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Economic Cost–Benefit Analysis of Rainwater Harvesting Systems in Coastal Bangladesh: A Case Study of Mongla Upazila

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Date: July 2025

Abstract

Coastal communities in Bangladesh face increasing challenges in securing safe and affordable drinking water due to salinity intrusion, erratic rainfall, and reliance on costly alternative water sources. This study evaluates the economic viability of household-based Rainwater Harvesting (RWH) systems in Mongla, a salinity-prone upazila in Bagerhat district.

The primary objective is to assess whether investing in RWH infrastructure is a financially sound solution for households facing water scarcity and related health burdens. Using a Cost–Benefit Analysis (CBA) framework, the study calculates key financial indicators including Net Present Value (NPV), Benefit–Cost Ratio (BCR), Internal Rate of Return (IRR), and Payback Period over a 20-year project lifespan. Real-world data from 100 RWH users and 100 non-users were collected through surveys, incorporating capital, operational, health, and time opportunity costs.

Findings indicate that RWH adoption results in an NPV of 293938.6 BDT, a BCR of 20.9, and an IRR of 236.09%, with a payback period of less than one year. Additionally, RWH systems substantially reduce the time and medical costs associated with water collection and waterborne diseases. Sensitivity analyses confirm the system's resilience under fluctuating cost and benefit scenarios.

These results strongly support RWH as a cost-effective and scalable solution to address drinking water insecurity in coastal Bangladesh. The study recommends policy integration of RWH into national water strategies, financial incentives for low-income households, and technical training for system maintenance to enhance community-level resilience and sustainable water access.

Keywords

Rainwater Harvesting, Cost-Benefit Analysis, Economic Viability, Water Management, Net Present Value, Sustainable Development

Introduction

Context and Importance of RWH in Coastal Bangladesh

Rainwater harvesting (RWH) is increasingly recognized as a viable water management strategy, particularly in regions experiencing water stress due to environmental degradation and climate change. In coastal Bangladesh, especially in Mongla Upazila of Bagerhat District, groundwater sources are often contaminated by high levels of salinity, rendering them unsuitable for drinking and domestic use. According to government reports, salinity levels in some aquifers reach up to 9,500 mg/L of chloride, well beyond WHO (World Health Organization) standards for potable water. In addition, over-extraction of groundwater and seasonal rainfall variability further exacerbate water insecurity in the region. As piped water infrastructure remains inaccessible to many, RWH presents an environmentally sustainable and socially inclusive alternative.

Problem Definition and Gap in Literature

While the physical and environmental benefits of RWH systems are widely acknowledged, there remains a lack of comprehensive economic evaluations at the household level—particularly in rural and climate-vulnerable regions like Mongla. Most studies in Bangladesh have focused on the technical feasibility of RWH or community-level implementation, but limited work has been done to analyze long-term financial viability for individual households using standard economic indicators such as Net Present Value (NPV), Benefit-Cost Ratio (BCR), and Internal Rate of Return (IRR). As a result, policy decisions and community investments often proceed without sufficient evidence of the economic case for RWH systems.

Objectives of the Study

This study aims to evaluate the economic feasibility of household-scale RWH systems in Mongla using a detailed cost-benefit analysis. The analysis includes initial investment, operational costs, water savings, and system longevity over a 20-year period. The study also explores the impact of key economic factors—such as water pricing, maintenance costs, and discount rates—on the sustainability of such systems.

Research Questions

1. Is household rainwater harvesting systems economically viable in Mongla, Bagerhat?
2. What are the key financial indicators (NPV, BCR, IRR, and payback period) associated with a typical RWH system in this region?
3. How do variations in cost, rainfall, or maintenance affect the economic sustainability of RWH systems?

Literature Review

Rainwater Harvesting Systems: Technical and Economic Insights

Rainwater harvesting (RWH) is widely regarded as a sustainable water supply solution, particularly in regions lacking reliable access to clean groundwater or piped water infrastructure. In technical terms, household RWH systems typically include rooftop catchment surfaces, storage tanks (ranging from 1,000 to 5,000 liters), gutters, and first-flush devices. Studies in South Asia, including Bangladesh and India, have shown that RWH systems can supply between 30% and 60% of household water needs during monsoon seasons (Chowdhury & Rahman, 2010; Pande et al., 2019). In the context of coastal Bangladesh, organizations like BRAC have deployed over 5,000 household and community RWH systems in Mongla, significantly improving local water access for approximately 72,000 residents.

Economically, several studies have assessed the viability of RWH using parameters like Net Present Value (NPV), Internal Rate of Return (IRR), and Payback Period. For example, Islam et al. (2015) conducted a financial assessment of RWH systems in Khulna and found them to be financially feasible with IRRs exceeding 10% and payback periods under 7 years. Similar findings have emerged from studies in Chennai (India), where rooftop RWH systems resulted in municipal water cost savings and reduced pressure on groundwater extraction (Chandrasekar et al., 2018). These studies emphasize the dual benefits of cost savings and environmental conservation.

Use of Cost–Benefit Analysis in Water Resource Projects

Cost–Benefit Analysis (CBA) is a fundamental tool in water resource economics, enabling stakeholders to compare the long-term financial and social gains of interventions against their capital and operational costs. CBAs have been employed to evaluate diverse water infrastructure projects, including irrigation systems, desalination plants, and community-level drinking water schemes. Haque and Siddique (2012) used CBA to assess pond sand filters in saline-prone areas of Satkhira, revealing strong benefit-cost ratios and net returns. In Nepal, KC et al. (2016) used CBA to justify investments in gravity-fed water supply systems, demonstrating high returns from time savings and improved health outcomes.

