TECHNO-ECONOMIC ANALYSIS OF A SMALL-SCALE RAINWATER HARVESTING SYSTEM FOR PRODUCING DRINKING WATER AT KUET CAMPUS

Rahul Chakrabarty*[1], and Kazi ABM Mohiuddin[2]

[1]Graduate Student, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET),
Khulna-9203, Bangladesh, e-mail: ck.rahul18@gmail.com
[2]Professor, Department of Civil Engineering, Khulna University of Engineering & Technology (KUET),
Khulna-9203, Bangladesh, e-mail: kzmohiuddin@ce.kuet.ac.bd

***Corresponding Author**

ABSTRACT

Rainwater harvesting systems (RWH) can be adopted to lower the demand for mains water by reducing the use of potable water for non-potable purposes. Since a centralized water supply system is not available everywhere, studies on rainwater harvesting systems for producing drinking water at the household level have nevertheless been rare. The purpose of this study is to determine whether or not installing a small-scale rainwater harvesting system at the KUET campus is technically and economically feasible for the production of drinking water. The size of the roof, the size of the tank, the amount of water needed, and the daily filtration rate were some of the parameters used to assess the technical effectiveness of the rainwater harvesting system. By developing a water balance model (WBM), the system's effectiveness was evaluated in terms of quantity. The WBM model was created to explore the impact of roof size, tank size, and filter capacity on system reliability and annual drinking water production. Although rainwater is typically fresh in nature and is simple to collect and store, it can be claimed that combining a decentralized water treatment system with a RWH system could successfully generate drinking water for rural families (Alim et al., 2021). Many combinations were investigated in order to determine the ideal configuration for the filtering materials (sand, charcoal, cheesecloth, limestone, gravel, etc.), and the findings have been captured from another journal by Alim et al. (2021). There is enough good-quality filtered water produced by the gravity-fed filtration units to minimize the need for further mineral additions. This analysis has needed to focus on choosing an appropriate tank size for an appropriate roof area with a reliable daily filtration rate. Yet, if the system is unable to generate a large amount of revenue, the payback period would be too short to be regarded as economically feasible. At the end of this analysis, it was found that the preferred rainwater tank size for a 300 m^2 roof area in an administrative building is 6 KL with a 1500 L/day filtration rate. The system life is considered to be 20 years, with filter material changed every 2 years. The LCCA assessment reveals a few unexpected aspects. The cost of drinking water production, including storage, disinfection, and material change, is less than the value of produced water annually. For economical feasibility, it was assumed that the production of drinking water would be reduced annually at the rate of 1000 liters per year. Further, it can be seen that the revenue starts to go in a significant positive direction from the third year ending. That means the proposed RWH system's payback period is between one and two years. A sensitivity analysis is carried out in this study, and the system output is significantly impacted by rising capital, maintenance, and operating costs. But any investment in this RWH system is supposed to return a profit to the owner. All these analyses indicate that a small-scale RWH system for producing drinking water at the KUET campus is not only technically possible but also economically feasible. We can use this planned RWH system in the Student Hall and Faculty Building as a secondary source of drinking water.

Keywords: *Rainwater harvesting system (RWH), Drinking water, Water Balance Model (WBM), Life Cycle Cost Analysis (LCCA).*

1. INTRODUCTION

One of the most significant concerns facing the globe today is the quality of fresh drinking water supplies. Due to population growth and the quick change in socio-economic situations, nearly one-fifth of the world's population has little or no access to clean drinking water (Alim et al., 2020). In many areas of the world, there is already a water shortage due to the ongoing increase in water demand and the limited supply of water resources, which can lead to health issues, economic problems, and even social unrest. As public health requires drinking water that is safe to drink, to address the rising water demand in a sustainable way, experts from all around the world have been looking for alternatives to traditional resources (Alim et al., 2020). Due to the exponential growth of water demand and a reduction in the amount of available fresh drinking water, rainwater collection is an effective way to reduce the demand for drinking water.

Drinking water issues are more significant and offer greater long-term hazards. Hashim (2018) reported that 75 million Bangladeshis are susceptible to serious water-related diseases since they are drinking unsafe water in both rural and urban areas. In addition, sewage water, arsenic, insecticides, and radioactive elements can contaminate groundwater, making it unsafe to be consumed by humans (Yang et al., 2016; Zhai et al., 2017). Although surface water is frequently highly contaminated, it is frequently regarded as the main source of drinking water in many regions of Bangladesh due to the lack of a centralized water supply system as well as an economical and sustainable drinking water approach. The dramatic change in recent precipitation patterns and groundwater recharge forces us to rethink the strategies of water management techniques (Famiglietti, 2014). The typical reaction to a drought is to draw more groundwater; however, doing so will have negative effects such as land subsidence, loss of springs, seawater intrusion, and environmental damage (Macpherson, 2009; McDonald et al., 2011). Furthermore, the use of the RWH system for drinking water production can be particularly beneficial during times of emergency or natural disasters when regular water supply systems may be disrupted.

A RWH system typically includes collecting surface water from roofs, gutters, and pipes that convey rainwater to a storage tank or cistern. This makes it an affordable option for people living in areas where water is scarce. However, most people think rainwater is already naturally clean and safe for use, and thus the health dangers connected to drinking untreated rainwater have largely gone unnoticed. Based on a number of studies, rainwater shouldn't be consumed without treatment. It has been suggested that hanging canopies and installing TV antennas on building rooftops may enhance the risk of microbial contamination from rainfall. Thus, the collected water undergoes a treatment process to make it safe for drinking purposes. The treatment process involves removing debris, sediment, bacteria, and other contaminants to produce high-quality drinking water. Several technologies and methods are available for treating rainwater, including filtration, disinfection, and chemical treatment. Additionally, because rainwater lacks several necessary nutrients that are often present in groundwater, a prior study has suggested that people who regularly consume it may be at increased risk for cardiovascular disease (Naser et al., 2017). To make up for the vital elements that the rainfall lacks, it is suggested that minerals be added.

The concept of rainwater harvesting has gained popularity in recent years due to its potential to provide clean and safe drinking water and conserve water in areas with water scarcity challenges. The benefits of the RWH system for producing drinking water are numerous. Rainwater is one of the safest sources and an alternate way to get fresh drinking water because it is clean by nature until it has been contaminated by air pollution and catching surfaces. For the majority of home and landscaping needs, harvested rainwater is a reliable, sustainable source of clean drinking water. One major advantage is the reduction of the burden on existing water supplies, particularly in areas with inadequate access to fresh drinking water sources. Additionally, RWH systems can save money on water bills, reduce storm water runoff and flooding, and promote an eco-friendly lifestyle. The main aim of this study is to assess the rainwater storage options (rainwater availability, roof area, daily filtration rate, and tank size) for producing drinking water and to examine the technical aspects with LCCA of the proposed RWH system on the KUET campus for producing drinking water.

2. RESEARCH METHODS

2.1 Study Location

When selecting a location for RWH system research, there are a number of key factors that need to be considered. These include things like the topography of this location, the availability of climate and rainfall patterns, adequate legal and regulatory requirements with utilities and infrastructure, the proximity to transportation routes and accessibility, and the potential for environmental impact. