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EVALUATION OF RAINWATER HARVESTING SYSTEM IN A LOCAL PUMP AND HOUSEHOLD FOR POTABLE WATER

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ABSTRACT

Bangladesh has an abundance of fresh water, but overconsumption has led groundwater levels to decline significantly. The need for water in Bangladesh during the dry season has mostly been met by groundwater due to the uneven distribution of its groundwater resources. Also, groundwater is heavily used to supply water to cities. Saving groundwater reserves requires an alternative approach, especially in metropolitan areas like Dhaka city. As a result, the search for non-conventional water supplies has increased. One possible approach is to use rainwater to alleviate water scarcity. This study aims to assess the potentiality of rainwater harvesting at the institutional level in North Shahjahanpur, Dhaka, Bangladesh. A building and a local pump in that area were chosen to quantify the prospective relationship between drinking water supply and demand. Also, investigating the rainwater harvesting system as a proper adaptation alternative. Moreover, the economic investment feasibility analysis of installing rainwater harvesting systems in both cases is addressed in this study.

INTRODUCTION

Water scarcity is becoming one of the most serious environmental issues confronting most arid and semi-arid regions, particularly in developing countries. The availability of clean drinking water has significantly decreased in some areas as a result of rapid population increase, slow to no economic growth, and the detrimental effects of climate change. Groundwater sustainability challenges are inextricably linked to increased groundwater consumption. Falling groundwater levels in some locations have raised worries about unsustainable groundwater use. According to multiple studies, (Kirby et al., 2016; Shahid & Hazarika, 2010), all concurred that groundwater consumption in some places, such as the barren area of northwest Bangladesh and surrounding Dhaka, is unsustainable. Dhaka, Bangladesh's capital, is experiencing a severe freshwater shortage as a result of groundwater depletion over the last few decades, with groundwater providing 82 percent of the city's water (M. S. Islam, 2017). The amount of water lifted from the aquifer in Dhaka was 2231 MCM over 14 years, from 1988 to 2002 (Hoque et al., 2007). A survey undertaken by the Bangladesh government discovered that the city's groundwater level is falling at a pace of two meters per year. Officials from Bangladesh's irrigation department claim that the country's fast-growing population is putting a strain on the country's water supply (Minor Irrigation Survey Report 2017-18, 2019). As a result, the search for non-conventional water supplies has increased. One possible approach is to use rainwater to alleviate the water deficit for safe drinking, cooking, and dishwashing (M. M. Islam et al., 2010). The technique of collecting rainwater that drops on a roof and storing it for various purposes, including drinking, washing, gardening, and flushing, is known as rainwater harvesting (RWH). It can collect and store rainwater directly in tanks installed on building roofs (Traboulsi & Traboulsi, 2017) and has a century-long tradition (AbdelKhaleq & Alhaj Ahmed, 2007). This is done all around the world, and as the water gets scarcer, it is becoming more widespread. Because of its greater quality and ease of access, this harvested water is the preferred source, making the community drought-resistant. A potable water system would need to be formed entirely of food-grade materials, and the water would need to be properly treated to meet drinking water quality standards. It's a technique for collecting and storing rainwater on rooftops, land surfaces, and rock catchments. As one millimeter of captured rainwater equals one liter of water per square meter, the advantages of a rainwater harvesting system may be easily understood

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(Helmreich & Horn, 2009). The main objective of this study is to assess the rainwater harvesting systems and uses of rainwater in a specific area of Dhaka, Bangladesh. The investment feasibility analysis was performed for two scenarios, i.e., one in which the system was installed on the roof of a building, and another in which a rainwater harvesting system was developed using the area of a local pump. So, for potable water, this study focused on installing an RWH in the local pump, and for other uses of the rainwater like washing, showering, and cleaning, this study focused on a reference building.