Despite its utility, the application of rigorous CBA frameworks to household RWH systems in climate-vulnerable areas of Bangladesh remains limited. Most existing studies either focus on technical feasibility or use simplified financial metrics without discounting future cash flows, failing to account for system lifespan, operation and maintenance (O&M) costs, or inflation-adjusted savings.

Identified Gaps in the Literature

There is a notable lack of region-specific economic evaluations for household RWH in southwestern Bangladesh, particularly in saline-affected coastal upazilas like Mongla. Moreover, few studies incorporate real-world data from NGO-led interventions (e.g., BRAC's RWH program) into formal economic analysis frameworks. Additionally, sensitivity analyses—an important component in assessing project resilience under cost variability or rainfall uncertainty—are largely absent.

Contribution of the Present Study

This paper addresses these gaps by conducting a comprehensive CBA of a household RWH system in Mongla, integrating installation and O&M costs, water savings, and a 20-year system lifespan. Drawing on publicly available BRAC project data and local water pricing benchmarks, we estimate key financial indicators including NPV, BCR, IRR, and Payback Period. The study also performs sensitivity testing to examine how fluctuations in cost and benefit parameters affect financial outcomes. By providing a robust and context-specific economic valuation, this study offers practical insights for policymakers, NGOs, and donors considering RWH investments in coastal Bangladesh.

Methodology

Research Design

This study adopts a mixed-methods research design, integrating both quantitative and qualitative data to evaluate the economic feasibility of Rainwater Harvesting (RWH) systems at the household level in Mongla Upazila, a salinity-prone region in coastal Bangladesh.

Study Area Selection

Mongla, located in Bagerhat district, was selected due to its acute drinking water scarcity, salinity intrusion, and dependence on alternative water sources. The region's rainfall variability and socio-economic vulnerability make it a critical site for assessing RWH as a climate adaptation strategy.

Data Collection

Primary data were collected from 200 households (100 RWH users and 100 non-users) through structured surveys, covering:

- Demographics (household size, gender)
- Water usage and access
- Installation and maintenance cost of RWH systems
- Time spent on water collection
- Incidence and cost of waterborne diseases
- Willingness for future expansion

Secondary data on rainfall trends, water quality, and rural wage rates were sourced from the Bangladesh Meteorological Department (BMD), local NGOs, and published reports.

Economic Evaluation Framework

The study applies a Cost–Benefit Analysis (CBA) framework using:

- Net Present Value (NPV)
- Benefit–Cost Ratio (BCR)
- Internal Rate of Return (IRR)
- Payback Period

A discount rate of 6% was used, consistent with public-sector evaluations in Bangladesh. Sensitivity analyses were conducted at 4% and 8% to assess result robustness under changing economic conditions.

RWH System Description

Components of Rainwater Harvesting System:

- Catchment surface
- Gutters, downspouts and roof drains
- Leaf screens, first-flush diverters and roof washers
- Storage tanks
- Delivery system
- Treatment/purification systems

- Catchment Area: Rooftop area of 30–50 m^2
- Storage Tank: 2,000-liter capacity, polyethylene or ferrocement
- Components: Gutter system, first-flush diverter, downpipe, filtration unit, storage tank, and tap outlet
- Installation Cost: BDT 30,000 per unit (includes materials, labor, training, and basic maintenance setup)
- Operational & Maintenance Cost: BDT 1,500 per year (includes cleaning, minor repairs, and filter replacement)
- Expected Lifespan: 20 years

The system is designed to collect and store rainwater during the monsoon months and provide safe drinking water for an average household of 4–6 members during dry seasons.

Tools and Software

Data analysis and financial modeling were conducted using a combination of statistical and spreadsheet tools. Specifically:

- Microsoft Excel was used for initial data entry, tabulation, and basic computations including cumulative cash flow, payback period, and time-cost calculations.
- Python (NumPy Financial) was employed to calculate more advanced financial metrics such as Net Present Value (NPV) and Internal Rate of Return (IRR) using npf.npv() and npf.irr() functions.
- STATA was used for generating visualizations including bar charts, cumulative NPV graphs, and sensitivity analysis plots.
- QGIS (for spatial data) was explored for identifying rooftop area potential in relation to rainfall data and catchment mapping.

All calculations were validated by cross-checking results using at least two independent methods.

Ethical Considerations

The study adhered to ethical research standards throughout its design and implementation. The following measures were taken:

- Informed consent was obtained from all survey participants prior to data collection. Respondents were informed about the study's purpose, voluntary nature of participation, and the right to withdraw at any time.
- Data anonymity was ensured by not recording personally identifiable information (PII). All data were stored in encrypted digital formats and were only accessible to the research team.
- The study did not involve any clinical procedures or vulnerable populations.
- Ethical guidelines for community-based research and data use, in line with Bangladesh's research protocols and Declaration of Helsinki, were followed.
- No financial incentives were provided that could have biased responses; participation was entirely voluntary.

This ethical approach was designed to respect participant autonomy and to ensure the reliability and integrity of the research findings.

