia has a long history of using this technique as well. Water gathering techniques date back over two millennia in Thailand. Roof canopies or earthen pots with basic channels have been used in Africa and Asia for thousands of years to capture rainwater.

Palestinian farmers have long built stone terraces to conserve soil water structures, increase soil organic matter by minimizing runoff and soil erosion, and mitigate severe rainfall (Abu Hammad, Borresen, & Haugen, 2006). Under the Ottoman Empire (1669–1898), fountains and baths were very popular, and water was supplied by massive hydraulic facilities Because of the importance of water to Muslims. Several places show that humans have collected and stored rainwater since prehistoric times for irrigation and cattle rearing. Throughout history, rainwater has been the main supply of potable and non-potable water. Hence, gathering rainwater is essential to human survival (Yannopoulos, Giannopoulou, & Kaiafa-Saropoulou, 2019).

2.2.1 Mediterranean islands

The majority of the islands in the Aegean are known for having limited water supplies. Santorini (located in Greece) is a volcanic island that doesn't have any hidden water sources. For a very long time, the people have beesn collecting rainwater and building methods to store it. Not only do people collect rainwater in their own homes, but public places like theaters and churches also do it.

Figure 6: Rainwater Harvesting in Palace of Phaistos (Mays, 2012), an open yard to collect the runoff water is shown on the left, and a special cistern with a sandy filter is shown on the right.

Cisterns of different sizes were used to gather water from flat or vaulted roofs, patios, and verandas, among other built surfaces. In point of fact, rainwater collection dates back to the Minoan era, which occurred approximately between 3200 and 1100 BC, and it is being done today in specific rural parts of the island of Crete. According to Antoniou et al. (2014): 681

2.4.2 Roman house

An 'impluvium' was an integral element of a conventional Roman dwelling, known as a 'domus'. The

Figure 7: A Roman House (Coulbois)

pool was rectangular in shape and linked to a cistern, serving the function of gathering rainwater. The entire structure operated in tandem with an external component called the 'compluvium', which comprised of inward-sloping roof surfaces specifically designed to direct rainfall into the impluvium pool. The layout was first conceived in Italy during the second century BC and later became an established feature of Roman houses from that time period (Papaioannou, 2007).

2.4.3 Venice

Due to the geographical location, Venice relies exclusively on rainwater as its primary source of freshwater. As a result, the local residents established a communal cistern system (Figure 7) throughout the region. This system collects rainwater from the streets, transports it through manholes, purifies it using sand filters, and stores it in subterranean reservoirs. So, the water supply can be kept up in all the neighborhoods of the crowded city. [Figure 8].

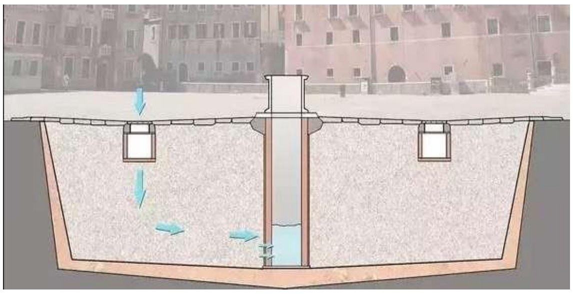


Figure 8: Underground tanks

Figure 9: Rainwater Cisterns of Venice (hometimes.com, 2016)

2.3 Components of rainwater harvesting system

There are three primary types of components that collectively make up a rain harvesting system:

1. **Collection system:** Rainwater harvesting systems have roof-surface and land-surface catchments. (Shakya & Thanju, 2013). Land surface harvesting is a relatively straightforward method of collecting water from building systems, such as paved areas (terraced, roadways and courtyards), without the need for a significant investment of money or expertise. A harvesting site is also established or constructed when floodwater from the ground's top reaches a stream bed. Bare soil, pastures, cultivated land, rocky areas with compacted surfaces, natural slopes, and uncultivated areas are all examples of unpaved areas (Gould, 2015). The roofing collection system involves a conventional method for collecting rainwater from the roof's surface utilizing a range of components, including corrugated and galvanized sheet metal that is connected to the storage system (Shakya & Thanju, 2013). Location, size, and roof material effect water collection amount and quality (Pradhan, 2019).

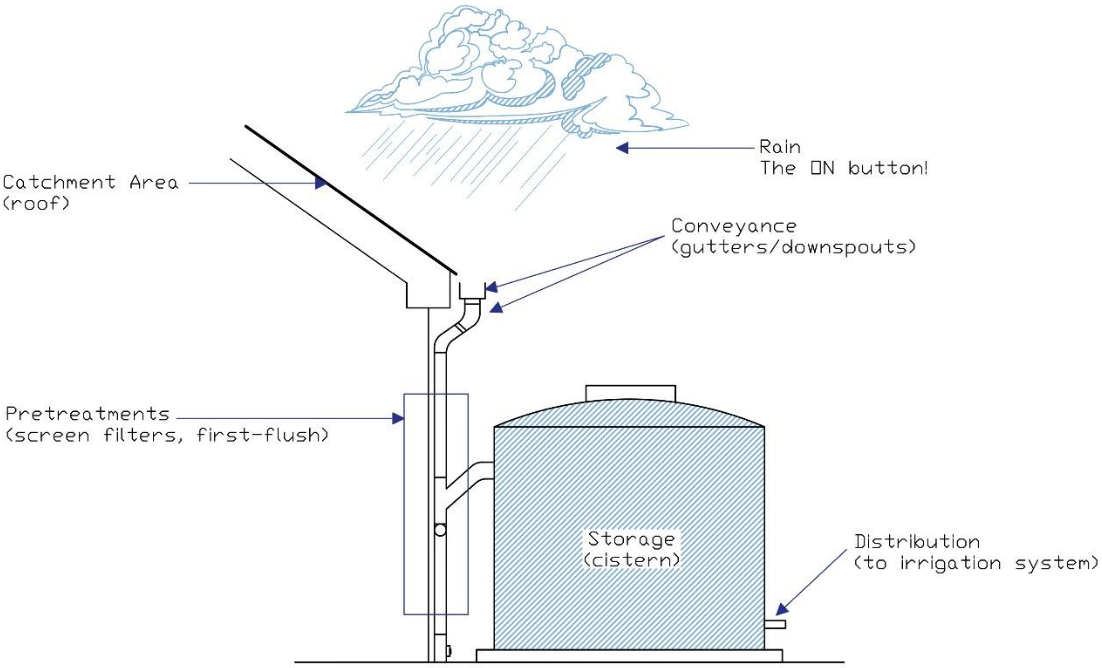


Figure 10: Components of rainwater harvesting

Source: source: https://slideplayer.com/slide/9100121/

Redraw: Author

1. **Transportation system:** The material of the water conveyance system, which is intended to move rain water from the receiving area to the storage area, is dependent upon the collection process; its elements can be made of polyvinyl chloride, galvanized iron or, RFL pipe. For instance, in a roof collecting system, the water is conveyed to subterranean storage through ditches and canals in residential conveyance systems (Shakya & Thanju, 2013). After rainwater is collected in rainwater harvesting systems, it is transported via transportation systems, filtered or unfiltered as needed, loaded into storage vehicles, and kept at these locations (Singh, 1992).
2. **Storage system:** A tank or subterranean storage facility can hold harvested water. This storage method is the last in water harvesting strategies, and the reservoir is the most essential component due to its high cost. (Shakya & Thanju, 2013) . The intended function of rainwater determines tank type, size, and location. To calculate the tank's capacity, consider the projected monthly water demand, using location, average monthly precipitation total, and collection area size (Stringer, Vogel, Lay, & Nask, 2017).

Stages	Components
Collection	Roof top
	Terraces & Balconies spaces
	Pavement
Conveyance	Drainage channel
	Downspouts
	Passage pipe
Storage	Pre-storage screens
	Tanks, cisterns, reservoirs
	Overflow drainage pipes
Management	Sand strainers
Distribution	Thrust
	Distribution channels

Table 2: Components of Rainwater Harvesting (table by Nazli, 2018)

2.6 Rainwater harvesting and architecture

The current century has seen an alarming pace of consumption of water resources because of global warming, pollution, climate change, and the world population's exponential rise (low in Europe, high in Asia). Because of this, environmentally friendly techniques for gathering water have emerged as a key area of current research (Aslan, 2022). Architects may be key players in encouraging sustainable water resource management by designing buildings with rainwater harvesting systems (Charlesworth, 2014). A city system is made up of several minor systems, such as the transportation system, buildings, industries, and municipal infrastructure. As a sustainable approach to water management, rainwater capture in architecture refers to the process of creating structures and landscapes that collect and repurpose rainfall. This can lessen the strain on municipal water supplies, cut down on water use, and lessen the negative environmental effects of storm water runoff. This environmentally friendly method promotes eco-friendly development and helps with conservation (Brears, 2023).

2.6.1 Rainwater harvesting design strategies

Integrating design parameters for architecture for water-efficiency helps not only to reduce the water consumption but also create cost efficient building. Using passive deign principles in architecture allows to reduce the energy consumption and livable environment (Syauqi, 2023).Detailed exploration of architectural design strategies that facilitate rainwater harvesting:

Roof design: roofs are the most significant architectural feature to harvest rain water.

Roof pitch which is also known as slope, is the roof's angle with respect to the ground.

The main purpose of pitching a roof is to redirect wind and precipitation, whether in the form of rain or snow.

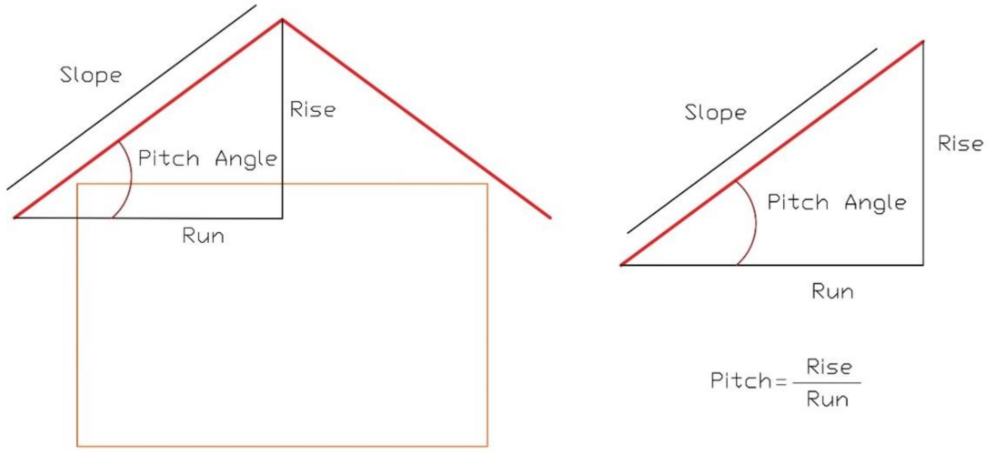


Figure 11: Roof Slop Angel

Source: https://roofvents.com/roof-pitch/

Materials: material plays also very crucial role for rain water harvesting. Common materials are cement concrete, tiles, CI/metal sheet, straw with or without polythene.

Such roof coverings are appropriate for use as rainwater catchments. (Kamal Ziaul Islam, 2014).

- Gutters and downspouts: Design considerations for efficient conveyance of rainwater.
- Storage solutions: Integration of rainwater storage tanks or cisterns into building design.
- Filtration and treatment: Incorporating filtration and treatment systems within the building envelope.
- Distribution: Designing distribution networks to efficiently utilize harvested rainwater for various purposes.

2.7 Case studies (urban and architecture) contemporary use

2.7.1 Primary Healthcare Center, Dharmapuri, India

	Overview
Architects	Rajesh Renganathan, Iype Chacko
Year:	2011
Location	India (Southern part)

The project 'Primary Healthcare Centre' is situated in Dharmapuri, situated in Southern India characterized by an extremely hot semi-arid climate. (Lafarge Holcim Foundation, 2012). The objective was creating an innovative prototype green modern building (inspired by traditional architectural elements like the protective "verandah") to inspire the local building construction

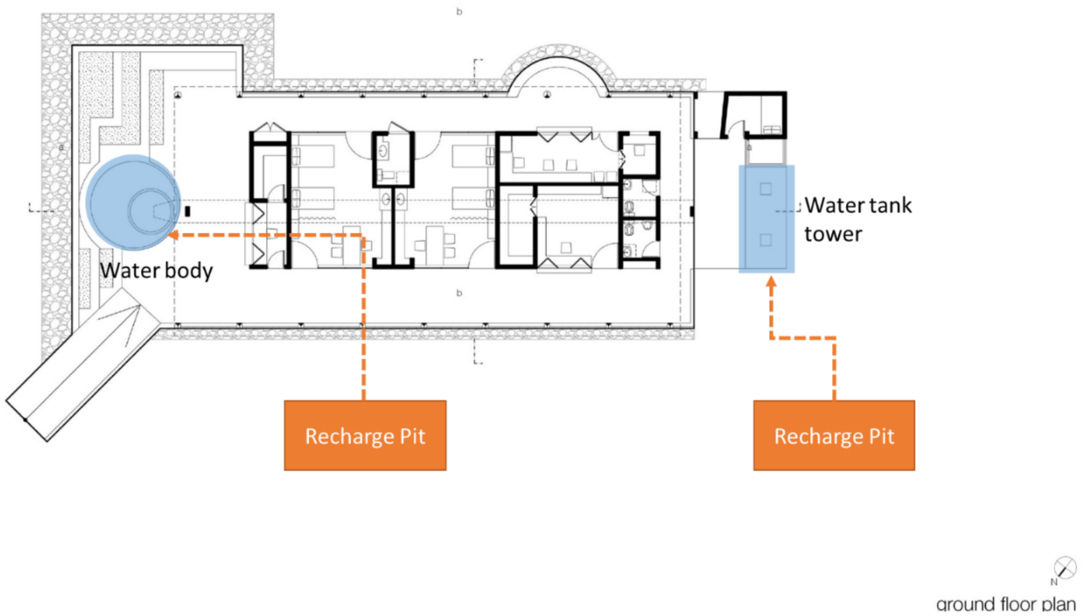


Figure 12: Ground floor plan analysis (Primary Healthcare Center, Dharmapuri, India) by author

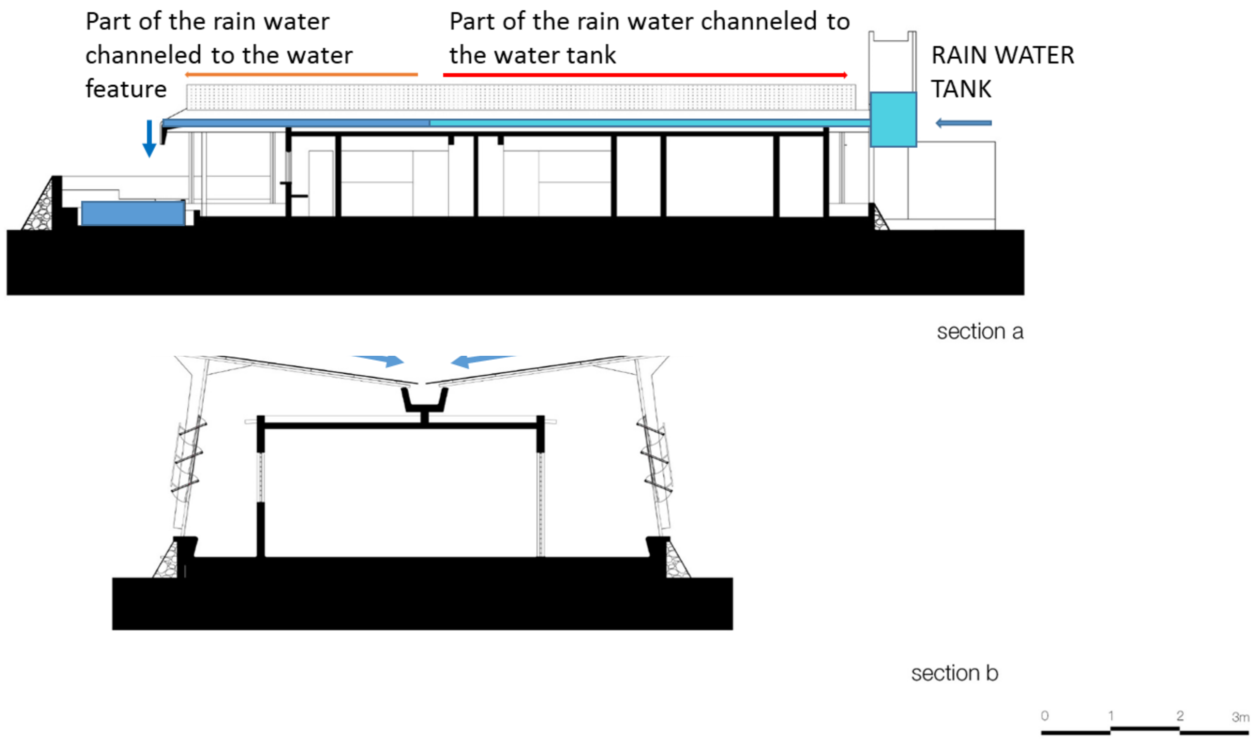


Figure 13: Section analysis (Ground floor plan analysis (Primary Healthcare Center, Dharmapuri, India) by author

system. By the lightweight corrugated galvanised steel and shade roof rainwater is directed into the central concrete gutter. (center, n.d.).