METHODOLOGY

Study Area

The Dhaka neighborhood of North Shahjahanpur was selected for this study. 253 buildings in the region have roofs that can be utilized as rainwater collection systems. None of the nearby buildings currently have a rainwater collection system. This study uses a 10-story building as a reference when estimating the amount of harvested rainwater and determining whether installing the system in the building is economically feasible. The building is called Toma Angelica, and it is located at 281, Amtola mosque lane, North Shahjahanpur, Dhaka. Figure 1 displays the building's position from Google Maps. The chosen building has 9 floors and 5 units on each floor. The building is located in latitude and longitude of 23.745°N and 90.423°E respectively. Here, water is provided by a nearby pump. The water is drawn from a deep tube well. The study will also take into account how much potable water the nearby pump will save if a rainwater collection system is developed in the pump using the pump area. The pump is a government-owned deep tube well pump. The pump's enclosed area offers a wide-open area, free of any structure, that is used in this study. The latitude and longitude of the pump location are 23.747°N and 90.424°E, respectively. Figure 2 depicts the pump area's shape as seen from Google Maps' top view. The pump location indicates that there are 130 meters between the neighborhood pump and the reference building. An underground RCC reservoir tank with an 80 m^3 capacity exists. Every day, about 60000 liters of potable water are served.

Figure 1 Location of the building in Google Map

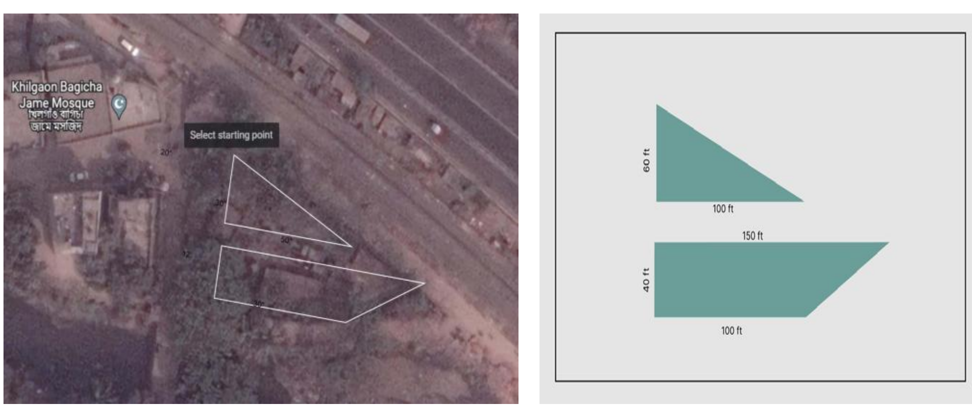

Figure 2 Shape of pump area from Google Map

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Data Sources

The catchment types of different roofs of that were identified by field survey. The plan of the reference building was collected from the homeowner. The total number and roof area of buildings in the area were calculated by Google Earth. The pump open area was identified by field survey. Average rainfall data in mm for Dhaka city for different months were collected from the Bangladesh Meteorological Department. Also, the frequency of rainy days over Dhaka for different rainfall ranges during the period 1981–2010 was collected from the Bangladesh Meteorological Department.

Installing RWH Facility

Figure 2 demonstrates the site area of the pump and provides a top view of it. This study considers building artificial shading over the top of the area and proposes a design for that infrastructure. Figure 3 shows the dimension and 3D design of that. This kind of shading can collect rainwater from a large area. Converting the pump's open area into a potential RWH catchment area, this study measures the potential harvested rainwater from the pump area. The list of other necessary facilities in both cases is shown in the bill of quantity section of the study. The life span adopted for the rainwater harvesting system was considered 20 years, considering the replacement of components would have a different life span. Also, installing a first flush filter would deposit fine materials elsewhere and keep the tank clean..