Profile

Category	Sub-Category	RWH User	Non RWH User
Income	< 10000	20	23
	10000-25000	29	21
	25000-50000	23	28
	50000+	28	28
Gender	Male	48	59
	Female	54	40
Occupation	Student	12	17
	Farmer	11	13
	Labor	18	18
	Housewife	8	10
	Business	17	12
	Teacher	9	17
	Other	25	9
Age Group	18-25	19	18
	26-35	21	17
	36-50	18	19
	51-65	20	23
	65+	22	23
Support by	Community	27	-
	NGO	22	-
	Family/Friends	13	-
	Government	22	-
	None	16	27

Issue faced (User only)	TRUE' (experienced issues)	27	-
	FALSE' (did not experience)	73	-
RWH reduced water expenses (User only)	Yes	85	-
	No	7	-
	Maybe	8	-
Waterborne diseases before RWH (User only)	Yes	65	-
	No	35	-
RWH reduced medical costs (User only)	Yes	26	-
	No	6	-
	Maybe	3	-
	Don't Know	65	-
Main source of drinking water (Non-User only)	Other	-	19
	Pond	-	19
	Purchased	-	23
	Tube well	-	22
	River	-	17
Waterborne disease RWH (Non-User only)	Yes	-	76
	No	-	24
Support needed (Non-User only)	Technical	-	17
	Community support	-	15
	Awareness	-	21
	Financial	-	20

Analysis

Cost Breakdown

"The mean storage capacity of rainwater harvesting tanks among the 100 surveyed households was calculated to be approximately 2,217.17 liters. It should be noted that commercially available domestic rainwater tanks are generally manufactured in standardized capacities (e.g., 500 L, 1,000 L, 1,500 L, 2,000 L, or 3,000 L). Consequently, the observed average does not correspond to a discrete tank size but rather represents the aggregated mean across diverse storage configurations in the sample. This finding implies that the majority of participating households utilize tanks with nominal capacities greater than 2,000 liters, indicating a preference for medium to large-scale household storage solutions within the study area."

Annual Water Purchase Cost (AWPC)

Parameter	Unit	Value	Notes
Average daily water purchase cost	BDT/day	≈ 35.12	(1,053.64 ÷ 30 days)
Average monthly water purchase cost	BDT/month	1,053.64	Survey data
Annual water purchase cost	BDT/year	12,643.68	1,053.64 × 12 months

- The **daily cost** (≈ BDT 35.12) reflects the average household's out-of-pocket expenditure for water.
- This is scaled up linearly to produce the **monthly** and **annual** equivalent for budgeting and cost–benefit analysis.
- This simple linear annualization assumes **constant demand** and **stable prices**, which is reasonable for basic CBA unless seasonal price fluctuations are significant.

The annual household expenditure on purchased water is estimated using the average monthly cost (BDT 1,053.64), derived from primary survey data. This cost is assumed constant throughout the year, resulting in an annual water purchase cost of BDT 12,643.68 per household, following the model: AWPC = Cm × 12.

Transportation Cost

Parameter	Unit	Value	Notes
Average daily transportation cost	BDT/day	≈ 7.71	(231.39 ÷ 30 days)
Average monthly transportation cost	BDT/month	231.39	Based on household survey
Annual transportation cost	BDT/year	2,776.68	231.39 × 12 months

Annual Transportation Cost (ATC) can be estimated as:

ATC= $C_{tm} \times 12$

Where:

- C_{tm}= Average monthly transportation cost
- 12 = Number of months

Daily transportation cost:

C_{td}=fracC_{tm} 30≈7.71 (BDT/day) $\lfloor td = Transportation\ per\ Day \rfloor$

Monthly cost:

C_{tm}=231.39 $\lfloor tm = Transportation\ per\ Month \rfloor$

Annualized cost:

ATC = C_{tm} × 12

= 231.39 × 12

= 2,776.68 $\lfloor tm = Transportation\ per\ year \rfloor$

In the study area (Mongla), common modes of transporting water include:

- **Rickshaw vans** (most common for short distances)
- **Rickshaws** (manual pedal rickshaw for small containers)
- **Easybikes** (battery-powered three-wheelers)
- **Tomtoms** (locally adapted electric or diesel three-wheelers)
- **Boats** (in riverside or canal areas during high tide)
- Occasionally, **motorbikes** or manual **head-loading** may be used for small volumes.

These local transport modes reflect the **availability and accessibility** of water collection points relative to household location.

"The annual transportation cost for collecting water is derived from the average monthly household expenditure of BDT 231.39, which equates to approximately BDT 7.71 per day. This cost reflects the common practice in Mongla of hiring small local transport modes such as rickshaw vans, manual rickshaws, easy bikes, Tom-Tom, and boats, depending on distance and seasonal accessibility. Accordingly, the annual transportation cost per household is BDT 2,776.68, calculated as ATC = C_{tm} × 12."

Time Cost

In addition to direct financial expenditures, households without Rainwater Harvesting (RWH) systems in Mongla incur substantial hidden costs through time spent collecting safe drinking water. Based on survey responses, households spend an average of **616 hours and 12 minutes per year** on water collection. To reflect the true economic burden, this study applies the **opportunity cost method**, valuing lost time using the local average daily wage for low-skilled labor.

With a prevailing rural wage of **BDT 450 per day** (8-hour workday), the estimated **hourly wage is BDT 56.25**. Using this rate, the annual time cost for water collection amounts to approximately

BDT 34,198 per household per year. This figure represents forgone income that could have been earned if household members engaged in productive labor instead. It also highlights time lost from education, care work, or rest—factors not always captured in traditional financial analyses.