Dual-skin buildings regulate the atmosphere of clinics. The illuminating effect created by the outer roof prevents the inside roof from being extremely hot, while the envelope panels may be adjusted to either open or close, depending on the need for climate control within the interior. The outer roof, including a prominent central gutter along the roof valley, efficiently collects rainfall and directs it into a collection pond, symbolizing the practice of rainwater harvesting in architecture.

2.7.2 Bullitt Center

Overview

Architects	Miller Hull Partnership
Area:	50,000 SF
Year:	2013
Location	Capitol Hill, Seattle, Washington.

The Bullitt Center known as the 'World's Greenest Commercial'. The office structure, spanning six stories and covering an area of 50,000 square feet, was architecturally crafted by Miller Hull Partnership. This build is well distinguished because of its sustainable features. It passes toxicological checks, generates more electricity than it uses, and recycles rainwater for all on-site needs. The concept was to design which is meant to related the natural environment, self-sustaining and contributing to its surroundings**.** It collects rainwater and stores it in a 56,000-gallon cistern for filtering and disinfecting. The roof serves as both a rainwater collection system and a solar panel array. It is consisting of 575 panels spanning 14,000 square feet which resembling a tree canopy above the property (Porada, 2023).

Figure 14: Bullitt Center

Source: Bullitt Center Website, New York Times

2.7.3 2017 Serpentine Pavilion, London, UK

	Overview
Architectural team:	Blake Villwock (Project Architect), Adriana Arteaga, Greta Nina Tescari, Andrea Maretto, Jaime Herraiz Martinez, Damien Greder, Valeria Molinari, Johanna Lehmann, Laura Bornet
Project Leader:	Julie Burnell, Serpentine Galleries
Project Curators:	Melissa Blanchflower (Curators), Amira Gad (Curators), Joseph Constable (Assistant Curator)
Location:	Kensington Gardens, London, UK
Building area	330 m²
Design & planning phase:	October 2016 – April 2017

The Serpentine Gallery Pavilion is built as temporary structure which was constructed in 2017 with area of 300 m^2. The pavilion was in Kensington Gardens, London, UK. The conceptual idea was to use a tree as a center point fostering a connection between individuals and the natural world. (Kéré Architecture) [Figure 15]. The concept was influenced by a tree or a canopy of trees that functions as a central meeting point in the architect's hometown of Gando, Burkina Faso. Design considerations were made with a traditional perspective, which included an open-air courtyard at the center. This courtyard was designed to store rainfall from the funneled-formed roof, thereby generating a waterfall effect. Additionally, the roof of the pavilion serves as a shade structure during the day and turns into an illumination source at night (Designboom., 2017).

Figure 15: Night View

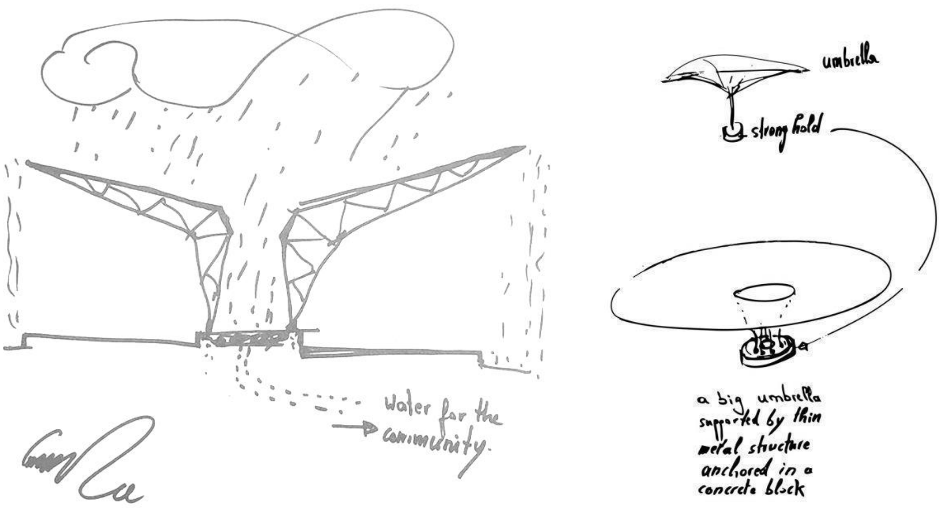


Figure 16: Conceptual sketches (Kéré Architecture)

2.7.4 Olympic Golf Course, Brazil

Architects	**RUA Arquitetos**
Area:	6400 m²
Year:	2015
Location	Brazil

The Rio 2016 Olympic Games golf site in Barra da Tijuca was designed by Brazilian Rua Arquitetos. The project's strategy and design were to reduce water use in humid climates (Rua Arquitetos: Évora + Rivera). To achieve this purpose, the architects used canopy surfaces to collect rainwater and shade indoor and outdoor spaces. The subterranean storage tank is used for golf course irrigation and visual and thermal comfort. [Figure 17]

Figure 17: Olympic Golf Course

Source: www.dezeen.com/2016/06/16/rua-arquitetos-golf-course-rio-2016-olympicgames-brazil

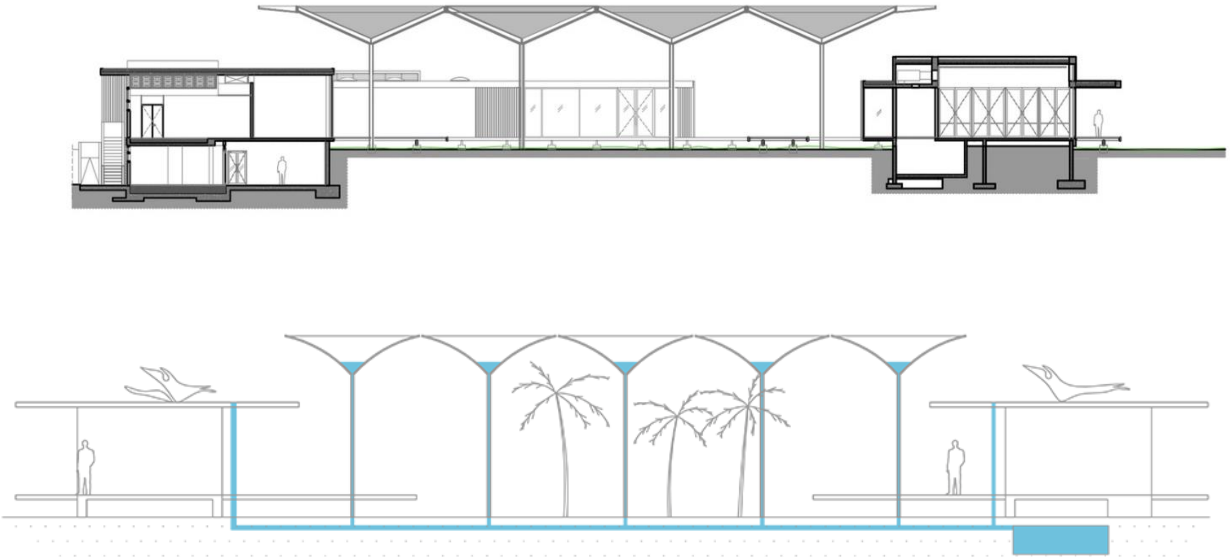


Figure 18: Section analysis

Source: www.dezeen.com/2016/06/16/rua-arquitetos-golf-course-rio-2016-olympicgames-brazil

2.7.5 Sustainable Market Square, Casablanca, Morocco

Overview

Architects	Tom David Architecten
Year:	2012
Location	Morocco

The design includes a 790m2 market for meat, seafood, shellfish, fruit, veggies, flowers, and spices, as well as cafes and newspaper kiosks. (Tom David Architecten) [Figure 19]. The project combined the indigenous and local techniques for shelter and heat control and deigned with and innovative low-maintenance materials.

The petal-shaped structure not only provides shades but also helps to collect rain water with vast area for cleaning and toilet flushing in underground tanks. Additionally, air circulation is made possible by the canopy's overlapping leaves which also ensures rainfall drains naturally. [Figure 20].

Figure 19: Sustainable Market Square, Casablanca, Morocco

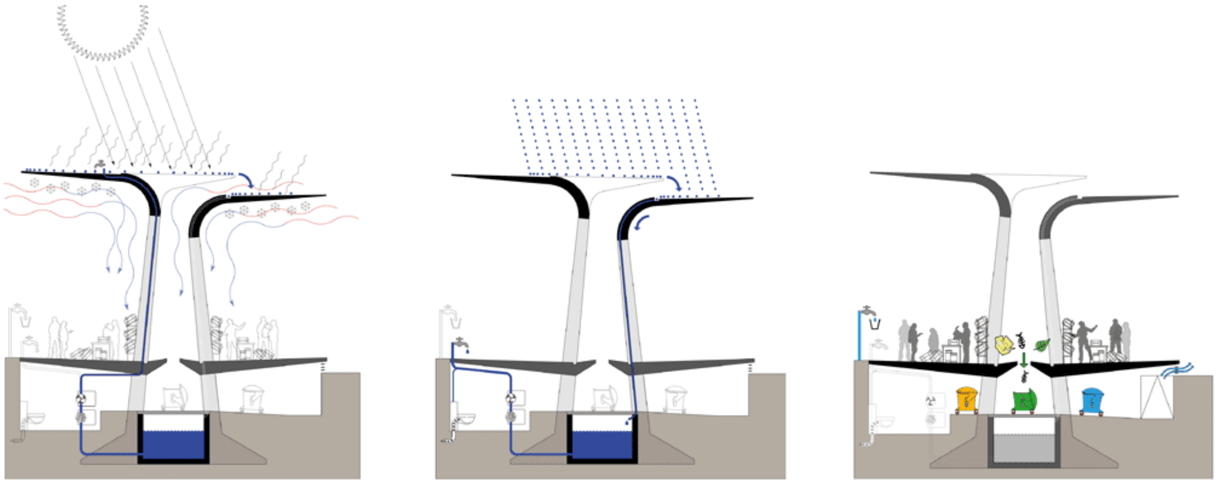


Figure 20: Section of Market Square Pavilion (dezeen)

2.7.6 Panchsheel Cooperative Group Housing Society

The Panchsheel Cooperative Group Housing Society, situated in Punjab, India, has successfully implemented a rainwater harvesting initiative, effectively collecting and utilizing every raindrop.

Total rooftop	3,57,150 sqm
Total volume (rainwater harvested)	1,74,575 cubic meter (m3), or 174,575,000 liters (2002)

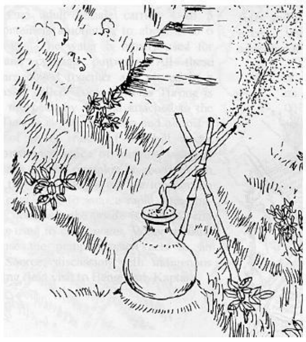
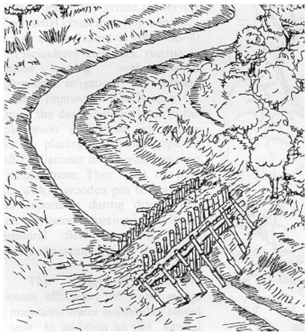
Figure 21: Masterplan

The project has the capacity to harvest of eighty percent of the total possible water collection capacity. Approximately over 28 meters under the ground level was the level prior to the implementation of rainwater harvesting system. In September 2002, the water level measured 26.1 meters, and in May 2003, it reached 27.6 meters. After the monsoon season, the water level in July 2003 reached 27.3 meters, which is an increase of 0.7 meters or 2.29 feet. (system., n.d.).

2.8 Rainwater harvesting practice in Bangladesh

In Bangladesh, rainwater collection is practiced almost everywhere on small scale. Mymensingh and Sylhet districts, located in the northeast are mostly use large-scale storage facilities. In Bangladesh's coastal regions, the majority of traditional rainwater gathering techniques are in use. There are roughly 52 native harvesting techniques that the tribe has used. Table 5 lists a few regional harvesting systems along with their intended uses

Water that is gathered for drinking and other household uses is frequently stored in the reservoirs at Jhurjhuri, Phour, and Thagalok-Kum. A sandy rock structure is called Jhurjhuri has a well built into it where water is collected. The water that is held in a Jhurijhuri is crystal clear due to the natural filtration that occurs through earth formations. Phour is a sort of local water pond designed to suit family demands in a small neighbourhood. These ponds average 7-8 square meters (Kabir & Faisal, n.d.). Natural vegetation, fish culture, and duckling raising are some of the irrigation uses for cross dams. In the space between two hills, they cross perennial creeks. There is a type of cross dam between Godha and Thelyathok. To make advantage of water during the dry season, they are constructed across a tiny hill creek. The water that Godha stores is put to use for both farming and domestic uses (Kabir & Faisal (n.d)).

Local System	Purposes	
Jhurjhuri, Earthen Motka	**Household**	
Cross dam, Retention ponds	**Irrigation**	
Godha, Thelyathok	**Multipurpose (Household, irrigation, navigation)**	

2.9 Coastal city and water problem

Major global urban areas coastline districts are at danger of being submerged by rising sea levels. Providing access to safe drinking water security is one of the biggest difficulties facing modern global development. Almost two billion people are presently exposed to unimproved water sources (WHO & UNICEF, 2017). About 2 billion people across the globe do not have access to clean water for drinking, as stated in the SDG report 2022. Around half of the world's population experiences severe water scarcity for part of the year, according to the IPCC. These figures will most certainly become worse as a result of both population expansion and climate change (WMO). Sea level rise will threaten all coastal cities, but some more than others. Especially Asian cities will suffer. Sea level rise will affect four in every five East and South East Asians by 2050 (Forum., 2020,) .

According to IPCC, it is predicted that sea level rise will accelerate groundwater salinization which will reduce freshwater supplies for coastal ecosystems and people. More than 90 US coastal cities are flooded, and the number is expected to double by 2030. Africa is threatened by coastal urbanization and destitute populations in informal settlements. Delta towns including Dhaka, Guangzhou, Ho Chi Minh City, Hong Kong, Manila, Melbourne, Miami, New Orleans, New York, Rotterdam, Tokyo, and Venice, home to over 340 million people, are already suffering from sea levels rising (Forum., 2020,).

2.10 Bangladesh and water problem

Salinity refers to the amount or percentage of salt in either water or soil. It is expressed as ppt, or parts per thousand. The process of salinity is caused by the intrusion of salt water, which is the movement of salt water from the sea to land (Gain et al., 2014). Since saltwater water has more pressure than freshwater, it constantly moves inland beneath it (Duan, 2016).. 80% of Bangladesh is a floodplain, which only slightly elevated above sea level. According to CCC (2016), the average elevation of the coastal zones in the southeast is 4-5 m, whereas that in the southwest is 1-2 m. Bangladesh is one of the world's most disaster-prone and naturally hazardous areas. The infiltration of saline water into the interior is also caused by a variety of natural hazards and disasters such as tidal inundation, storm surge, and cyclones, etc. Bangladesh has seen several significant cyclones, among them the Bhola Cyclone in 1970 and the Bangladesh Cyclone in 1991 was major (Ali, 1996). Saline water infiltrates agricultural land, ponds, canals, and rivers in the coastal zone, which continue to be impacted by the presence of saline water following hurricanes Sidr (2007) and Aila (2009). People are still experiencing the adverse effects of the coastal zone problem (Mahmuduzzaman et al., 2014).

2.8.1 Agriculture and water salinity

Because of salt fixation in the roots, saline water inhibits plant growth and throws off the balance of nutrients. Hence, agricultural production decreases with time. As a result, production costs are rising and there is a loss of productivity. The Pakshi Paper Mill in north Khulna closed in 1993 because to seawater intrusion. (Mirza, 1998).

2.8.2 Water salinity and health issues

According to the Environment Conservation Rules, the acceptable range of chloride in drinking water in Bangladesh is 150–600 ppm (mg/l). A greater salinity value of up to 1,000 ppm is taken into consideration for drinking in few coastal areas of Bangladesh. FAO has categorized the water according to its salinity content with an updated version of the Bangladesh Standard for Drinking Water is displayed in Table (Duncan et al. (2000)).

Type	sS/cm	mg TDS/l	Drinking or irrigation
Non-saline or fresh water	<0.8 0.	<600	For Drinking and irrigation
Slightly saline	8- 2	600-1,500	Irrigation
Moderately saline	2- 10	1,500-7,000	drainage water and groundwater

High salinity	10- 25	7,000-15,000	Secondary drainage water and groundwater
Very highly	25- 45	15,000-35,000	Seawater is 35,000 TDS mg/I
saline Brine	>45	>45,000	

Table 3: Bangladesh Standard for Drinking Water

Source: Duncan et al. (2000)).