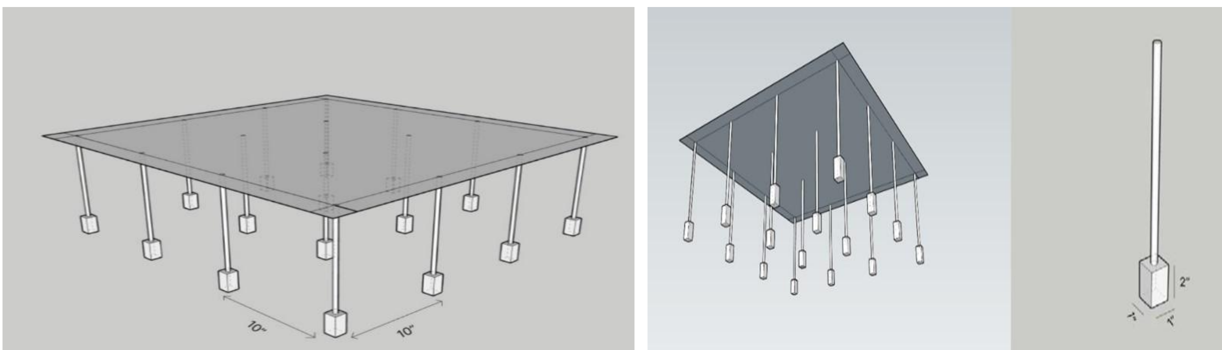

Figure 3 Dimension and 3D design of catchment shade in local pump

Estimation of Average Harvested Rainwater in Buildings

For calculating the amount of harvested rainwater and to assess the economic feasibility, the total catchment area of the chosen building was calculated from the plan of the building and also by using Google Earth. A correction factor was developed from the ratio of the area of the roof of the reference building calculated by plan and Google Earth. This study calculated the total catchment area of North Shahjahanpur, Dhaka, using Google Earth. A total of 253 buildings' area was calculated, then multiplied with the correction factor. The expected average amount of harvested rainwater was calculated using the rational method. According to (Biswas, 1970) the rational method is demonstrated in Equation (1). The Rational Method has been in use for more than 150 years and has been popularized during that time.

$$V = C \times I \times A \qquad (1)$$

Where, I = Average rainfall intensity of different months in meters; A = Roof area of building in m²; C = Runoff coefficient; V = Total harvested rainwater in Liter. The runoff coefficient of water for the concrete roof was considered 0.85 (American Society of Civil Engineering, 1969). By inputting the catchment area, harvested rainfall amounts for different months for different buildings in the area were calculated using Microsoft Excel software. Also, the size of the underground rainwater storage tank was calculated using equation (1) and compared with the building's underground storage tank.

Estimation of Water Demand of Reference Building

The water demand of the reference building was calculated according to Equation (2) and liter per capita per day water consumption, peak factor, or, the time factor was chosen according to BNBC Table 8.5.1.(a) (Bangladesh National Building Code, 2015). Also, the peak demand was calculated using Equation (3).

$$\text{Average present demand} = \text{Total people in the building} \times \text{selected lpcd} \qquad (2)$$

$$\text{Peak demand} = \text{Average present demand} \times \text{peak factor} \times \text{time factor} \qquad (3)$$

Costing and Bill of Quantity (BOQ) of installing the RWH System in the Building and the Pump

There was no need to invest in a storage facility if the current reservoir satisfied the demand. Furthermore, there was no need to perform catchment treatment because the catchment region met the necessary criteria. Additionally, since the water will not be used for drinking, there was no need to install a UV filter or pump since one is already in place to feed water to the entire structure. The market prices for all necessary equipment were estimated and listed. The local market and the owners' opinions were taken into consideration while choosing the materials and maintenance costs.

Estimation of Average Harvested Rainwater and Demand in the Local Pump

The area of the potential shading area in the local pump was calculated by field survey. A new correction factor was developed from the ratio of the potential pump area calculated by field survey and Google Earth. Using the rational method (Biswas, 1970) of Equation (1), the potential harvested rainwater was calculated. The runoff coefficient was considered 0.85 (American Society of Civil Engineering, 1969). Total potable water demand was taken from the customer list of the pump. And the cost of the potable water per month was generated from the customer bill as well.

Investment Feasibility Analysis

To find out the investment feasibility in both reference building and local pump, benefit-cost analysis was done according to equation (4) (Newnan et al., 2004)

$$\frac{B}{C} = \frac{\text{Present worth of benefits}}{\text{Present worth of cost}} = \frac{\text{Equivalent annual worth of benefits}}{\text{Equivalent annual worth of cost}} \tag{4}$$

To convert the present and future benefit or cost to equivalent annual worth of benefit or cost, equations (5), (6), and (7) were used (Newnan et al., 2004)

$$F = P(1+i)^n \tag{5}$$

$$A = F \times \frac{i}{(1+i)^n - 1} \tag{6}$$

$$A = P \times \frac{i(1+i)^n}{(1+i)^n - 1} \tag{7}$$

Here, A = Equivalent annual worth; P = Present value; i = Discount rate, F = Future single payment

RESULTS AND DISCUSSION

Harvested Rainwater from the Reference Building

From the plan, the roof area of the reference building was 461.22 m^2 and from google earth, the area was found 515.84 m^2. So, this study did consider (461.22/515.84) = 0.89 as the correction factor. This study calculated the total catchment area of 253 buildings in North Shahjahanpur, Dhaka using google earth. Then multiplied with the correction factor to get an effective catchment area.