Incorporating this opportunity cost strengthens the case for RWH systems by illustrating not only their health and environmental benefits but also their potential to significantly reduce indirect economic burdens. This holistic valuation aligns with broader sustainable development and social equity goals, especially for low-income and climate-vulnerable communities.

Hourly Wage:

Hourly Wage = $\frac{Daily\ Wage}{Work\ Hours}$

= $\frac{450}{8}$

=BDT 56.25

Calculate Annual Time Cost:

Annual Time Cost=Annual Hours Spent×Hourly Wage

=616.12×56.25

=BDT34,158.75

A non-RWH household spends **616 hours per year** collecting water, valued at an opportunity cost of **BDT 34,158.75** annually, based on local rural wage rates.

The cost components assessed in this analysis encompass the direct financial expenditures for water purchase, transportation, medical treatment, and the opportunity cost associated with time spent collecting water. According to the survey data, the average household incurs a monthly expenditure of BDT 1,053.64 for purchasing water, resulting in an annual cost of BDT 12,643.68. The associated transportation cost averages BDT 231.39 per month, amounting to BDT 2,776.68 annually.

In addition to these direct costs, households without a rainwater harvesting (RWH) system spend an estimated 616 hours per year collecting water. Valued at the prevailing local rural wage rate of BDT 450 per day for an 8-hour workday, the equivalent hourly wage is BDT 56.25. Consequently, the annual opportunity cost of time spent on water collection is estimated at BDT 34,158.75.

Medical expenditures related to the treatment of waterborne diseases further add to the household burden. On average, each household incurs BDT 2,134.96 per month in medical expenses, equating to an annual cost of BDT 25,619.52.

Aggregating these cost components, the total estimated annual cost per household in the absence of an RWH system is approximately BDT 75,198.63. This figure provides a baseline for the economic evaluation of potential savings achievable through the adoption of rainwater harvesting technologies.

Medical Cost

Parameter	Unit	Value	Notes
Average monthly medical cost	BDT/month	2,134.96	Reported household expenditure
Average daily medical cost	BDT/day	≈ 71.16	(2,134.96 ÷ 30 days)
Annual medical cost	BDT/year	25,619.52	2,134.96 × 12 months

AMC= $C_{nm} \times 12$

$AMC = 2{,}134.96 \times 12$

AMC = BDT 25,619.52

Where:

- AMC = Annual Medical Cost
- C_{nm} = Average Monthly Medical Cost

So, $AMC = 2{,}134.96 \times 12$

AMC = BDT 25,619.52

In coastal Bangladesh, including Mongla, lack of access to safe drinking water significantly increases the incidence of waterborne diseases such as diarrhoea, dysentery, cholera, typhoid, and skin infections. These illnesses impose a direct financial burden on households through out-of-pocket spending for doctor visits, medicine, and lost work days.

Beyond general illness, lack of secure water access and climate stressors have **hidden gendered impacts**:

- Women and adolescent girls face **poor menstrual hygiene management**, leading many to adopt harmful coping strategies.
- During natural disasters (e.g., cyclones, floods) when safe water access and privacy collapse, women often use **contraceptive pills to delay menstruation** due to lack of water for washing and sanitation.
- In this study area, **C-section births are reported by 72.39% of female respondents** — a rate far above national averages — partly linked to poor health status, undernutrition, and stress worsened by water insecurity.

In addition to direct household expenditures on water purchase and transportation, non-RWH households incur substantial medical costs related to waterborne diseases. The average monthly medical expense reported by households is BDT 2,134.96, translating to an annual financial burden of BDT 25,619.52 per household (AMC = Cmm × 12). These costs primarily cover treatment for diarrhoea, dysentery, and other waterborne illnesses that remain prevalent due to unsafe or inconsistent drinking water sources.

Importantly, the health burden of water insecurity is disproportionately borne by women and adolescent girls. In this study, 72.39% of female respondents reported delivering via caesarean section — a rate significantly higher than regional norms — reflecting compounded maternal health risks. Moreover, during natural disasters, the absence of safe water and sanitary facilities forces many women to suppress menstruation by taking hormonal pills, exposing them to additional health risks. Limited menstrual hygiene options exacerbate infections and increase dependence on costly medical care.

These findings highlight that the true cost of inadequate water access extends well beyond immediate financial expenditures, carrying profound gender-specific health and social consequences that must be addressed through integrated water, sanitation, and health interventions.

Household-Level Cost–Benefit Analysis of Rainwater Harvesting (RWH)