Containing sodium or salinity in Drinking water a risk factor for hypertension or blood pressure. High intakes of sodium, salt, or drinking water are linked to hypertension or high blood pressure in women especially. (Khan et al. 2014; Scheelbeek et al. 2016b;).According to a survey, it has been noticed that the rates of pre- eclampsia, eclampsia, and gestational hypertension in pregnant women is high due to drinking water salinity.(Khan et al. (2008, 2011), Khan (2014)) .People who drinks water containing somewhat saline level of (1000–2000 mg/L) and moderately saline level of (2000 mg/L),were shown to have a 17% ($p < 0.1$) and 42% ($p < 0.05$) increased risk of hypertension, respectively, in comparison to those who drinks freshwater (<1000 mg/L) (Scheelbeek, et al., 2017). It was also found that women are 31% more likely than men to suffer hypertension and above age 35 had a roughly 2.4 times higher risk of hypertension (Scheelbeek, et al., 2017).

2.11 Context study

2.11.1 Geographical context of the study location

The Cox's Bazar District, located in the Chittagong division, covers an area of 2382.38 square kilometres. It is situated between 20°43' and 21°56' north latitudes and 91°50' and 92°23' east directions. The eastern boundary of the area is marked by the Naf River, while the western boundary is the Bay of Bengal. To the north, it is bordered by the Bandarban District, Arakan (Myanmar), and the Chittagong District (banglapedia, n.d.). Most of the city is located on lower ground, making it more vulnerable to cyclones and storm surges (Alam, Huq, & Rashid, 1999).

2.11.2 Demography the study area

The upazila is made up of 144 villages, 1 paurashava, 12 wards, 95 mahallas, 10 unions, and 20 populated mauzas. This union has an average population of 2, 9161, a mauza an average of 14580, and a village an average of 2025 (all figures are from the Population and Housing Census). According to the 2022 census, there are 417,354 people living in Cox's Bazar Sadar, the district's principal sub district. This population consists of both local residents and temporary/tourist or refugee groups. Based on recent government figures, approximately 17 percent of domestic tourists, amounting to millions, annually visit Cox's Bazar. The presence of both local people and a significant number of development officials in the area, along with the influx of tourists, although appreciated, poses management challenges for the city, especially in water management.

In Cox's Bazar Sadar Upazila Province, the majority of households (88.2%) have access to drinking water from tube-wells, while a smaller percentage (8.1%) obtain water from taps. The remaining 3.7% of households rely on alternative sources for their water supply, as reported by the Population and Housing census.

2.11.3 Climatic condition

Every year, the Cox's Bazar district in the Chittagong hill tracts experiences landslip disasters due to heavy rainfall during the monsoon season. The district spans an area of 2,491.85 square kilometers (962.10 square miles), with forest covering 940.58 km2 of this total. Approximately 50% of the district's entire geographical area is comprised of the mountainous region, including the coastline. Based on the data, May is the month with the highest temperature in a year. The mean temperature during this interval reaches a maximum of 28.0 °C | 82.5 °F, establishing it as the peak period of the year in terms of heat. January is the month with the lowest temperatures, with temperatures averaging 26.9 °C (Cox’s Bazar climate: Average Temperature by monthCox’s Bazar water temperature., n.d.).

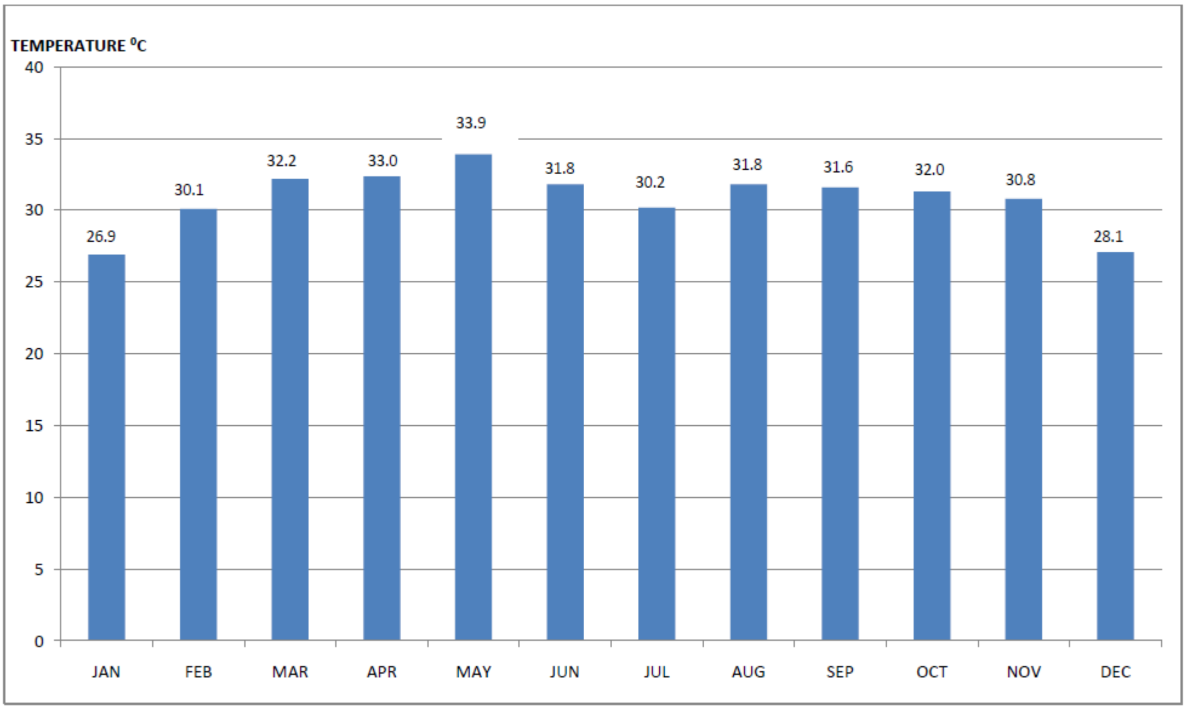


Figure 22: Monthly mean maximum temperature

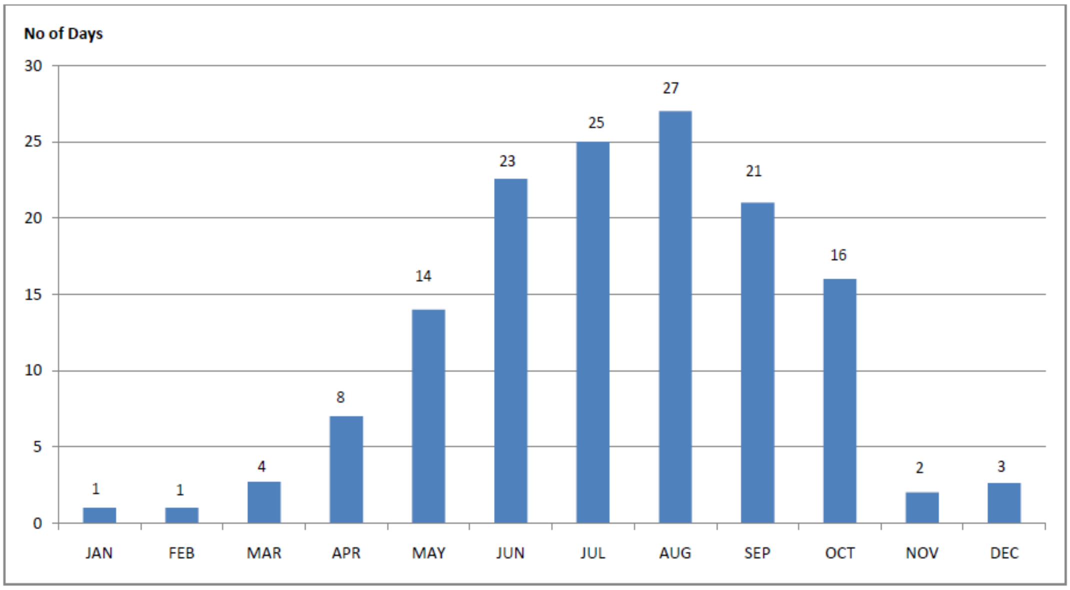


Figure 23: Monthly mean maximum temperature

The least quantity of precipitation is recorded in January, at 4 mm or 0.2 inches. The month of July experiences the highest level of rainfall, with an average of 673 mm (26.5 in). The data analyzed monthly average maximum Final Report Preparatory Survey on Matarbari Port Development Project in the People's Republic of Bangladesh shows 2824.2 mm/yr of annual rainfall. 4-7 rainfall occurred in July (763.7mm/month) and monthly average minimum rainfall happened in winter (December–February), indicating that the rainy season is dominant in this region. The 30-year average monthly rainfall graphs below show that the monsoon season (June to September) has the most rainfall. From December to February, rainfall is low. This study employed Kutubdia station (BMD station ID: 11925) time series rainfall data.

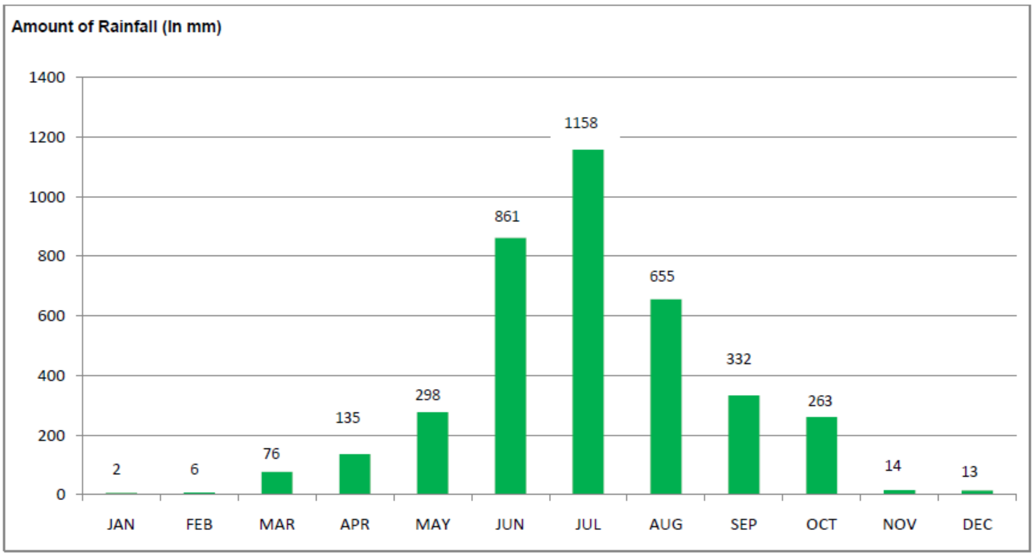


Figure 24: monthly average amount of rainfall (2013-2022)

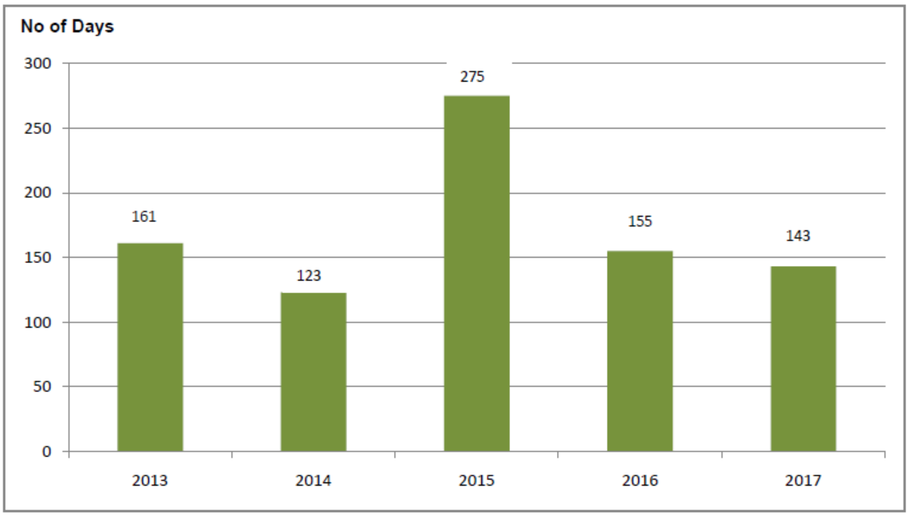


Figure 25: Yearly total no of rainy days yearly total no of rainy days

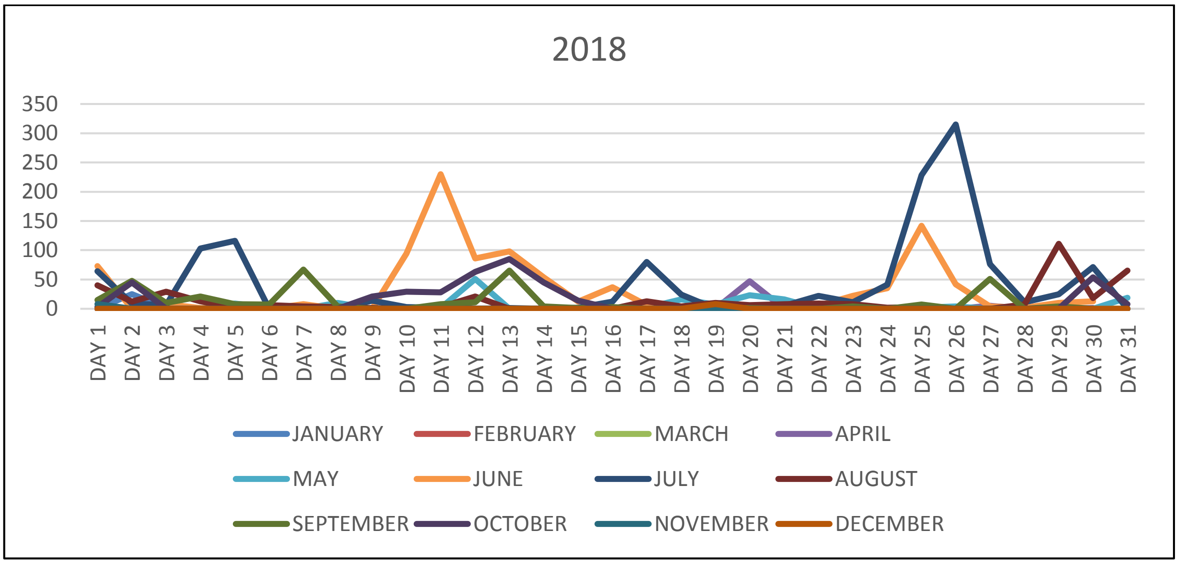


Figure 26: Rainfall data of 2018 (Cox's Bazar)

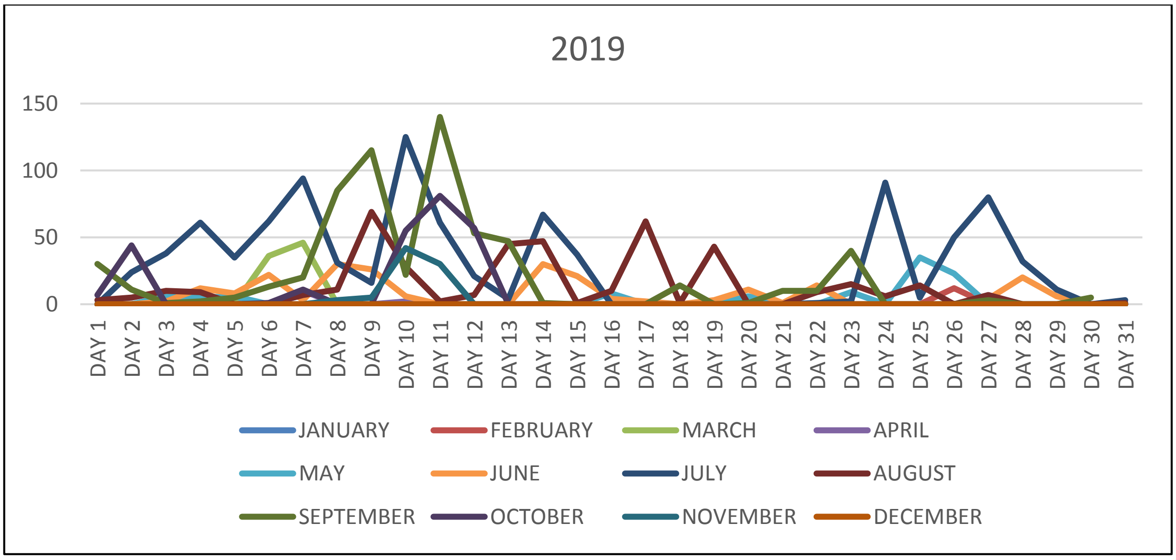


Figure 27: Rainfall data of 2019 (Cox's Bazar)