Using data of figure 3 as rainfall intensity, I (Normal Monthly Rainfall | Bangladesh Meteorological Department, n.d.) and calculated area of the roof, A, harvested rainwater for different months of reference building was calculated using equation (1) and shown in Table 1.

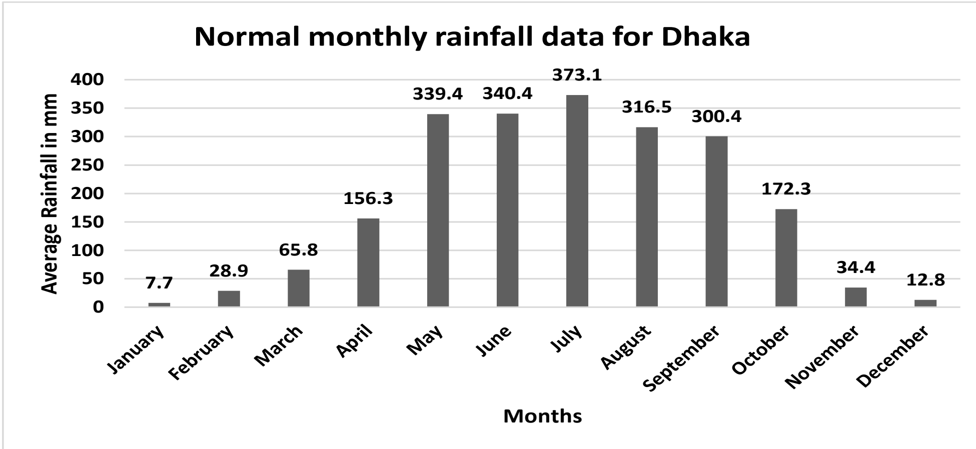

Figure 3 Normal monthly rainfall data for Dhaka

Table 1 Harvested rainwater of reference building

Month	Average Monthly Rainfall (mm)	Catchment Area (sq. m)	Runoff Co-efficient	Effective Catchment Area (sq. m)	Harvested Water (L)
Jan	7.7	461.22	0.85	392.037	3018.6849
Feb	28.9	461.22	0.85	392.037	11329.8693
Mar	65.8	461.22	0.85	392.037	25796.0346
Apr	156.3	461.22	0.85	392.037	61275.3831
May	339.4	461.22	0.85	392.037	133057.3578
Jun	340.4	461.22	0.85	392.037	133449.3948
Jul	373.1	461.22	0.85	392.037	146269.0047
Aug	316.5	461.22	0.85	392.037	124079.7105
Sep	300.4	461.22	0.85	392.037	117767.9148
Oct	172.2	461.22	0.85	392.037	67508.7714
Nov	34.4	461.22	0.85	392.037	13486.0728
Dec	12.8	461.22	0.85	392.037	5018.0736
Total					842056.2723

Estimation of Water Demand and Storage Tank capacity of Reference Building

Total family in the building (9*5) = 45. The total number of people in the building was 237. For moderator apartments (<2000 square ft), per capita consumption is 135 lpcd from BNBC Table 8.5.1.(a) (Bangladesh National Building Code, 2015). According to BNBC, peak factor = 2.5 and time factor= 1/1=1. Average present demand according to Equation (2) = 237×135 = 32000L/day. Peak demand using equation (3) = 32000×1×2.5 = 80000L/day where peak factor = 2.5 and time factor = 1/1 =1 according to BNBC.

In this study, the building has a water reservoir underground. The dimension of the reservoir is 22×20×9 ft. Considering 1 ft for clear cover and brick, length and breadth will be 20 ft & 18 ft respectively. So, it can store up to 20×18×9×28.31=91724L of water.

But the water demand is 32000 L per day. So, the reservoir is filled once about every 64 hours. So, considering we can fill the reservoir with harvested rainwater each time we can save up to 64 hours' worth of water.

Table 2 Frequency of rainy days over Dhaka for different rainfall ranges during the period 1981-2010.