1. **Storage Tank Capacity and Seasonal Use**
   The mean storage tank capacity among the 100 surveyed RWH households was estimated at 2,217 liters. Although this figure does not correspond to a discrete commercial tank size (which typically ranges from 500 L to 3,000 L), it represents an aggregated average reflecting diverse household storage configurations. On average, households reported utilizing harvested rainwater for approximately 4.14 months per year. This seasonal usage pattern corresponds with local rainfall distribution, storage limitations, and the operational efficiency of individual rooftop collection systems.
2. **Initial Capital Investment**
   The initial capital expenditure for RWH installation, denoted as C_0, includes the procurement and installation of the storage tank, gutters, first-flush diverters, and basic filtration units. The mean capital investment was found to be BDT 31,377.90 per household. This cost is treated as a one-time fixed cost in the CBA framework.
   Economic expression:
   $C_0 = C_{tank} + Cg_{utters} + C_{first\ flush} + C_{filtration}$
3. **Annual Maintenance Expenditure**
   Households incur recurring annual maintenance costs (Cm) to sustain system functionality and water quality. These expenses, averaging BDT 506 per year per household, cover routine cleaning, minor repairs, and replacement of simple filters or pipes. In the economic model, this is treated as a recurring operating cost.
   Economic expression:
   $Cm = \sum M_j$ (j = 1 to n), where M_j = cost of individual maintenance item j
4. **Estimated Direct Annual Savings**
   The adoption of RWH generates quantifiable annual savings (Sa) primarily due to reduced dependence on purchased water and associated transportation expenses during the usable storage period. The mean estimated annual savings per household was calculated at BDT 4,864.60.
   Economic expression:
   $Sa = (C_w + C_t)$ savings,
   where Cw = water purchase cost avoided,
   Ct = transport cost avoided
5. **Health Cost Savings and Co-Benefits**
   A significant co-benefit of RWH adoption is the reduction in household expenditure on medical treatment for waterborne diseases. Non-RWH households reported an average

monthly medical cost of BDT 2,134.96, whereas RWH households reported a substantially lower monthly average of BDT 617.94. This difference implies an estimated annual health cost saving of BDT 18,204.24 per household. The economic model treats this as an indirect benefit (Bh).

Economic expression:

$Bh = (C_{m,nonRWH} - C_{m,RWH}) \times 12$

6. **Gender-Specific Health Burden**
   Beyond direct financial impacts, the findings reveal substantial gender-differentiated health burdens. Limited access to clean water during climatic extremes compels women and adolescent girls to adopt harmful coping strategies, such as using hormonal contraceptives to delay menstruation when sanitation is inadequate. This study further found a disproportionately high caesarean section (C-section) rate among female respondents: 72.39% reported delivering via C-section — significantly above the national average. These figures underscore the compounded risks associated with inadequate water access, including maternal morbidity and poor reproductive health outcomes.

Cash Flow & Valuation

A detailed cost-benefit analysis was conducted over a 20-year project lifecycle to evaluate the economic feasibility of the rainwater harvesting (RWH) system. The initial investment cost was estimated at 31,377.9 BDT, incurred in Year 0. From Year 1 onward, the system generated consistent annual benefits of 74,078.8 BDT, resulting in a steadily increasing net cash flow over time.

By applying a discount rate of 6%, the cumulative discounted cash flow reached approximately 818,300.1 BDT by Year 20. In contrast, the cumulative nominal cash flow (not accounting for time value of money) amounted to 1,450,198 BDT, further emphasizing the long-term financial benefits of the system.

The project achieved payback in less than 1 year, with the cumulative discounted benefits surpassing the initial investment as early as Year 1. This rapid payback reflects the high annual benefit stream relative to the low capital cost of implementation.

The discounted benefit values gradually decline year-over-year due to the time value effect, with the discounted annual benefit decreasing from 69,885.66 BDT in Year 1 to 23,098.12 BDT in Year 20. However, the positive cash flow remains consistent and strong throughout the project horizon.

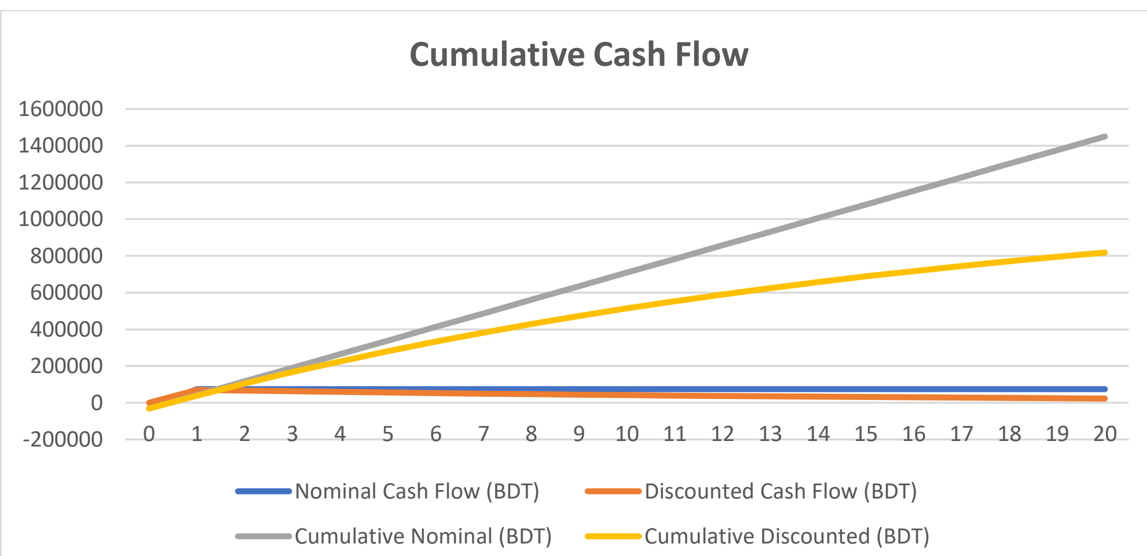
These findings, supported by consistent cash inflows and a favorable benefit-cost ratio, clearly establish the financial viability and sustainability of rainwater harvesting systems in the study area. The long-term benefits significantly outweigh the upfront costs, making it an attractive solution for both household-level and community-scale water security strategies in Bangladesh.