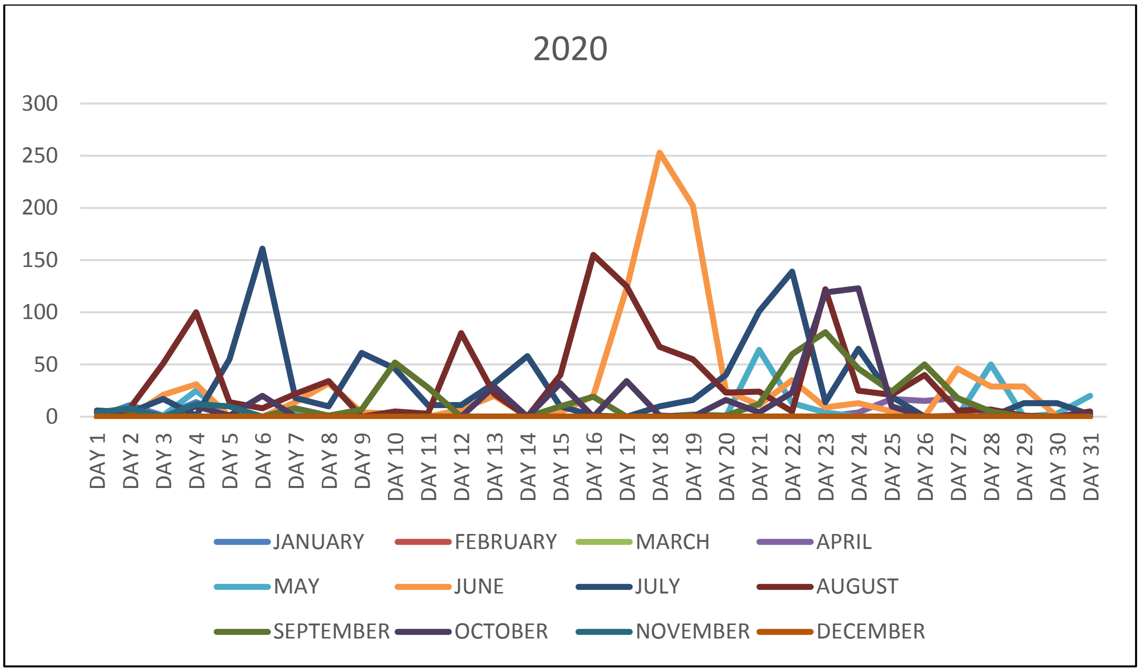


Figure 28: Rainfall data of 2020 (Cox's Bazar)

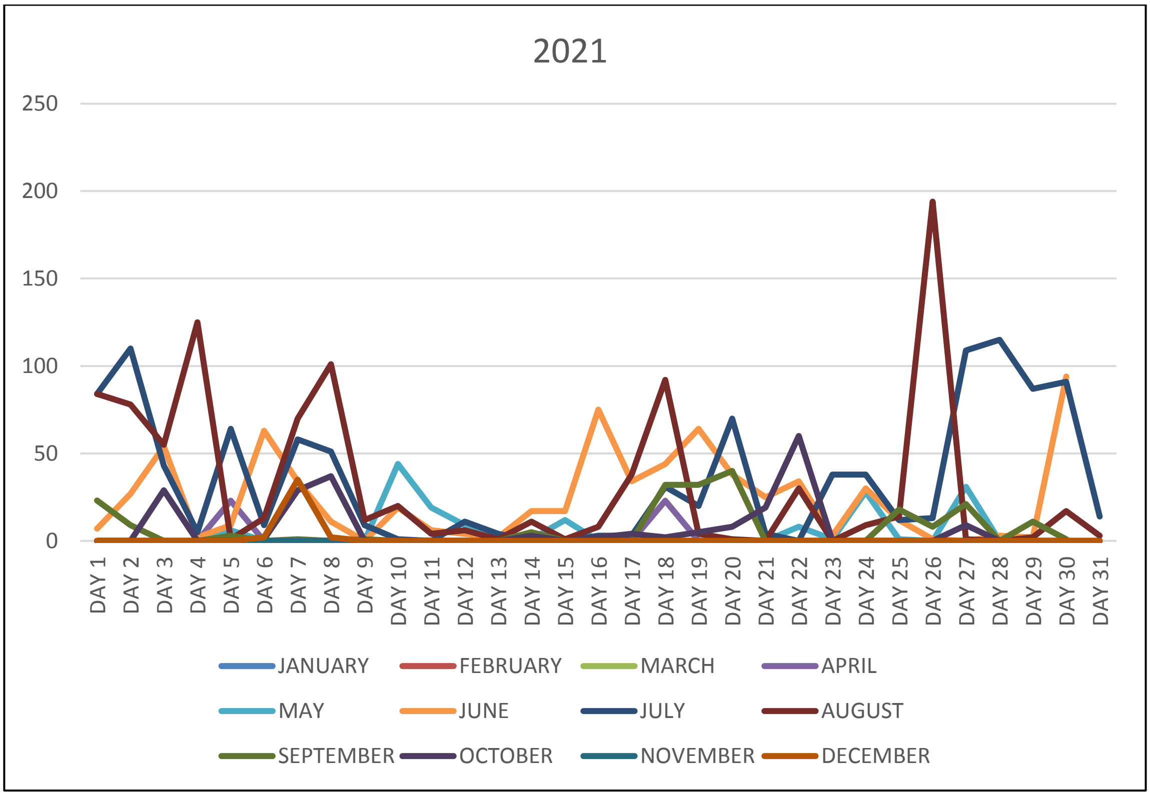


Figure 29: Rainfall data of 2021 (Cox's Bazar)

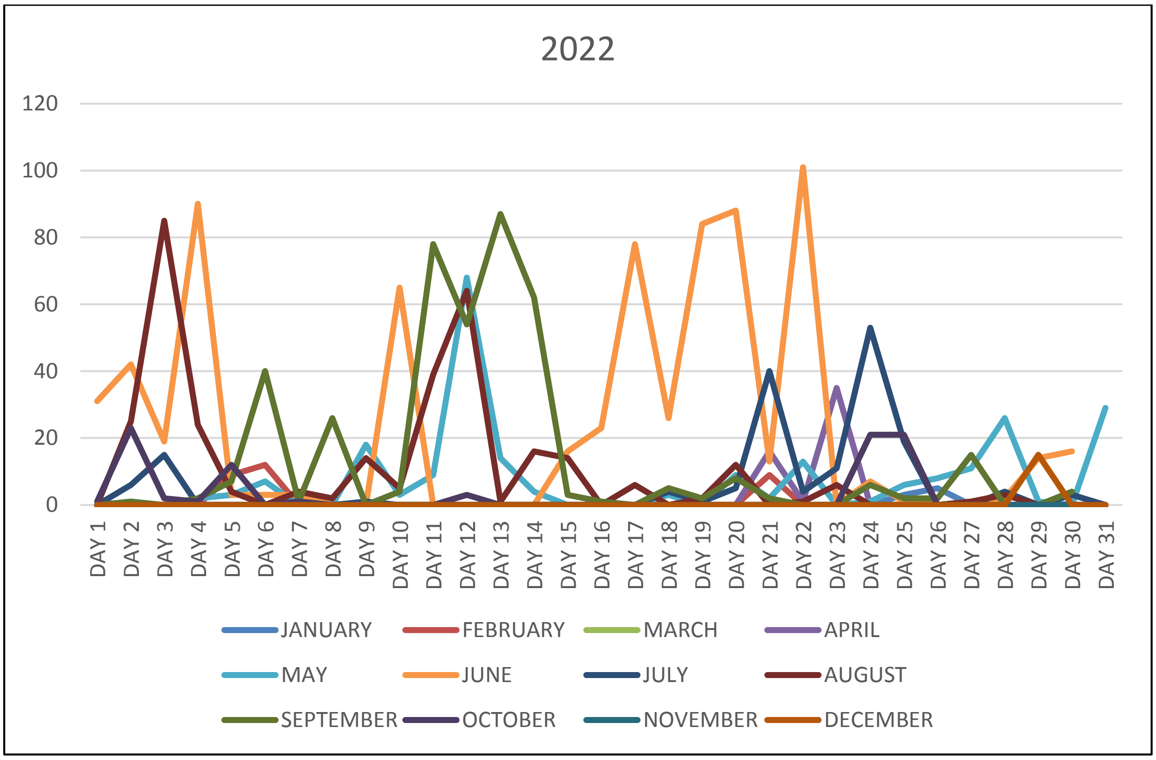


Figure 30: Rainfall data of 2022 (Cox's Bazar)

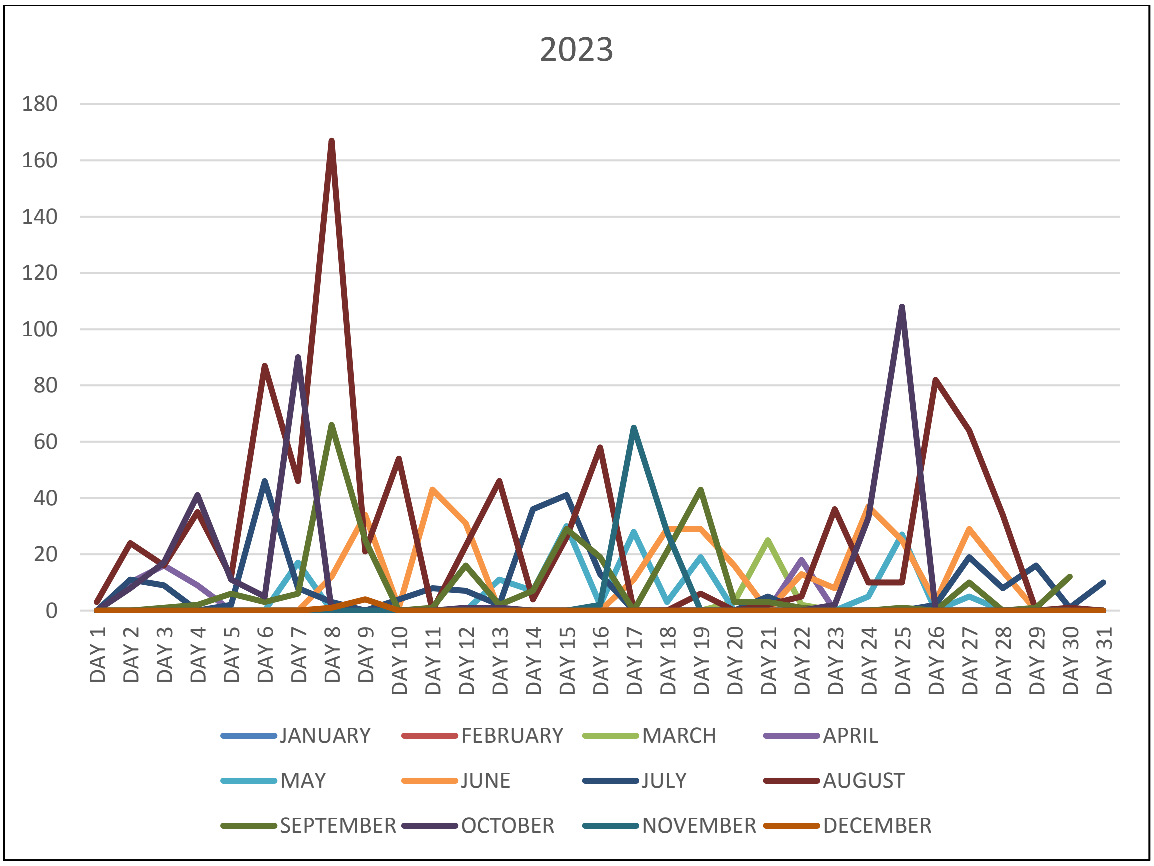


Figure 31: Rainfall data of 2023(Cox's Bazar)

2.11.4 Economy and development

Fisheries industry: Approximately 18 percent of rural households in Cox's Bazar sustain themselves by engaging in fishing activities using trawlers or boats. They are sold outside the city and supplied to the entire nation. A large number of people make their living by harvesting prawns from the coast.
Salt industry: As per the Bangladesh Cottage Industries Association, the Cox's Bazar district has 63,532 acres of salt fields. In 2004–2005, 935,000 tonnes of salt were produced from these salt fields Cox's Bazar is home to 43500 salt farmers. BSCIC began producing salt in a polythene system in order to boost output and enhance quality which later on produced 30% more with higher quality.
Dry fish industry: In the Bay of Bengal, about 25–30% of the fish caught and processed into dry fish. They export dried fishes, such as shark fin, liver oil, and airborne (2024).
Handicrafts Industry: Cox's Bazar is also known for traditional handicrafts. Rakhaina of Arakan made various types of clothes, made garments, towels, bags, etc. these handicrafts are widely accepted in the country and abroad (2024).
Tourism industry: Cox's Bazar The beach is quite appealing to tourists. Over the past three years, the sea beach management committee has been enhancing the infrastructure to enhance the experience of tourists. More than one hundred motels, including luxury five-star hotels, have been constructed. The rise of the tourism industry in Cox's Bazar has led to the emergence of significant employment prospects (2024).

2.11.5 Built environment

Cox's Bazar attracts tourists and visitors from around the world year-round due to its huge beach and natural beauty. The zila Gazetteers' residential hotels, motels, and cottages suggest Magh people were Cox's Bazar's initial occupants.
Housing and household characteristics: There are a total of 82,683 households in the upazila. The percentage breakdown is as follows: 0.10% for rural units, 0.10% for institutional units, and 1.30% for other units. 11.8% of households in the upazila reside in pucca houses, which is a type of durable housing building, which is shown in a pie-chart in figure 26.

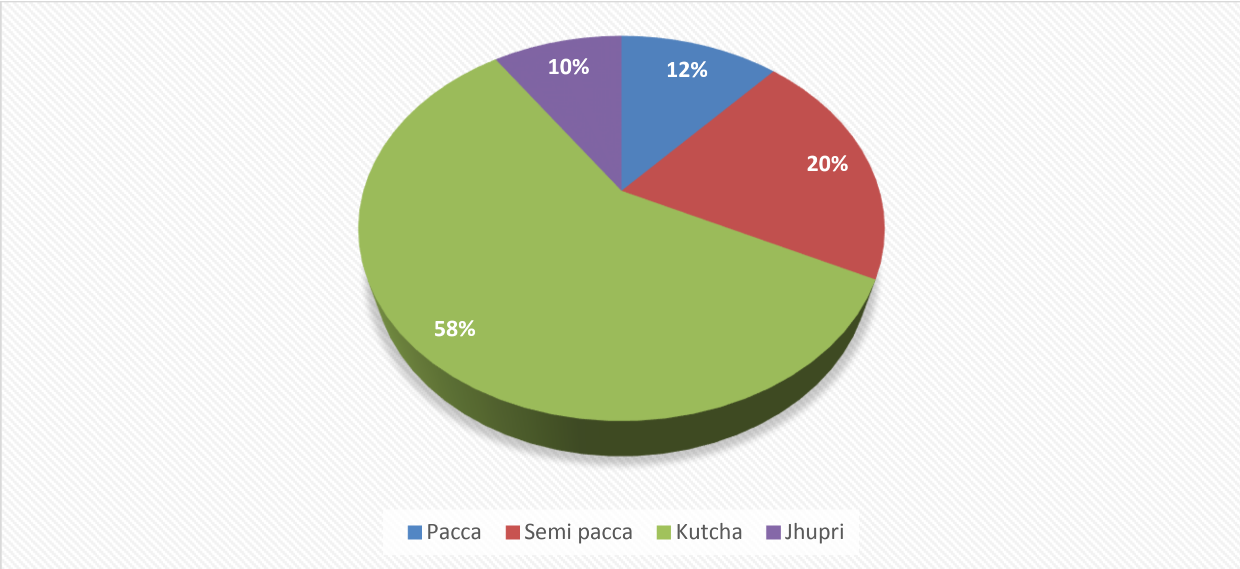


Figure 32: Housing structure by type, 2011

2.11.6 Roads and transportation

Road: The (N110) national highway links to Dhaka, the capital of Bangladesh, as well as to several regions of the nation by the (N1) highway. It takes about 9–12 hours travelling from Dhaka (capital) to Cox's Bazar depending on the traffic.
Airport: Cox's Bazar Airport is located in the northwest of the city. It is one of the busiest domestic airports in Bangladesh. To draw in more travelers, Cox's Bazar Airport is currently completed a renovation to an international airport.
Rail: Cox's Bazar railway station officially opened On November 11, 2023. In December 1, 2023 was the station's public opening date.

2.12 Cox's bazar surface and groundwater salinity

At present, a total of 15 million individuals are currently consuming saline water, while an additional 30 million people are unable to get drinkable water due to a scarcity of safe water sources (Galiulin, et al., 2001). In (coastal areas) Bangladesh, the pre-monsoon saw highest soil salinity levels, while the monsoon saw the lowest levels. The soil salinity begins to rise after the monsoon season and continues to increase until it reaches its peak during the pre-monsoon period. Winter, highest average soil salinity was ("1.09 dS/cm") and in pre-monsoon ("1.04 dS/cm"). Groundwater level between 0.35m and

2.4m due to an increasing intake in Cox's Bazar area (Muhammad Risalat Rafiq, 2017). According to 'Institute of Water and Flood Management (BUET)', the majority of the salinity hotspots are found in the eastern and western zone of Bangladesh and the risk is creasing day by day. (Figure 41). In the future due to increasing of salinity danger and altering exposure and sensitivity factors. There are twenty future risk hotspots and twenty baseline risk hotspots in all. The risk of salinity will increase in 17 hotspots in the future (Anisul Haque).