Rainfall (mm)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Dry days	886	768	806	653	504	366	284	294	371	655	844	904	7335
Light rain 1-10	36	60	22	116	208	263	348	408	281	151	34	15	1942
Moderate rain 11-22	5	12	18	64	85	119	138	113	108	44	10	4	720
Moderate heavy 23-43	2	5	8	41	70	84	86	67	78	43	3	6	493
Heavy rain 44-88		2	3	24	53	53	61	37	48	27	4	1	313
Very heavy rain > 89			1	2	10	15	13	11	14	10	3		79
Very heavy rain 100-199				2	4	10	8	9	11	9	1		54
Very heavy rain 200-299													0
Very heavy rain >300													2

Table 2 shows the frequency of rainy days over Dhaka (Rashid, 2020) for different rainfall ranges during the period 1981-2010. From these tables, it is seen that the number of days with moderate rainfall (11-23 mm) is the highest in February and lowest in December. Rainfall and rainy days increase during the remaining months of the year. During the months of May to September, the frequency of moderately heavy to heavy rainfall days becomes higher over the country. Heavy to very heavy rainfall days are the highest in July among the monsoon months (June to September).

Storing all the available water even for heavy rain (44-88 mm), using Equation (1), the reservoir size should be = $0.088 \times 461.22 \times 0.85 = 34.5\ m^3$.

So, considering heavy rain (up to 88mm), 34.5 m^3 of storage should be enough. Water will overflow in only 135 days out of 30 years (1981-2010) in cases where rainfall was greater than 88 mm according to Table 2.

In this study, the building has a water reservoir underground. The dimension of the reservoir is 22×20×9 ft. Considering 1 ft for clear cover and brick, length and breadth will be 20 ft & 18 ft respectively. So, it can store up to 20×18×9×28.31=91724 L=91.724 m^3 of water which is more than enough for storing harvested water.

Costing and BOQ of Rainwater Harvesting System in the Building

The condition of the building roof as a catchment area was found good enough, it did not require catchment treatment. Additionally, since the collected water won't be consumed, it did not require a UV filter or a pump because the building already had one for distributing water throughout it. The system only needed the installation cost of gutters, pipes, and the first flush. Table 3 shows the BOQ of installing an RWH system in the building using the existing reservoir.

Table 3 BOQ of installing an RWH system in the building using the existing reservoir

	Bill of Quantity (BOQ)		Date: 08.03.2022		
Sl No	Item	Unit	Quantity	Rate (Tk)	Amount (Tk)
1.	Catchment treatment		Not needed		
2.	Rainwater collection & supply				
a.	150 mm inside diameter best quality PVC rainwater downpipe.	ft	116	60	6960
b.	Pressure pipes		Installed		
c.	Gutters with all necessary accessories	ft	40	60	2400
d.	uPVC pipe	Piece	4	350	1400
e.	First flush diverter with installation.	Each	1	10000	10000
f.	Screen	Piece	1	50	50
g.	Clamp	Piece	50	10	500
3.	Filter gravel materials	Each	2	50	1000
4.	Pump, UV filter		Not needed		
5.	Installation charge				2500
	Total				24810

Harvested Rainwater in the Local Pump

Using data from Figure (3) as rainfall intensity, I and calculated area of the catchment area of the local pump, A = 8000 ft^2, harvested rainwater for different months of the local pump was calculated using Equation (1) and shown in Table 4.

Table 4 Harvested rainwater per month in the local pump

Month	Catchment area (sq. m)	Runoff coefficient	Monthly average rainfall (mm)	Harvested water (L)
January	743.2	0.85	7.7	4864.244
February	743.2	0.85	28.9	18256.708
March	743.2	0.85	65.8	41567.176
April	743.2	0.85	156.3	98737.836
May	743.2	0.85	339.4	214405.768
June	743.2	0.85	340.4	215037.488
July	743.2	0.85	373.1	235694.732
August	743.2	0.85	316.5	199939.38
September	743.2	0.85	300.4	189768.688
October	743.2	0.85	172.2	108782.184
November	743.2	0.85	34.4	21731.168
December	743.2	0.85	12.8	8086.016
			Total	1356871.388

Size of the Reservoir for Harvested Rain Water in Local Pump

According to the proposed infrastructure in the methodology section, a catchment area was calculated that can be used to harvest rainwater in the pump area. Then the collected water was planned to be treated in the installed filters. Usually, the pump draws water from underground using a deep tube well which is further purified in the filters to make it potable.

As per previous standards, considering 88mm rainfall in a single day, recommended size of the reservoir should be = 8000×0.0929×0.088×0.85= 55591L

As, the existing reservoir of the pump was 80,000 L, no need to extend the reservoir in size. Considering the daily demand was 60,000L potable water, 88 mm of rain can almost cover the potable water demand for the whole day.