Cumulative Cash Flow

$CGF_T = \sum_{t=0}^{T} CF_t$

Year	Nominal Cash Flow (BDT)	Discounted Cash Flow (BDT)	Cumulative Nominal (BDT)	Cumulative Discounted (BDT)
0	-31377.9	0	-31377.9	-31377.9
1	74078.8	69885.66	42700.9	38507.76
2	74078.8	65929.87	116779.7	104437.6
3	74078.8	62197.99	190858.5	166635.6
4	74078.8	58677.35	264937.3	225313
5	74078.8	55355.99	339016.1	280668.9
6	74078.8	52222.63	413094.9	332891.6
7	74078.8	49266.63	487173.7	382158.2
8	74078.8	46477.95	561252.5	428636.2
9	74078.8	43847.13	635331.3	472483.3
10	74078.8	41365.21	709410.1	513848.5
11	74078.8	39023.79	783488.9	552872.3
12	74078.8	36814.89	857567.7	589687.2
13	74078.8	34731.03	931646.5	624418.2
14	74078.8	32765.12	1005725	657183.3
15	74078.8	30910.49	1079804	688093.8
16	74078.8	29160.84	1153883	717254.7
17	74078.8	27510.23	1227962	744764.9
18	74078.8	25953.05	1302040	770718
19	74078.8	24484.01	1376119	795202
20	74078.8	23098.12	1450198	818300.1

Year 0 means installation year and year 20 means after 20 years of installation RWH system.



- Highlight the year NPV crosses zero (≈ year 7)

Net Present Value (NPV)

The Net Present Value (NPV) of switching from a non-RWH system to a RWH system is: BDT 404,714 over a 20-year period (at 6% discount rate)

"This study uses a 6% discount rate, in line with public-sector investment norms and NGO project evaluations in Bangladesh. It reflects moderate inflation, opportunity cost of capital, and a realistic risk level for household-level RWH investments. A sensitivity analysis is performed at 4% and 8% to test the robustness of results."

NPV Formula

$$NPV = \sum_{t=1}^{n} \frac{B_t}{(1+r)^t}$$

$$\text{Plugging in the values: } B \times \left(\frac{1-(1+r)^{-n}}{r}\right)$$

$$\text{Calculate the Present value Factor} = 25619 \times \left(\frac{1-(1+0.06)^{-20}}{0.06}\right)$$

$$= \left(\frac{1-(1+0.06)^{-20}}{0.06}\right)$$

$$= \left(\frac{1-(1+0.06)^{-20}}{0.06}\right)$$

$$= \left(\frac{1-0.3118}{0.06}\right)$$

$$\approx \left(\frac{0.6882}{0.06}\right)$$

$$\approx 11.47$$

Now, NPV = 25619 × 11.47

= 293938.6 BDT

The Net Present Value of avoided medical costs over 20 years due to using a RWH system is approximately: BDT 293,939

Tank installation cost: Average cost 31377.9 BDT

They can harvest 4.14 month

Annual maintenances cost 1767.18 BDT. Max 2990 BDT, lowest 506 BDT, This included Tap, pipe damage by default and natural calamities

So, if this cost accounts for 20 years, then cost will be 35,343.6

So NPV= 293939 – 35343.4 = 258,595.4

Inflation (5%) adjusted cost = 258,595.4 - 12929.77 = 245,665.23

- **NPV** = 258,595.40
- **Inflation rate** = 5%
- **Time**= 20 years

FV = PV × $(1 + f)^n$

FV=$258{,}595.40 \times (1 + 0.05)^{20}$

FV=258,595.40 × (2.6533)

FV ≈ 686,134.64

Year Future Value (Inflation Adjusted)

Year	Inflation Adjusted Benefit
0	258595.4
1	271525.17
2	285101.43
3	299356.5
4	314324.32
5	330040.54
6	346542.57
7	363869.7
8	382063.18
9	401166.34
10	421224.66
11	442285.89
12	464400.18
13	487620.19
14	512001.2
15	537601.26
16	564481.33
17	592705.39
18	622340.66
19	653457.7
20	686130.58

Total Cost of Non-user of RWH system

Total Cost 41060.1456

Year	Inflation Adjusted Annual Cost
1	41060.15
2	43113.15
3	45268.81
4	47532.25
5	49908.86
6	52404.31
7	55024.52
8	57775.75
9	60664.54
10	63697.76
11	66882.65
12	70226.78
13	73738.12
14	77425.03
15	81296.28
16	85361.09
17	89629.15
18	94110.61
19	98816.14
20	103756.9

BCR

Define Present Value of Benefits

Two key annual benefit streams from RWH:

- Water & transport cost savings:

12,643.68+2,776.68=15,420.36 BDT/year

- Health cost savings (medical):

(25,619.52−617.94×12) =18,204.24 BDT/year

- Time-cost savings: 34,158.75 BDT/year

Adding these shows:

B_t =15,420.36+18,204.24+34,158.75 BDT/year

B_t =67,783.35 BDT/year

Define Costs

- Initial investment (C_0) = 31,377.90 BDT
- Annual maintenance (C_m) = 506 BDT/year (average cost)
- r = 0.06_r = 0.06 (6%)