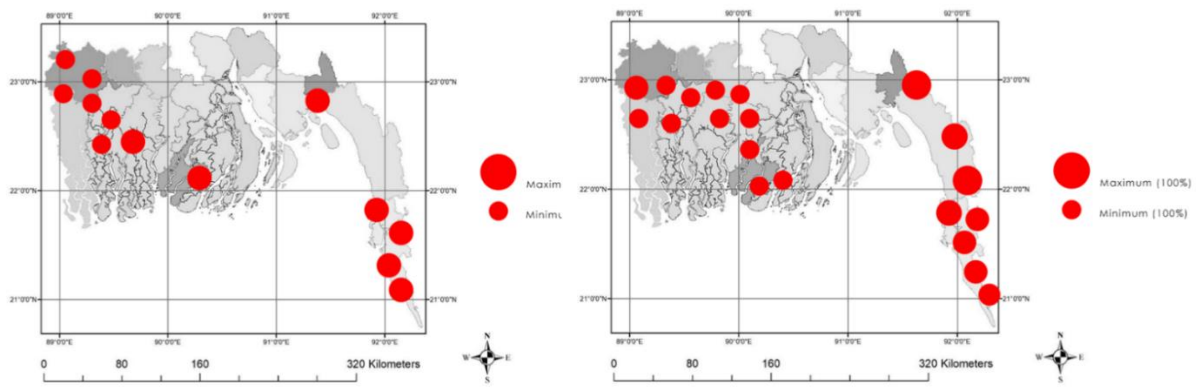


Figure 33: Salinity risk hotspots: Base condition (left); Future condition (right)

2.13 Design guidelines for rainwater catchment area and installation standards in Bangladesh.

According to Bangladesh National Building Code (BNBC, 2020), Rainwater management is covered in full in Part 8, Chapter 7. Following the information is collected from the guidelines:

7.8 Roof Top Rainwater Harvesting		
7.8.1	Precautions in rainwater harvesting	(a) No sewage or waste water should be admitted into the system. (b) Wastewater from areas likely to have oil, grease or other pollutants shall not be connected to the system. (c) Each rainwater seepage well shall have an inlet chamber with a silt trap to prevent any silt from finding its way into the sub- soil water. (d) The wells should be terminated at least 5 m above the natural static sub-soil water at its highest level so that the incoming flow passes through the natural ground condition and prevents contamination hazards. (e) No recharge structure or a well shall be used for drawing water for any purpose.
7.8.2	Qualifying rainwater for harvesting	a) For using rainwater in drinking, cooking, washing utensils bathing and ablution it shall be disinfected along with filtration. (b) For cloth washing, floor washing, fountain, water fall cascade etc. Rainwater shall be filtered. (c) For using in sprinkler firefighting, air conditioning etc. sedimentation of suspended particles will be required. (d) For toilet flushing, gardening, cleaning artificial ground, parking lots etc. screening floating materials are needed.

7.8.3	Catchments area for collecting rainwater	Rainwater can be collected from following built up areas for harvesting. (a) Roof top surfaces (b) External walls and other vertical surfaces (c) Balconies, sunshades etc. (d) Metal surface of play grounds, open yards etc.
7.8.4	Determining catchment area	For flat surface, the catchment area is its plan area plus 50 percent of the adjoining vertical wall contributing rainwater accumulation on the concerned catchment. For sloping roof, catchment is considered to be the actual inclined roof area
7.8.5	Storing rainwater	Where rainwater will be used for domestic purpose, rainwater from roof or terrace may be led straight from conductor (or leader) to one or more storage tanks. Storage tanks shall be provided with ventilating covers. An arrangement shall be made in the rainwater leader to divert the first washings from the roof or terrace catchments as they will contain more undesirable materials. The open end of all pipes shall be covered with mosquito (insect) proof wire net.
7.8.6	Flushing out first rainwater	Before storing initial rainwater, just after starting raining, shall be drained out for a period as mentioned below. Location Time, Dhaka metropolitan area 20 min, Sylhet 15 min, Chittagong **15 min** and Other urban areas 15 min
7.8.7	Precautions for rainwater storage	Following precautionary measures shall be taken for rainwater storage. (a) Storage tank shall be made water tight in all respect. (b) Tank shall always be kept covered. (c) Regular cleaning at least once a year, preferably at end of dry periods, shall be done. (d) Disinfection shall be done after cleaning operation. (e) Tank shall be ventilated and vent pipe shall be covered by mosquito net. (f) The tank must have an overflow pipe leading to a natural water course. (g) If raw rainwater and potable water is to be stored in the same storage tank separated by a separating wall, then the separating wall shall have no openings.
7.8.8	Rainwater treatment	For portable systems, a plain galvanized roof or a metal roof with epoxy or latex paint is recommended. Composite or asphalt shingles are not advisable, to improve water quality, disinfection shall be done in the following way. 7.8.8.1 Chlorination Chlorine must be present in a concentration of 1 ppm to achieve disinfection. Liquid chlorine, in the form of laundry bleach, usually has 6 percent available sodium hypochlorite. For disinfection purposes, 2 fluid ounces (¼ cup) must be added per 1,000 gallons of rainwater. Bleach products, however, not labeled cannot be used in water treatment. A purer form of chlorine, which comes in solid form, is calcium hypochlorite, usually with 75 percent available chlorine. At that strength, 0.85 ounces by weight in 1,000

<table>
<tr><td></td><td></td><td>gallons of water would result in a level of 1 ppm. Chlorine contact times are shown in Table 8.7.1. To filter out Giardia and Cryptosporidium cysts, an absolute 1- micron filter shall be used.

Table 8.7.1: Contact Time with Chlorine
<table>
<tr><th rowspan="3">Water pH</th><th colspan="3">Water temperature</th></tr>
<tr><th>50°F or warmer</th><th>45°F</th><th>40°F or colder</th></tr>
<tr><th colspan="3">Contact time in minutes</th></tr>
<tr><td>6.0</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>6.5</td><td>4</td><td>5</td><td>6</td></tr>
<tr><td>7.0</td><td>8</td><td>10</td><td>12</td></tr>
<tr><td>7.5</td><td>12</td><td>15</td><td>18</td></tr>
<tr><td>8.0</td><td>16</td><td>20</td><td>24</td></tr>
</table>
</td></tr>
<tr><td>7.8.9</td><td>Determining volume of rainwater storage</td><td>Determining volume of rainwater storage Rainwater storage volume in m^3 = D x N x D p / 1000+ Floating
Where, D = Rainwater demand in liter per capita per day.
N = Population number.
D p = Number of days for which water will be stored. Consider 90 days for drinking, cooking, utensils cleansing, bathing and ablution purposes; 210 days for other purposes.</td></tr>
</table>

Table 4: Minimum standards of Design for Rainwater Catchment Area and Installation Standards in Bangladesh National Building Cod

Chapter Three
Methodology

3.1 Introduction

This chapter will cover the research procedures used to gather data for the study. Starting with topics of choosing a research site and then the methods used to gather and analyses data through surveys.

3.2 Research design

The research is designed with finding out the rain water harvesting social parameters including the acceptance rate among the community and efficiency of rainwater harvesting. To find out the results from the community research tool FGD, KII and individual survey has been conducted. Secondly, series of case study of architectural projects has been analyzed to find out the architectural design potentiality for harvesting rain water and reviewing secondary data on climate and design resiliency.

Combining the both qualitative and quantitative research methods the research design include three main components:

1. Community Research
2. Case Study Analysis
3. Secondary Data Review

3.3 Research gap identification

Bangladesh has the full potentiality of using rainwater especially in coastal zones. However, it is not widely use in practices. The will emphasizing finding on the gap between the implication and policy mapping.

3.4 Study area selection

The research was carried out in Ward 2 and Ward 10, Cox’s Bazar district, of Sadar Upazila of Cox's Bazar. This study region was chosen considering the following factors:

- This area is experiencing water scarcity.
- There is drinking water shortage in the study area (According to the Cox's Bazar Pourashava)
- The study area was severely affected saline water
- One of the most hazardous coastal climate change and disaster zones.
- Rainwater harvesting systems already exist in the study area (beside the ward to in hilly areas)

3.5 The study area

Cox’s bazar is considered to sustain a unique environmental pattern due to its topography, climate, and geographic location. The Southern region of Bangladesh, is vulnerable to saline incursion. Over thirty percent of Bangladesh's arable land is located on the deltaic coastal region (Mia, 2020). Soil salinity affects 1.056 million hectares, or around 1.689 million acres, of coastal terrain to varied degrees (Mia, 2020). Cox’s bazar local community of is not only facing the natural disaster such as cyclones, landslides, and flash floods but also facing risks due to Rohingya crisis, population rate and tourism. The Rohingya crisis brought deforestation, hill cutting, and infrastructure pressure (Quader, 2019).

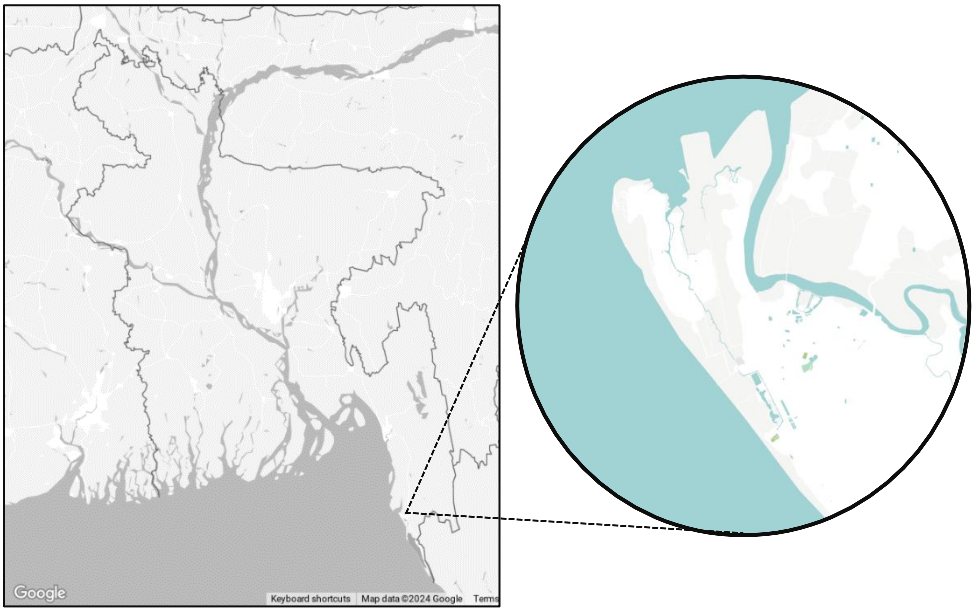


Figure 34: Study location

Due popular tourist destination, increasing number of structures such as hotels and resorts have been building In Cox’s Bazar (Rasel, 2021).(Rasel et al., 2021). Local community is suffering from severe lack of drinking water in Cox's Bazar. Every year, the level of the ground drops by ten to fifteen feet. In many unions of the total nine upazilas, including Cox's Bazar town, the water level is declining. These are particularly problematic in the areas around Ukhia, Teknaf, Chakaria, and Cox's Bazar city (Cry for potable water in Cox’s Bazar., (n.d.)).

According to Cox’s Bazar Municipality, approximately 7000 of the district's 31000 tube wells are no longer functional. At least many thousand tube wells are devoid of water. According to Executive Engineer Mostafizur Rahman of Cox's Bazar Public Health Engineering Directorate that the level of underground water of Cox's Bazar’s underground water level is dropping quickly and this pressure only can be reduce by storing rainwater and using more water from ponds, lakes, and rivers. Groundwater pressure should be decreased by conserving rainwater and using more water from ponds, lakes, and rivers. He has also stated if not any alternative measures are taken then this crisis may increase in the future (Express, 2024).

In Cox's Bazar, the groundwater level is dropping at a pace of 10 to 15 feet in every year. In the Tekpara neighborhood of the city, the ground water level was discovered to be between 120 and 150 feet even ten years ago.

However, now it is more than 300 feet. Moreover, Kalatali area of Cox's Bazar Sagarpar has dropped by 10 to 15 feet in last few years. As a result, the water level was usually 30–35 feet below the ground which has dropped to 50 to 60 feet.

Ahmed Ghiyas, a researcher on nature and animals at Cox's Bazar, claims that because of the rapid unplanned urbanisation there are fewer open spaces and reservoirs, as a result, there is enormous pressure on the groundwater table. A survey conducted by the water resources engineering department at Bangladesh University of Engineering (BUET) indicates if the pressure on ground water is not reduced, the water will drop by 10m yearly.

3.6 Tools of survey and analysis

The study used a mixed-method approach that involved a literature review. Case studies analysis, Focus Group Discussion (FGD), Simple Random Survey (SRS), Key Informant Interviews (KII), in-depth interviews. Utilizing the insights gathered from the desk research and FGD, the questionnaires are prepared.

3.6.1 Community research

To understand the community perspective was one of the prime objectives of the research.

The following tool were used to understand to have the sense of community people's acceptance and concern level of rainwater harvesting system.

Serial	Research Objectives	Corresponding Research Questions	Parameters	Tools
1	To explore and evaluate the current challenges, limitations, and barriers hindering the widespread adoption and effectiveness of rainwater harvesting in Cox's Bazar	What is the place and importance of rainwater harvesting worldwide? What is the acceptations rate among the local community people?	Concept rainwater harvesting, system (definition, type, composition, source)	1.FGD 2.Individual Survey
			Current challenges around the world on water scarcity	
			Knowledge on law, rules, regulations	
			Social aspect (Awareness and Knowledge)	

3.6.1.1 Sampling design

A survey of Cox's Bazar district selected houses will serve as the main quantitative tool. To choose the households, a stratified multi-stage sampling approach has employed. It has focused on ward 2 and ward 10, chosen sampling locations were used to collect data by the community feedback. The questionnaire was closed ended. 48 random numbers corresponding to 48 households have been selected for the survey. The answers from the responders' sample were collected in hard copy, transferred to an Excel file, and then the result was produced in graphs.

Figure 35: FGD

The description of the respondents in this research has been described below in detail.

Age Group	Male	Female
25-34	2	2
35-44	10	10
45-54	4	16
55-64	4	0

3.6.1.2 Focus group discussion (FGD)

Two focus group discussions (FGDs) were performed in the research region of Cox's Bazar between March and April 2024. Each FGD included seven participants. Due to the constraints of limited resources, time, and workforce, the participants were chosen in a random manner in the area of ward 2 and 10. Figure 29 shows the FGD sessions in Cox's Bazar Upazila.

Target Audience	Number of FGD
Category-1. Community people	6 people (Female)
Category-2. Community people	8 people (Male)
Total	2

3.6.1.3 Key informant interview (KII)

Based on the professional and academic expertise and similar research area interest. The KIIs includes four practicing architects who are concern about designing rainwater harvesting on their projects and five academic professionals who have research experience on community development of and focus on sustainability and two civil engineers with technical expertise.

Practicing architects who have direct experience in designing and implementing rainwater harvesting systems in various projects.

Survey tool	Key informants	Number of KII
KII	Architects (Professionals)	04
	Architects (Academicians)	05
	Engineers	2
		1

3.6.2 Case study analysis

A number of case studies are analyzed to find the possibility for rainwater harvesting in architectural design.

3.6.2.1 Selection of the of case studies

The selection of the architectural projects was mainly on based on their innovative and creative application of rain water harvesting system and different other factors such as geographic location and climate conditions. And the data was collected with various sources including architectural journals, project reports and websites. Several related caste studies of integrating architecture and rainwater harvesting from past and present architectural practice allowed a detailed perspective of different ways to implement design consideration with rain water harvesting to utilize the sustainable water management system. Total (06) cases presented earlier are from different countries; four of them are public building (Serpentine Pavilion, Olympic Golf Course, Sustainable Market Square, one commercial building and one residential colony.

Serial	**Research objectives**	**Corresponding research questions**	**Parameters**	**Tools**
2	To examine as to how key architectural design principles can be effectively integrated maximize the potentials of rainwater harvesting in the study area	How can architectural design parameters can be effectively integrated to increase the potentially of rainwater harvesting capacity and adaptability in the coastal urban community to enhance resilience to climate change?	Building type, construction material, building surroundings, inside materials, Building area, water reservoir, accessibility, land use the number of stored etc.	1.Data Analysis 2.Case Study analysis

3.6.3 Secondary data review

A descriptive review of secondary data was studied to find the climate data including rainfall data, temperature. Journals, government project reports and publications were studied to identify the present condition and design strategies for effective rainwater harvesting.

3.7 Questionnaire preparation and data collection

To collect primary data, two semi-structured questionnaires were prepared for the study. Data and information were gathered from both primary and secondary sources. Individual respondents collected primary data using a field survey. Secondary data and information have been collected from published books, reports literature, and internet sources.

The first step was doing desk research to get idea of the current problem and to identify gap in the literation on rainwater harvesting. Secondly, based on data from desktop review, survey questionnaire was developed for gathering detail information by conducting Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs). One other hand, a set of highly relative case studies was prepared based on their potentiality for integration of rainwater harvesting and architecture.