Costing and BOQ of Rainwater Harvesting System in the Local Pump

There was no need for financial investment in a storage facility due to the utilization of the pump's existing reservoir. The cost of the new infrastructure was taken into account. Moreover, the harvested water was not planned to be used for drinking, so it did not need a UV filter. Table 5 shows the BOQ of installing an RWH system in the pump area using the existing reservoir.

Table 5 BOQ of installing an RWH system in the pump area using the existing reservoir

	Bill of Quantity (BOQ)			Date: 08.03.2022	
Sl. no	Item	Unit	Quantity	Rate (Tk)	Amount (Tk)
1.	Catchment preparation				
a.	Catchment shade	sq. ft	8000	60	480000
b.	4” diameter 2mm steel pipe	ft	700	410	287500
c.	T bar (4”,2”)	ft	1800	60	108000
	T bar (2”,1”)		3600	35	126000
d.	Concrete				
2.	Rainwater collection & supply	m^3	18	5000	90000
a.	6” diameter PVC pipe and gutters	ft	700	60	42000
b.	Gravel Pack Filter	m^3	400	200	80000
c.	Labor		20*15	800	240000
d.	First flush diverter with installation.	each	5	10000	50000
	Total				15,03,500

Investment Feasibility Analysis

For building, the existing reservoir was 91724 liters. As it was more than the recommended storage volume, this study considered that all the available rainwater was harvested throughout the year. Yearly, this building can save up to 842056 liters. For each unit (1000 liters) WASA spends 25 taka and charges people 15 taka. So, for 842 units total cost for WASA would be (842×25) taka = 21,050 taka.

People will save (842×15) = 12630 taka. So, the owner would save 12630 taka yearly if the rainwater harvesting system is installed.

The system needs to be maintained regularly and some components must be changed after several years. Table 6 shows the components with their lifespan and maintenance frequency.

Table 6 Maintenance frequency of RWH system

Components	Catchment, Leaf catcher and gutters	First flush diverter	Pipe, valves, all opening in storage tank	Filter materials	Storage tank & sedimentation on Tank
Maintenance	Twice a year	Once a year	Once a year	Twice a year	Once a month
100% change	Every 3 years	Every 5 years	Every 7 to 10 years	Every 3 years	Every 30 to 50 years

This study assumed, 4500 BDT as the maintenance cost each year. The cost of the reinstallation of a device or replacement of it was taken into consideration. The cash flow diagram for installing and maintaining of RWH system in the reference building and the local pump for 10 years is shown in Figure 4 and Figure 5 respectively.

Equations (4), (5), (6), and (7) were applied to the cash flow diagram to do the benefit-cost analysis

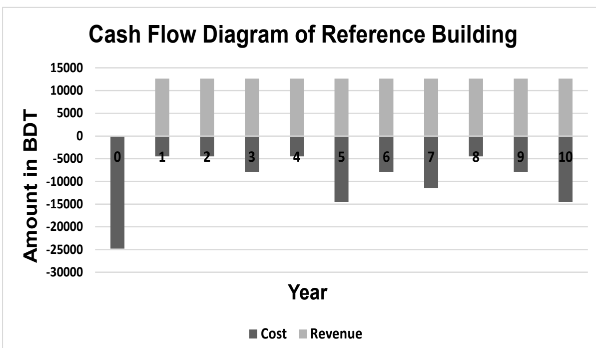

Figure 4 Cash flow diagram for installing RWH system in reference building for 10 years

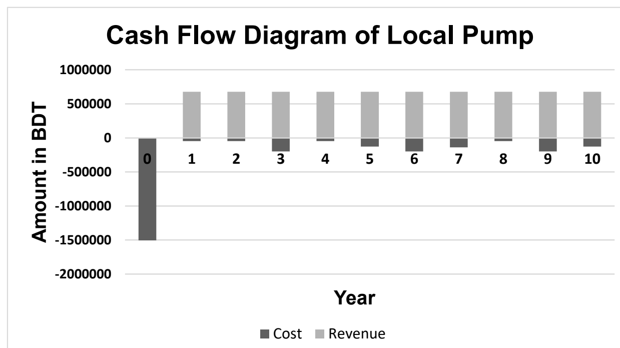

Figure 5 Cash flow diagram for installing RWH system in local pump for 10 years

for the equivalent annual worth under the assumption of a 5% discount rate.

$$\text{For the reference building, } \frac{B}{C} = \frac{12630}{11155} = 1.13 > 1$$

$$\text{For the local pump, } \frac{B}{C} = \frac{678435}{300986} = 2.25 > 1$$

In both cases, the benefit-cost ratio was greater than 1, which implies both investments would be economically feasible.