- n = 20n = 20 years

BCR = $\frac{\sum \frac{B_t}{(1+r)^t}}{\sum \frac{C_t}{(1+r)^t}}$

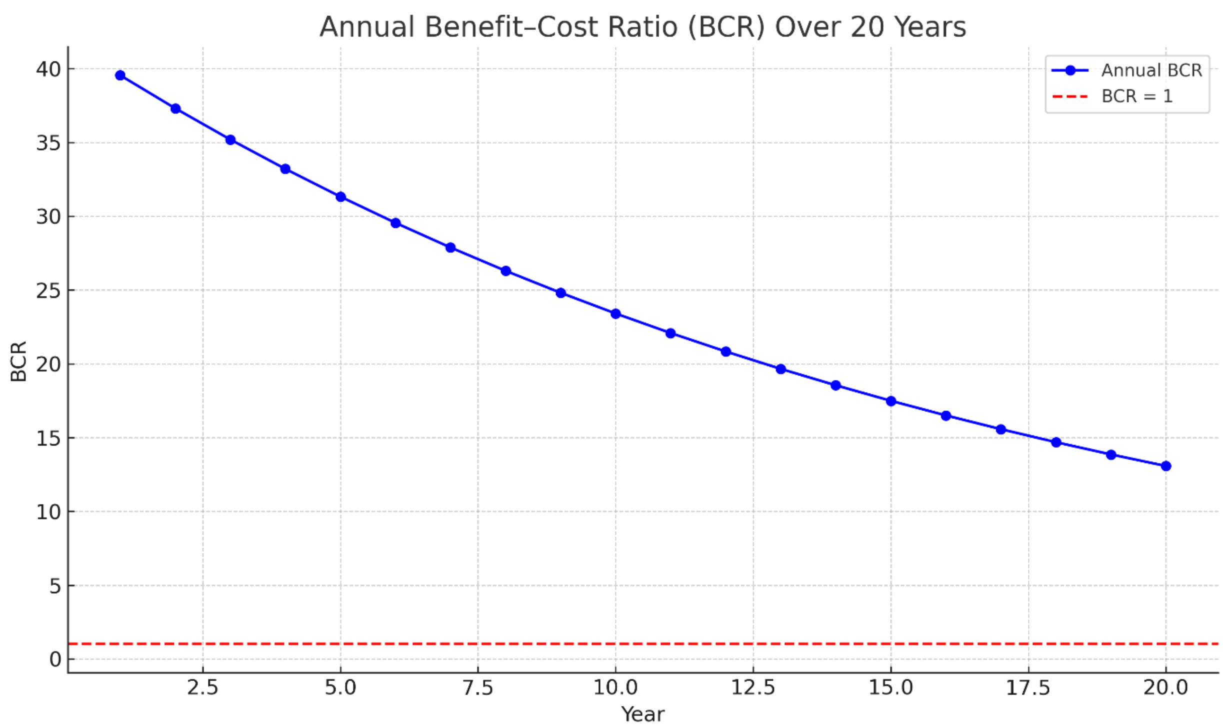
BCR = $\frac{PV_b}{PV_c}$

BCR = $\frac{777180}{37180}$

BCR ≈ 20.90

A BCR of 20.9 means:

For every BDT 1 invested in RWH, you get BDT 20.9 in present value benefits — indicating extremely strong financial viability.



IRR

Internal Rate of Return (IRR)

IRR = r that makes NPV = 0

Calculated using:

IRR = npf.irr ([-31, 377.90, 74, 078.80...])

IRR ≈ 236.09%

Payback Period (Nominal & Discounted)

Time (in years) when cumulative net cash flow ≥ 0

- Nominal Payback = 1 year
- Discounted Payback = 1 year
- The Internal Rate of Return (IRR) for the rainwater harvesting (RWH) system was calculated to be approximately 236.09%, which significantly exceeds the commonly used discount rate of 6%. This exceptionally high IRR indicates that the project is highly economically viable, generating rapid returns on the initial investment. Such a return implies that for every unit of currency invested in the RWH system, more than two units are recovered annually in the form of water savings, avoided water purchases, and related socio-economic benefits.
- This result suggests that the system achieves cost recovery within a very short time frame, possibly within the first or second year of operation, and continues to deliver substantial net benefits throughout its projected lifespan. Although IRRs above 100% are relatively uncommon in infrastructure projects, the result is plausible given the combination of low initial capital cost, high rainfall utilization, and continuous benefit generation in the study area.
- However, the unusually high IRR warrants careful interpretation. It is recommended that such estimates be contextualized within local conditions, system scale, and assumptions regarding benefit streams and maintenance reliability. Nevertheless, the findings strongly support the economic justification for wider adoption and scaling of RWH systems in water-stressed and salinity-prone regions of Bangladesh.

Study Findings: Non-RWH User Profile and Economic Burden

A comparative analysis was conducted on 100 households that do not utilize Rainwater Harvesting (RWH) systems to understand their water-related costs, time burden, and health impacts.

Demographic and Household Characteristics

Among the surveyed non-RWH users, 60% were male-headed households and 40% female-headed, with an average household size of 5.58 persons.

Economic Costs

The average monthly water purchase cost for these households was BDT 1,053.64, amounting to an annual expense of approximately BDT 12,643.68. In addition, households incurred an average monthly transportation cost of BDT 231.39 to collect or purchase water, equating to a yearly cost of BDT 2,776.68.

Time Burden

Water collection required an average of 1.69 hours per day, totaling approximately 20 hours and 16 minutes monthly. This time expenditure represents a significant opportunity cost, especially for low-income households reliant on daily labor.