3.8 Data interpretation, analysis draft and final report

In this stage, data collected from survey have been analyzed using SPSS and Microsoft Excel. Using Microsoft Word and Excel, different types of charts, figures, and tables are produced based on the results and analysis. Then the results and finding have been compiled to make the draft report. After creating the draft, it was reviewed for the necessary corrections and the final report has been formed under the guidelines of the supervisor and then finally submitted.

3.9 Limitations of the research

The research carried place in the district of Cox's Bazar. Water scarcity is more prevalent in the Cox's Bazar district compared to other parts of the country because of the high salt content and the frequency of natural disasters. With the limitation of man power and study timeline, the research could not get more participants for study. Very few KII has been conducted through online due to the shortage of time.

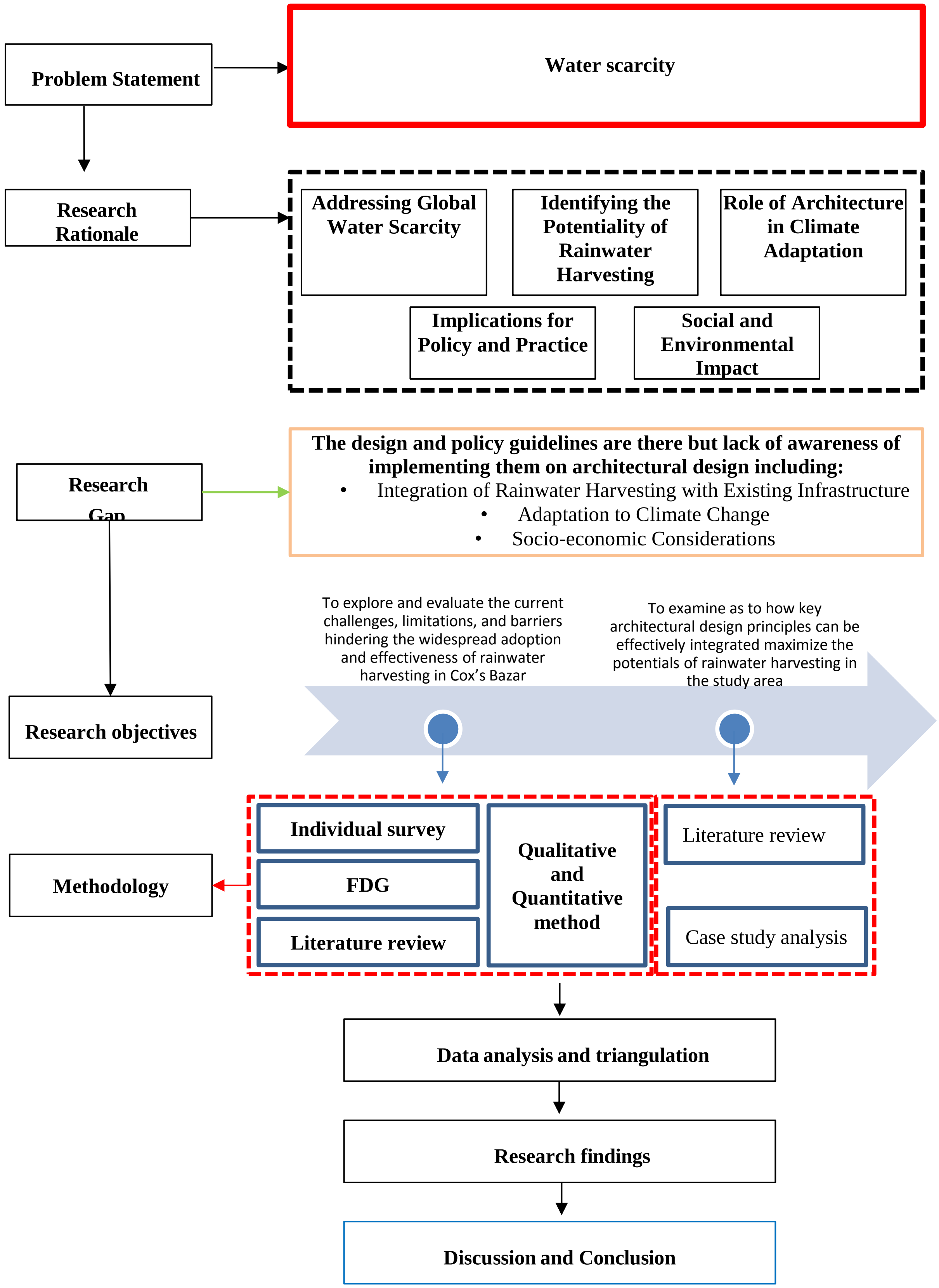


Figure 36: Research framework

Chapter Four

Findings and Analysis

4.1 Introduction

This chapter will briefly discuss the results and examination of the data gathered during survey emphasizing community acceptance, system effectiveness and architectural design possibilities. Various research methods such, as surveys, group discussions, interviews, with informants (KIIs) case studies, reviews of secondary data and other data collection techniques are all integrated into this section.

4.2 Community acceptance of rainwater harvesting

4.2.1 Findings from the community:

The Household Survey for the work on rainwater harvesting focusing on 'awareness and knowledge', 'community participation acceptance' and 'usage patterns. As described in section 3.3, a total of 48 surveys conducted in Cox's Bazar Sadar.

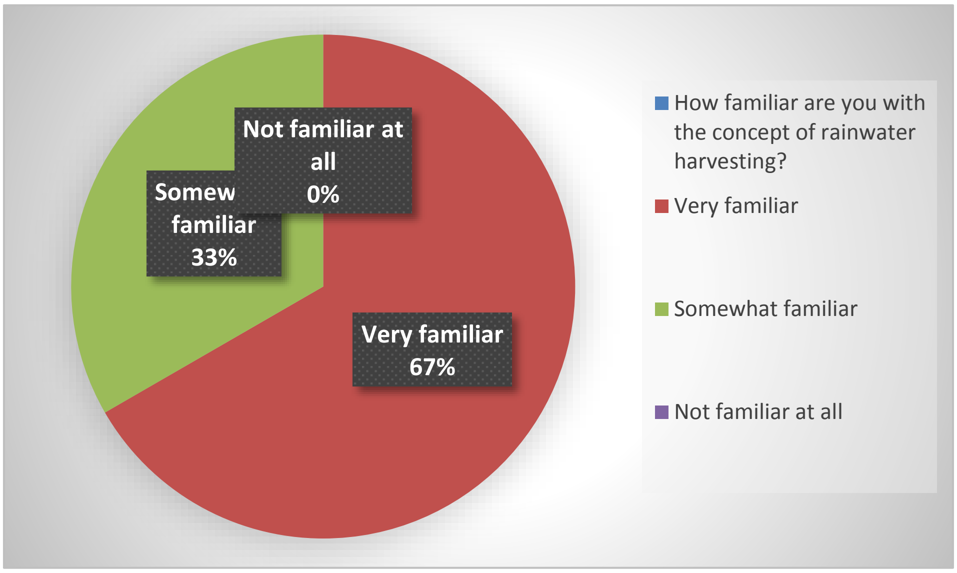


Figure 37: Familiarity of rainwater harvesting concept in the community

The pie chart provides a visual representation of the level of familiarity among respondents with the concept of rainwater harvesting. The chart is divided into three segments, each representing a different level of familiarity: Very Familiar, Somewhat Familiar, and Not Familiar at All. The responder's answers about familiarly on the concept of rain water harvesting was 67% reported they are very familiar and have worked and experienced firsthand.

33% of them have seemed to have somewhat familiar idea about RWHS.

Interpretations: From the survey it can be said that the percentage shows that there is a base of knowledge within the community about rainwater harvesting. This knowledge can be used to encourage people to adopt and use rainwater harvesting systems. Additionally, the 33% of respondents who're somewhat familiar present an opportunity for targeted campaigns.

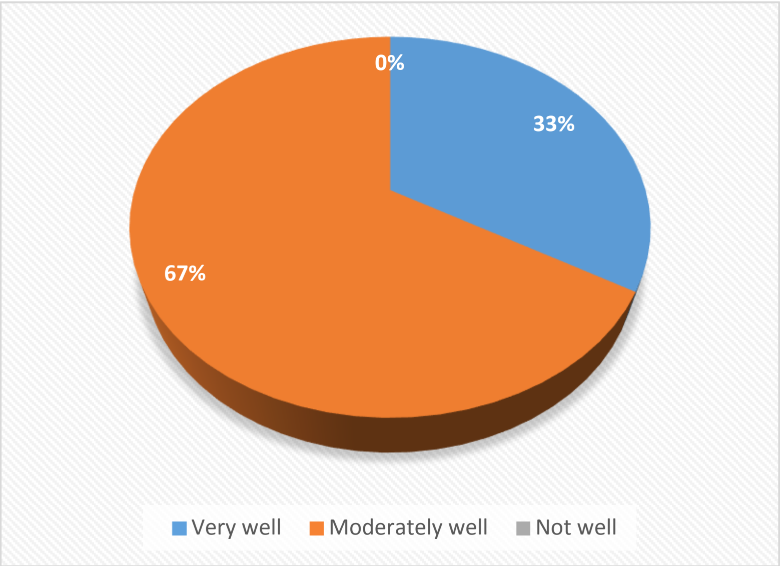


Figure 38: Awareness of Rainwater Harvesting Techniques and Practices

The orange section of the pie chart, shows that 67% of participants rated their familiarity, with rainwater harvesting techniques and methods. This implies that most people in the community have a grasp of rainwater harvesting practices although there could be potential, for learning and specialization. Only 33% of them have seemed to have very well knowledge about RWHS.

Interpretations: The survey indicates that community is well known about the technique of rainwater harvesting. Proper education and training can move this number to a higher level.

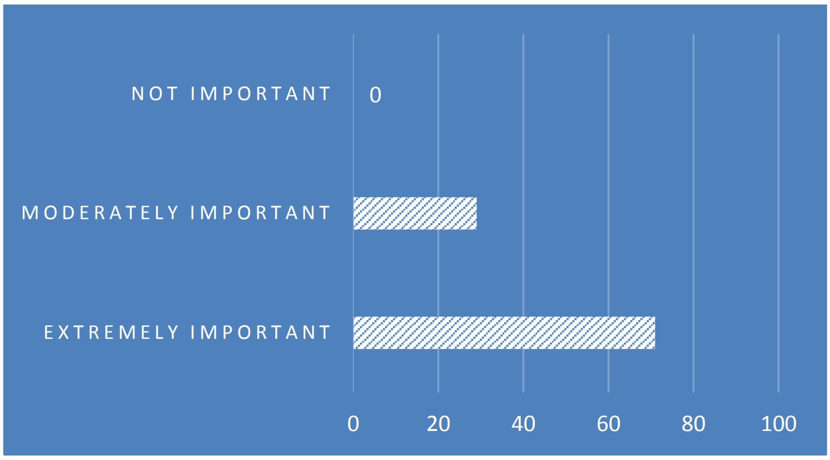


Figure 39: Response on the Importance of Community Involvement in Rainwater Collection Projects

According to the survey, 71% responded that they think community involvement extremely important to the success of rainwater collection projects. And only 29% answered that they feel it is moderately important.

Interpretations: Majority people (71%) believe community involvement is extremely important suggests that respondents see it as a vital component for achieving long-term success for rainwater collection efforts.

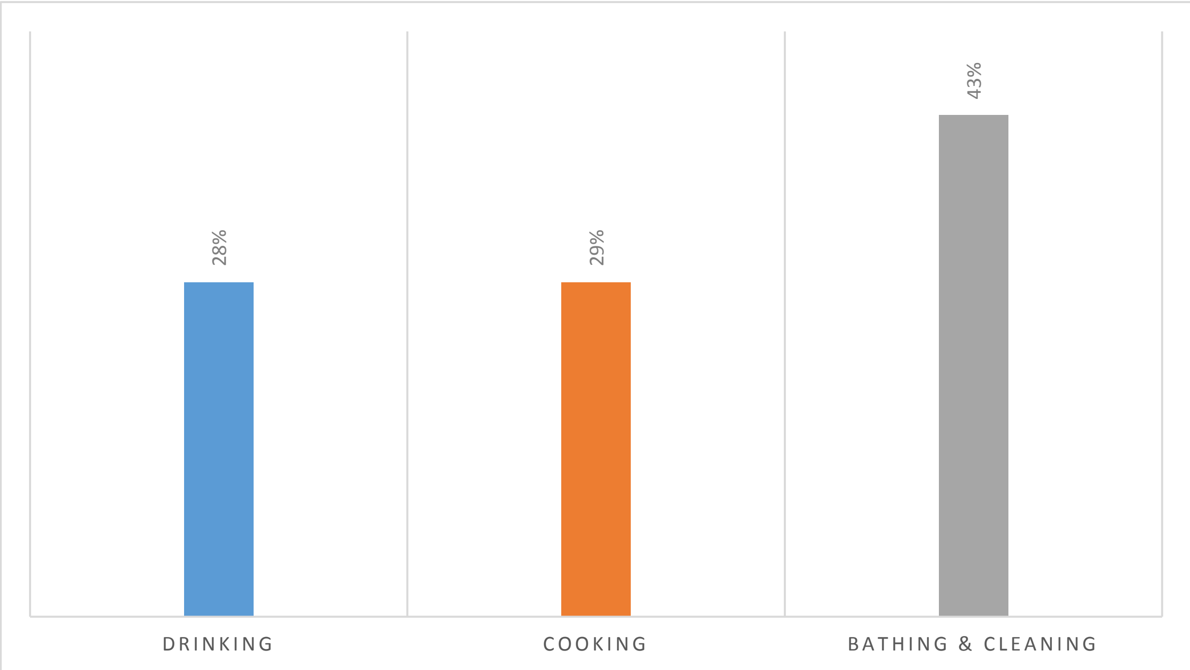


Figure 40: Household Uses of Harvested Rainwater

They gray bar indicates, 43% of responders are likely to use rainwater for bathing and cleaning. They consider the water for cooking which is only 29% of them. They also said they will use almost for drinking which is 28%.

Interpretations: The lower percentages for drinking and cooking indicates that some respondents are free to use harvested rainwater for these purposes, however they are concern about the quality and taste. Although the percentage for bathing and cleaning shows a better acceptance of using harvested rainwater. Findings also highlights the developing the community knowledge about safety and benefits.

From the survey, it was found that about 38% participants think that the main challenge is maintenance. 25% and 13% answered that heath issues and lack of suitable irrigation infrastructure respectively.12 % respondents think that quantity of harvested water won't be sufficient and the same amount of percentage respondents said lack of knowledge on technical issue will be a problem. Interpretations: According to the result it can be said that people are more concern on the maintenance of the water. Also, effective water treatment technique and public awareness needs to be highlighted.

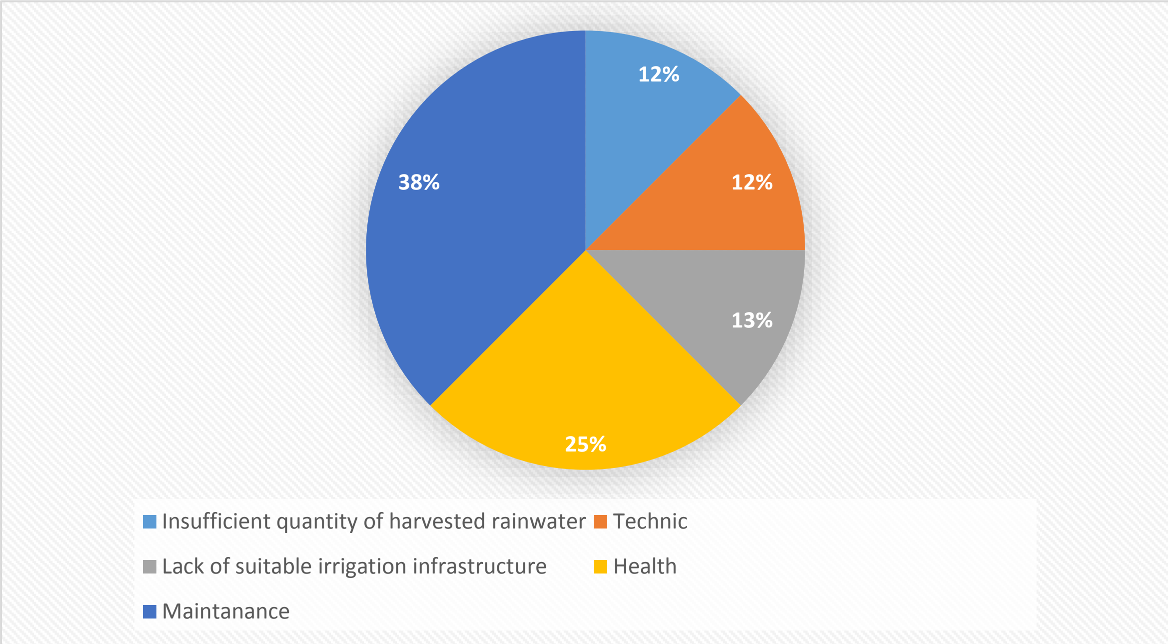


Figure 41: Main challenges in using rainwater community perspective

43% responded that they been involved in any community initiatives or projects related to rainwater harvesting. And 29% and 28% answered that they will somewhat likely and not likely respectively.