CONCLUSIONS

From assessing the values, this study has come to a very prospective solution to the unconventional water source, creating a huge opportunity to preserve our groundwater level. Also, this system can solve urban water problems, which can be a big plus. The biggest limitation of the system being dependent on heavy rainfall is not much of an issue in Bangladesh. In the absence of rainfall or drought, this system will not work. As the result showed, the tank storage at the reference building and pump area should not be changed, the main cost will go into installing the facility. Moreover, the feasibility study shows that both investments would be economically feasible. This means investing in an RWH system in a building or using the local pump area if available is economically feasible. Overcoming the lack of initial funds, this system can bring forth a tremendous prospect in water-related problems.

REFERENCES

AbdelKhaleq, R. A., & Alhaj Ahmed, I. (2007). Rainwater harvesting in ancient civilizations in Jordan. In *Water Science and Technology: Water Supply* (Vol. 7, Issue 1, pp. 85–93). https://doi.org/10.2166/ws.2007.010

American Society of Civil Engineering, N. Y. (1969). *Design and Construction of sanitary and storm sewers*.

BANGLADESH NATIONAL BUILDING CODE (Vol. 3, pp. 207–236). (2015).

Biswas, A. K. (1970). *History of Hydrology*. https://www.researchgate.net/publication/361910655

Helmreich, B., & Horn, H. (2009). Opportunities in rainwater harvesting. *Desalination*, *248*(1–3), 118–124. https://doi.org/10.1016/j.desal.2008.05.046

Hoque, M. A., Hoque, M. M., & Ahmed, K. M. (2007). Declining groundwater level and aquifer dewatering in Dhaka metropolitan area, Bangladesh: Causes and quantification. *Hydrogeology Journal*, *15*(8), 1523–1534. https://doi.org/10.1007/s10040-007-0226-5

Islam, M. M., Chou, F. N. F., Kabir, M. R., & Liaw, C. H. (2010). Rainwater: A Potential Alternative Source for Scarce Safe Drinking and Arsenic Contaminated Water in Bangladesh. *Water Resources Management*, *24*(14), 3987–4008. https://doi.org/10.1007/s11269-010-9643-7

Islam, M. S. (2017). *Spatial Disparity of Groundwater Depletion in Dhaka City*. https://www.researchgate.net/publication/325390176

Kirby, J. M., Mainuddin, M., Mpelasoka, F., Ahmad, M. D., Palash, W., Quadir, M. E., Shah-Newaz, S. M., & Hossain, M. M. (2016). The impact of climate change on regional water balances in Bangladesh. *Climatic Change*, *135*(3–4), 481–491. https://doi.org/10.1007/s10584-016-1597-1

Minor Irrigation Survey Report 2017-18. (2019). *Government of the People's Republic of Bangladesh Ministry of Agriculture, Minor Irrigation Survey Report 2017-18, Bangladesh Agricultural Development Corporation (BADC), Department of Agriculture Extension (DAE) Barind Multipurpose Development Authority (BMDA),*.

Newnan, D., Eschenbach, T., & Lavelle, J. (2004). *Engineering economic analysis, 9th edition*.

Normal Monthly Rainfall | Bangladesh Meteorological Department. (n.d.). Retrieved January 16, 2023, from https://live4.bmd.gov.bd/p/Normal-Monthly-Rainfall

Rashid, B. (2020). *Climate of Bangladesh Climate change View project Enhancing National Climate Services initiative (ENACTS) & Adapting Agriculture to Climate Today, for Tomorrow. (ACtoday) View project*. https://www.researchgate.net/publication/347453656

Shahid, S., & Hazarika, M. K. (2010). Groundwater drought in the northwestern districts of Bangladesh. *Water Resources Management*, *24*(10), 1989–2006. https://doi.org/10.1007/s11269-009-9534-y

Traboulsi, H., & Traboulsi, M. (2017). Rooftop level rainwater harvesting system. *Applied Water Science*, *7*(2), 769–775. https://doi.org/10.1007/s13201-015-0289-8