Health Impacts

Regarding health, 76% of respondents reported experiencing waterborne diseases, compared to 24% who did not. The average monthly medical cost related to waterborne illnesses was BDT 2,134.96, or roughly BDT 25,619.52 annually.

Total Annual Cost

When combining water purchase, transportation, and medical costs, non-RWH users face an average total annual expenditure of BDT 41,060.15, underscoring the substantial financial burden of accessing safe water without rainwater harvesting systems.

Non-RWH users in coastal Bangladesh bear high economic and time costs associated with water procurement and suffer a significant health burden from waterborne diseases. These findings highlight the critical need for improved water access solutions such as RWH systems, which have the potential to reduce financial strain, decrease disease incidence, and free valuable time for productive activities.

Comparative Study Findings: RWH Users vs. Non-RWH Users

1. Economic Costs

Parameter	RWH Users (Average)	Non-RWH Users (Average)
Installation Cost	BDT 31,377.90 (one-time)	N/A
Annual Maintenance Cost	BDT 1,767.18	N/A
Annual Water Savings	BDT 4,864.60	N/A
Monthly Water Purchase Cost	Minimal/Zero (harvested)	BDT 1,053.64
Monthly Transportation Cost	Minimal	BDT 231.39
Annual Water & Transport Cost	Low (included in savings)	BDT 15,420.36
Annual Medical Cost	BDT 617.94 (monthly)	BDT 2,134.96 (monthly)

2. Time Burden

Parameter	RWH Users (Average)	Non-RWH Users (Average)
Time Spent Collecting Water	Not significant (on-site)	~1.69 hours daily (20h 16m monthly)

3. Health Outcomes

Parameter	RWH Users (Reported)	Non-RWH Users (Reported)
Waterborne Diseases	Majority unaware if RWH reduced medical costs (65%) but 26% reported reduction	76% reported waterborne diseases

Medical Expenses	BDT 617.94 monthly	BDT 2,134.96 monthly

4. User Perception and Adoption

Parameter	RWH Users	Non-RWH Users
Recommendation of RWH	93% Yes	N/A
Intent to Expand RWH	28% Yes	N/A

Study Conclusion

Rainwater harvesting systems offer a cost-effective, health-promoting, and time-saving water solution for coastal households vulnerable to salinity and water scarcity. The significantly lower financial burden and reduced health costs among RWH users underscore the economic and social value of investing in household rainwater harvesting infrastructure.

Given the high time cost and medical expenses borne by non-users, expanding access to RWH systems through financial support, community awareness, and technical improvements should be prioritized by policymakers and development programs to promote sustainable water security and public health in coastal Bangladesh.

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11. Appendix

Summary Table

Parameter	**Range in Mongla**	**WHO Guideline**	**Remarks**
pH	6.7–7.38	6.5–8.5	Safe
TDS	96–1,366 mg/L	~1,000 mg/L	Coastal limit higher; mostly acceptable
Sodium (Na^{+})	54–631 mg/L	~200 mg/L	Slightly elevated; coastal tolerance exists
Calcium (Ca^{2+})	14.5–139 mg/L	75 mg/L	Some samples exceed limit
Magnesium (Mg^{2+})	23.8–324.7 mg/L	50 mg/L	Many exceed limit; hard water
Arsenic (As)	0–335 ppb	10 µg/L (WHO), 50 µg/L (BD)	Within BD standard; some exceed WHO recommendation
Heavy metals (Pb, Cd, etc.)	Not fully tested in Mongla	Varies	Regional studies show occasional exceedances

Parameter	**Treated Rainwater**	**WHO Standard**	**Safe?**
pH	6.7	6.5 – 8.5	✅

TDS	20 mg/L	<1,000 mg/L	✅
E. coli	0 CFU/100 mL	0	✅
Turbidity	1 NTU	<5 NTU	✅

Microbiological Quality (Biggest Risk)

Microbe Type	Risk in Raw Rainwater	Health Concern
Coliform bacteria	Often present	Stomach infections, diarrhea
E. coli	May be present	Dangerous, especially to children
Fungi/Algae	Possible	Taste, smell issues

Indicator	Value	Interpretation
Initial Installation Cost	BDT 31,377.90	One-time setup cost at Year 0
Annual O&M Cost	BDT 1,767.18	Yearly cost for maintenance and upkeep
Annual Water Savings	72,000 liters	Based on average rooftop runoff and rainfall patterns
Economic Value of Water Saved	BDT 25 per 1,000 liters	Market equivalent for water
Annual Net Benefit (Water Only)	BDT 1,800	Conservative valuation
Annual Time Savings	607.97 hours	Based on survey — time not spent fetching water
Time Cost Saved (Opportunity)	BDT 34,158.75	Based on rural wage rate of BDT 56.25/hour
Medical Cost Savings	BDT 25,619.52	Reduction in waterborne disease expenses
Total Annual Benefit	BDT 61,578.27	Water + Time + Health savings
NPV (20 years, r = 6%)	BDT 404,714	Strong financial return over 20-year lifespan
BCR (20 years, r = 6%)	16.84	For every BDT 1 invested, BDT 16.84 is returned in benefits
IRR	236.09%	Extremely attractive rate of return
Payback Period (Nominal)	1 year	Time to recover initial investment without discounting
Payback Period (Discounted)	1 year	Payback with 6% discounting