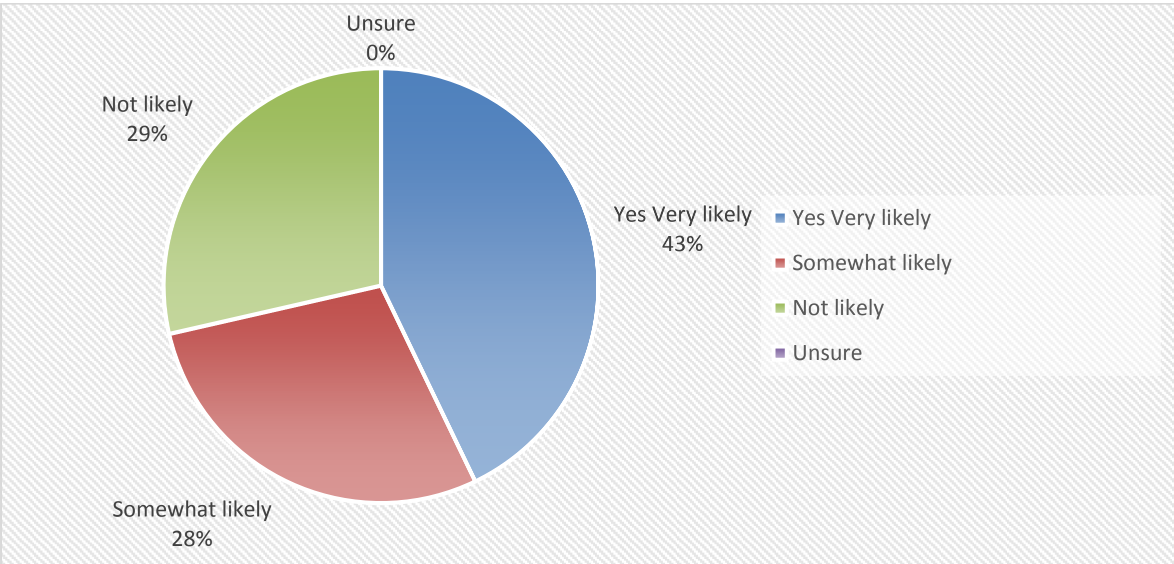


Figure 42: Community involvement in rainwater harvesting initiatives

71% responded that they think it is highly sustainable. And 29% answered that they will use moderately sustainable idea.

Interpretations: The Majority people indicate strong motivation in the long-term viability and benefits of rainwater harvesting in Cox's Bazar. 33% respondents believe that sustainable practices may face challenges or require improvements on about infrastructure, maintenance, or ensuring enough rainwater.

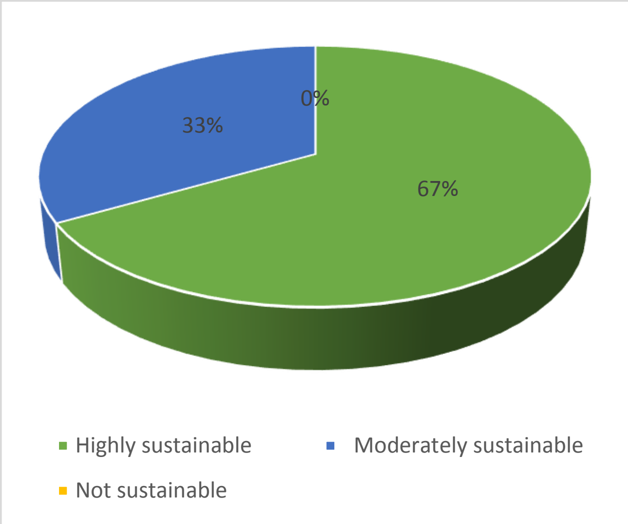


Figure 43: Sustainability of Rainwater Harvesting in Cox's Bazar (Community perspective)

4.2.2 Key informant interview (KII) findings: architectural perspectives on rainwater harvesting

From the KII survey, it was found that about 66.7% participants thinks that architecture have the potentiality to enhance the effectiveness and aesthetics of rainwater harvesting systems. And 16.70% said it can contribute moderately and considerably. Interpretation: The graph () show that professionals thinks that advanced designed architectural elements can significantly improve the functionality of rainwater harvesting systems. Including better integration of collection and storage systems into building designs and ensuring efficient usage.

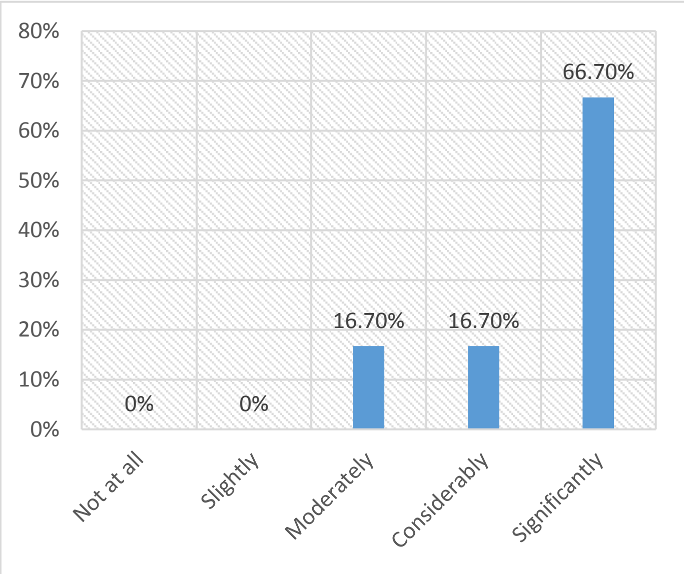


Figure 44: Architectural impact on the effectiveness and aesthetics of rainwater harvesting systems

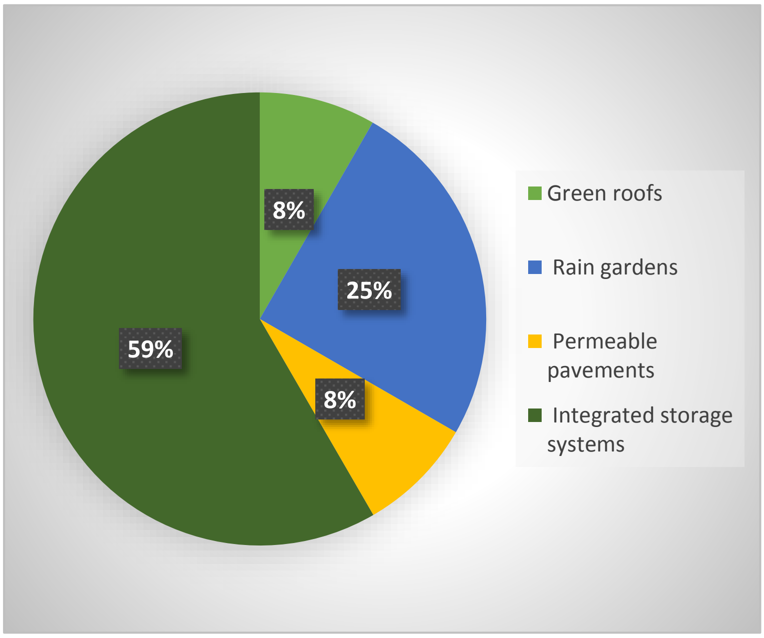


Figure 45: Architectural strategies for enhancing rainwater harvesting

59% participants answered that integrated storage systems need to improve to increase the rainwater harvesting. 25% responded to design in rain garden across the household of structure. 8% answer was for both green roofs and permeable pavements. This presents that integrated storage systems need to be improved to enhance rainwater harvesting.

About 61.7% participants answered that design optimization can be a key area for research and development to advance the integration of RWH systems in architectural designs and 16.7% said that policy development and community engagement have also potential for researching. Only 5% said material innovation is necessary. The results highlight that the design optimization is the first priority for architects and urban planners.

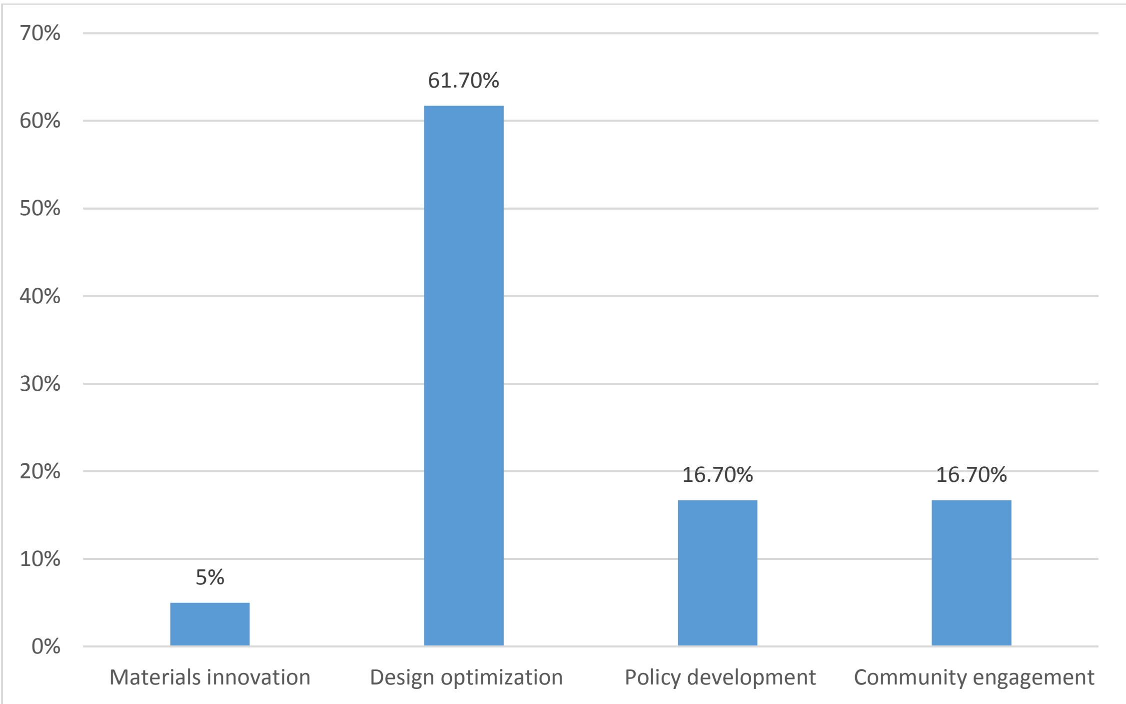


Figure 46: Research areas for enhancing RWH systems in architecture

Based on responses from 53% participants believe that to encourage the implementation of RWH in architecture and urban planning, they need policy generative workshops. 25% and 16.7% thinks to establish the joint training programs and better communication respectively.

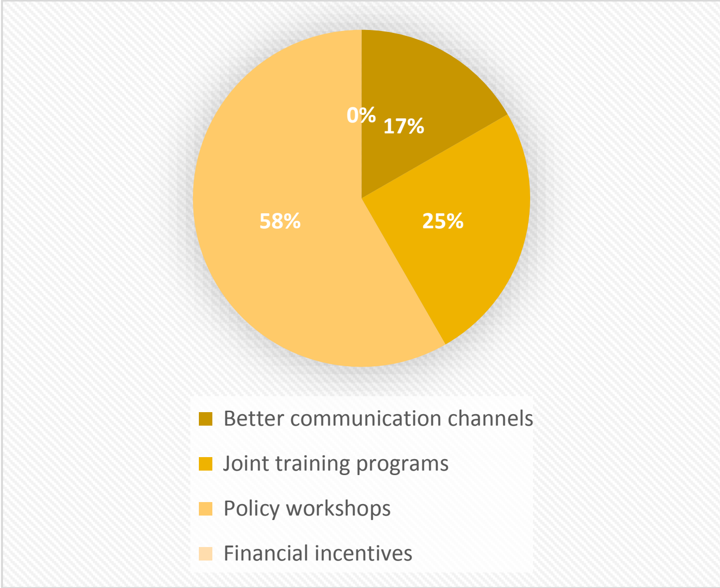


Figure 47: Multidisciplinary priorities for advancing rainwater harvesting integration

Hence overall it can be said that the professional persons think there is need to develop policies first to implement architecture into rainwater harvesting. (Figure 41)

33.3% participants answered that they could face the primary challenge incorporating architectural elements into rainwater harvesting systems with high initial costs. And 25% said they think technical complexity and lack of regulatory support could be a challenge. Only 17% answered limited public awareness is also a challenge.

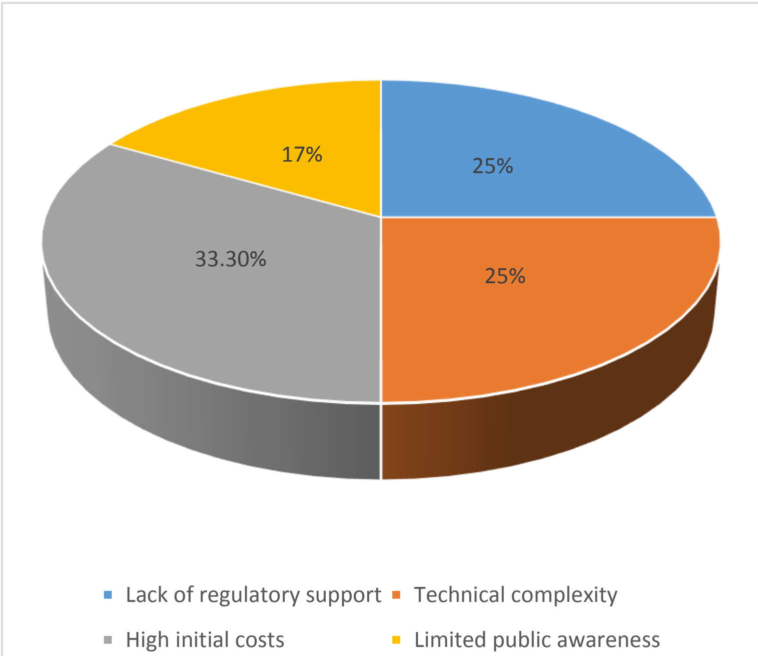


Figure 48: the primary challenge incorporating architectural elements into rainwater harvesting systems

Respondent's additional comments:

- Proper policy making, community engagement and optimized design solution needed to develop RWH system. It has to be a team effort. Architects and structural engineers should play a vital role to develop proper design solution
- Making proper design idea and deliver the idea to the client

to create a sustainable society.

- I think keeping the BNBC in mind, designers and engineers need to keep at least 50% of the land area for permeable paving. If we do so rain rainwater harvesting system will have a large area to collect water. Other issues like fire incidents and planting spaces for trees also will be ensured by that.
- Rainwater harvesting is very effective in case of high-density areas like some areas of Dhaka city, where the there is a shortage of water supply from WASA.
- For a better life & better living environment, we should enthusiastically people about RWH. If we Architects develop our policy it will be more helpful.

4.3 Architectural case study findings

The six architectural projects for various purposes and belong from different countries. **Primary Healthcare Center**, a Healthcare Center which is located in India. It has not utilized the rainwater but also showed how aesthetically can be implemented with architectural design. **Bullitt Center,** rainwater is used for meeting auxiliary functions such as watering plants and flushing toilets. **In Serpentine Pavilion,** Rainwater is highly valued. Its only function is to enhance spatial perception. Rainwater is gathered in a way that makes it easy to accumulate in a small pond, all with the purpose of providing children a place to play and celebrating nature. **Olympic Golf Course,** rainwater helped to mitigate the high demand in irrigation of the golf field**. Sustainable Market Square,** in Morocco showed how to use best in cleaning and toilet flushing for public place. **Panchsheel Colony**, showed rainwater harvest system has eighty percent of the total possible water collection capacity.

Following Table shoed all the comparison and key point of the findings.

Aspect	Case Study 1 	Case Study 2 	Case Study 3 	Case Study 4 	Case Study 5 	Case Study 6 
Name	**Primary Healthcare Center**	**Bullitt Center**	**Serpentine Pavilion**	**Olympic Golf Course**	**Sustainable Market Square**	**Panchsheel Colony**
Location	Southern India	Capitol Hill, Seattle, Washington.	London, UK	Brazil	Casablanca, Morocco	Delhi
Year Built	2011	2013	2017	2015	2012	2002
Architect(s)	Rajesh Renganathan, Iype Chacko	Miller Hull Partnership	Blake Villwock (Project Architect), Adriana Arteaga	RUA Arquitetos	Tom David Architecten	-
Building Type	Healthcare Center	Commercial	Public	Public	Public	Residential
Area	6000 sft	50,000 sft	3600 sft	68890 sft	-	3844330 sft
Roof Area*: Square Footage	5920square ft (AutoCAD analysis)	50,000 sft	3600 sft	70000 sft	-	3844330 sft
Materials	Light weigh corrugated steel, cement	PVC, lead, mercury, phthalates, BPA and formaldehyde, Steel	Wood, steel, slatted timber roof	Wood, steel, cement, timber roof	Wood, steel, cement,	Brick, concrete
Design Concept	Traditional architectural elements	Self-sufficiency, environment friendly	The form of the canopy is informed by a tree in the village of Gando in Burkina Faso	preventing excessive water consumption in humid climates	indigenous and local techniques	-
Water Catchment Purpose:	Irrigation	Building	Irrigation,	Irrigation, thermal comfort	cleaning and toilet flushing	Tap water, garden irrigation, thermal comfort, cleaning and toilet flushing
Sustainability	Climatic protection required for interior, Water Management, Green	Zero net energy	shade structure	Thermal comfort, water consumption	heat control and deigned with and innovative low-maintenance materials	water-efficient
Special feature	Roof design, water feature	Rainwater collection system with green roof	Water fall effect, Umbrella	Canopy surfaces	Canopy surfaces	80 % of the total water harvesting potential
Annual Average Rainfall: Inches	800mm/31.5 inch	815mm/ 32 inch	585 mm/23 inch	1,000/1500mm/39.37 inch	1200 mm/47.24 inch	774 mm/30.47 inch
Potential Annual Collection	**402 cubic metre (m3)**	**56,000-gallon**	**160 cubic metre (m3)**	**5950 cubic metre (m3)**	**-**	**1,74,575 cubic metre (m3)**
Material Efficiency Coefficient	0.9	0.9	0.8	0.9	0.9	0.9

Chapter Five
Discussion and Recommendation

5.1 Introduction:

This chapter will make an overall discussion about the major findings of the research and the role of architecture in creating resilient solution for water scarcity.

5.2 Discussion

5.2.1 Social parameter

From the study, it reveals that foundational level of knowledge within the community regarding rainwater harvesting is impressing but they need a base to encourage the adoption and utilization of rainwater harvesting systems. For adaptation of RWHS, Community involvement is seen as crucial. Regarding the use of harvested rainwater, the study found the overall over 70% people are familiar with the concept of rain water harvesting and they are willing to use the water for bathing, cooking and drinking purposes. The community will store the water at Chila (local term of small reservoir). By improving access to water, rainwater harvesting systems benefits the poor community. In the household survey, 67% of participants indicated that they already use and restore the rainwater. They also mentioned that during monsoon they harvest the rain water for bathing and cooking purposes. Efforts should focus in educating the community about safety and benefits of using harvested rainwater for various purposes. The survey also reveals important on the maintenance of rainwater harvesting systems. Majority of community people are concern about the long-term viability and benefits of rainwater harvesting in Cox's Bazar. However, it may face challenge due to lack of measures on creating infrastructure and maintaining the quality of the water.

5.2.2 Architectural design parameters

Architectural Solutions: The scope of application for the technical measures of rainwater utilization.

Design scopes	**Resiliency**	**Remarks**	**Reference**
Roofing Design	• Resilience to Climate Change • Sustainability and Self-sufficiency	Shape and Slope, material, Gutters and Downspouts	*Olympic Golf Course, Sustainable Market Square,* *VanDusen Botanical Garden*
Roof Material	• Durability and Longevity	Aesthetic consideration, Environment friendly	*Serpentine Pavilion, Bullitt Center*

	• Thermal comfort • Cost-effectiveness		
Permeable Pavements	• Urban heat and flood mitigation, • Maintaining ecosystem	Sustainable water supply	*VanDusen Botanical Garden*
Rain Garden	• Run off reduction • Flood mitigation	Sustainable water supply, Environment friendly	*Bullitt Center*
Water feature	• Structurally strong	Aesthetic consideration	*Primary Healthcare Center, Serpentine Pavilion*
Green roof	• Run off reduction • Thermal comfort • Carbon sequestration	Environment friendly	*Bullitt Center*
Roof structure	• Load-bearing Capacity	Structure design and materials	*Bullitt Center, Primary Healthcare Center, Serpentine Pavilion*
Wall Facade	• Thermal comfort • Water filtration	Sustainable water supply, Environment friendly	*https://www.greenbiz.com/article/spider-webs-and-succulents-inspire-water-collection-startup*

Table 5: Scope of Architecture

- According to study and analysis it can be state that "Roofing design" plays a significant role in increasing rainwater consumption. In order to maximize water flow towards collecting stations, the slope angle should be designed.
- Selection of roof material is another important design consideration. Metal Roofs, Tiles, Green Roofs (Vegetative Roofs), light corrugated sheets are found from the study.
- An inventive and environmentally friendly way to improve groundwater recharge, manage rainwater runoff, and reduce the pressure on urban drainage systems is through permeable pavements and landscape. It can be implemented on the residential driveways, large urban areas and park.
- Integrating the rainwater harvest system with building Systems offers a comprehensive and sustainable approach to water management by reducing freshwater use which also lowers the water bills.

- Government incentives, building codes, and zoning, design perimeters should be upgrade according to the efficiency of collecting more rainwater. RWH systems have the potential to use in adaptive ways.
- Initiatives for public education and awareness can strengthen the advantages of RWH and encourage a resilient and sustainable culture.

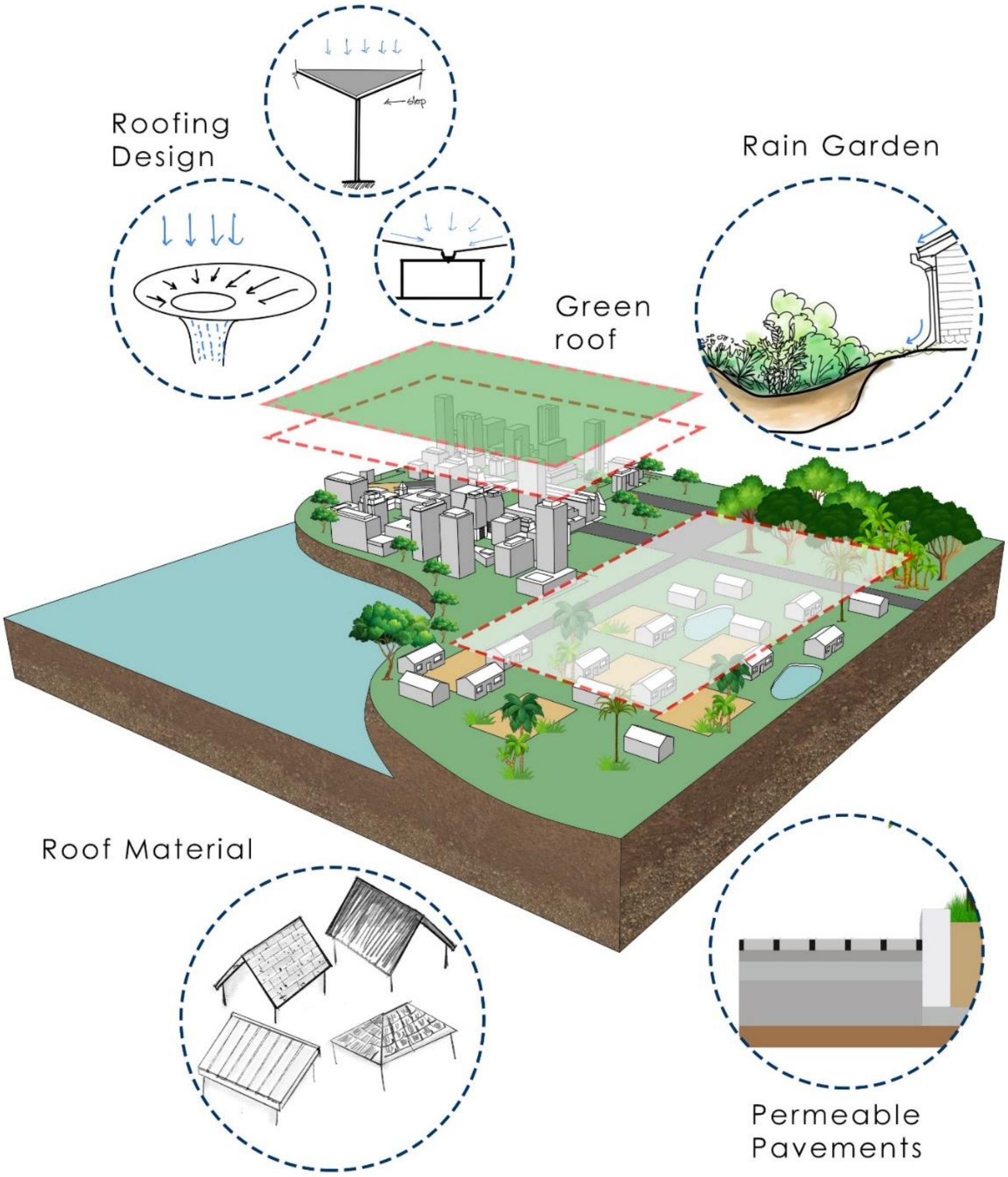


Figure 49: Scope of Architecture (Illustration by author)

Two major causes of the saline water intrusion in Cox's Bazar town including over-pumping of groundwater demand and the decrease in natural recharge as a result of the increasing coverage of land with pavements, buildings, and other structures. Form the survey and desktop study, it can be said that rainwater is preferable as alternative source of water over all other sources and it can be used in various ways. From the community perspective, they will be very happy if they can have an alternative source of water. One of the primary objectives of this study was to address global water scarcity which helps to create more focus on achieving sustainable development goal.

Additionally, the study also found about the success stories about the acceptance from the community and the potentiality of rainwater harvesting. From the case study review, it can be also established that role of architecture is very crucial in mitigating water scarcity by focusing on design of the build form and creating climate responsive structure. Implementing design with policy and guidelines encourages the integration of rainwater harvesting systems in architectural designs which will also help to minimizing the negative environmental effects. The SDG goal 6 is highly concerned with the management of sustainable water management and it aims to benefits the society and the environment as well. This study has focused on the community perspective about addressing the challenges and efficiency of rainwater harvesting. And the SDC goal 11, to make the city resilient and sustainable.

The paper has also studied the scope of architecture on the rainwater harvesting by creating climate and disaster resilient design. The study found that the architecture and rainwater harvesting has potentiality to implement and to create resilient and sustainable. However, there is a lack of knowledge about rainwater as a ground water alternative source among the community people.

5.3 Recommendation

Survey interpretations and insights suggest the following recommendations to promote rainwater harvesting (RWH):

• Conducting informational meetings and seminars to teach the public about the advantages, security, and useful applications of collected rainwater, with a particular emphasis on issues related to flavor and quality.

• Involving community people in the design and execution of rainwater collection initiatives. This will guarantee sustained achievement and cultivate a feeling of ownership.

• Creating guidelines for preserving the quality and safety of collected rainwater for consumption and food preparation. This may involve the implementation of filtering systems and the implementation of frequent quality checks.

• Establishing preliminary initiatives that demonstrate the efficacy and security of Rainwater Harvesting (RWH) systems, offering concrete evidence to the community.

• Engaging cooperation with local authorities to formulate policies that endorse and advance rainwater harvesting, guaranteeing that the construction of infrastructure incorporates rainwater harvesting systems.

• Involving architects and structural engineers in developing efficient design solutions for rainwater harvesting (RWH) systems. Ensure that the designs adhere to the standards set by the Bangladesh National Building Code (BNBC) and dedicate a minimum of 50% of the land area for permeable paving.

• Incorporating Rainwater Harvesting (RWH) systems into urban planning, specifically in densely populated places such as Dhaka, where there is a significant scarcity of water supply. This has the potential to enhance the accessibility and adaptability of water resources.

• Coordinating and arranging events and activities aimed at fostering enthusiasm for Rainwater Harvesting (RWH) among members of the community. Emphasize the enduring advantages and ecological consequences.

• Promoting architects to actively engage in the development and promotion of policies that endorse rainwater harvesting (RWH), so contributing to the establishment of a more sustainable society.

•Retrofitting with rainwater harvesting system in mega structures with large roof area such as new rails station, stadium, Marin culture, Circuit House, Parjatan Motels, Big restaurants, Markets, Khurushkul special ashrayan project.

By employing these suggestions, the community can improve its understanding, involvement, and infrastructure for efficient rainwater collection, resulting in a more sustainable and resilient environment.

Chapter Six
Conclusion

6.1 Conclusion

Water has been always an essential to human survival since the beginning of the time. Water resources are seriously endangered due to a number of factors, including industrialization, environmental pollution, rapid population growth, improper agricultural practices, distorted urbanization, climate change, and global warming. Creating alternative source of water is there for very crucial in this time. Following this, researchers made predicts that rainwater harvesting is highly productive with the help of technologies and designs innovation.

By integrating rainwater harvesting systems (RWH) into building designs, architects can create structures that are not only self-sufficient in water management but also contribute to broader urban resilience and plays crucial role improving climate and disaster resilience.

Ensuring best design guidelines for effectively integrating rainwater harvesting systems into building architects and policymakers should take the lead.

The interconnection between technology, creative design, and environmentally friendly strategies highlights RWH's ability to solve present and future water-related problems.

In the end, rainwater harvesting in architecture is an essential step towards creating sustainable, adaptable, and resilient urban ecosystems that can endure the effects of natural disasters and climate change. Rainwater harvesting should to be encouraged as a sustainable approach to reduce water scarcity. In conclusion, the primary step to acknowledge people about the advantages of rainwater harvesting then incorporate with technology. The legislative structure and financial incentives from the government must come next in order to encourage the use of rainwater collection technologies.

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Appendix A.

Individual survey questionnaire

Household survey

Name:	**Age:**
Gender:	**Occupation:**

Awareness and Knowledge			
1. How familiar are you with the concept of rainwater harvesting?			
Very familiar	Somewhat familiar	Not familiar at all	
2. How would you rate your level of awareness regarding rainwater harvesting techniques and practices?			
Very aware	Moderately aware	Not aware at all	
3. How well do you understand the potential benefits of rainwater harvesting for improving water access in Cox's Bazar?			
Very well	Moderately well	Not well	
Community Participation			
4. How much do you think community involvement matters to the success of rainwater collection projects?			
Extremely important	Moderately important	Not important	
Acceptance and Usage Patterns			
5. How likely are you to consider implementing rainwater harvesting systems in your household or community?			
Yes, very likely Somewhat likely Not likely Unsure			
6. How frequently do you currently use harvested rainwater for domestic purposes in your household??			
Yes, very likely	Somewhat likely	Not likely	Unsure

7. In what sector do you use/or likely to use harvested rainwater in your household?

Drinking	Yes	Somewhat	No
Cooking	Yes	Somewhat	No
Bathing	Yes	Somewhat	No
Cleaning	Yes	Somewhat	No

8. Do you currently use harvested rainwater for agricultural or farming purposes?

Yes	No

9. What are the main challenges do you face using rainwater for domestic, agricultural or farming purposes? (Select all that apply)

Insufficient quantity of harvested rainwater
Inconsistent rainfall patterns
Lack of suitable irrigation infrastructure
Soil quality issues
Other (please specify)

10. Have you been involved in any community initiatives or projects related to rainwater harvesting?

Yes Very likely	Somewhat likely	Not likely	Unsure

11. Are there any government or NGO support programs for rainwater harvesting in your area?

Yes	No

If there would be interested to participate?

Yes	No

12. In your opinion, how sustainable is rainwater harvesting as a sustainable water management solution in Cox's Bazar?

Highly sustainable
Moderately sustainable
Not sustainable

- Describe challenges you may face of facing?
- How to engage community in this practice?
- Main source of water?

Appendix B.

Key informant Interview Sample Questionnaire

Survey on Integrating Architecture in Rainwater Harvesting Systems

Introduction:

Thank you for participating in this survey. This survey aimed at understanding perspectives on integrating architecture in rainwater harvesting systems (RWH). Your input as an architect, engineer, or policymaker is invaluable in shaping sustainable practices in urban development.

Demographic Information:
a. What is your profession?

Architect

Engineer

Policymaker

Other (please specify): ________________

b. How many years of experience do you have in your field?

Less than 5 years

5-10 years

More than 10 years

1. To what extent do you think architecture can enhance the effectiveness and aesthetics of rainwater harvesting systems?

A. Not at all B. Slightly C. Moderately D. Considerably E. Significantly

2. In your opinion, which of the following architectural sector or technological expansions could be improved further to increase rainwater harvesting?

A. Green roofs B. Rain gardens C. Permeable pavements D. Integrated storage systems E. Other (please specify): ________________

3. What are the key areas for research and development to advance the integration of RWH systems in architectural designs?

A. Materials innovation
B. Design optimization
C. Policy development
D. Community engagement
E. Other (please specify): ________________

4. In order to encourage the implementation of RWH in architecture and urban planning, how can multidisciplinary cooperation between architects, engineers, and policymakers be improved?

A. Better communication channels
B. Joint training programs
C. Policy workshops
D. Financial incentives
E. Other (please specify): ________________

5. In your opinion what are the primary challenges could be faced when incorporating architectural elements into rainwater harvesting systems?

A. Lack of regulatory support
B. Technical complexity
C. High initial costs
D. Limited public awareness

6. Kindly add any additional comments or insights you would like to recommend regarding the integration of architecture and rainwater harvesting?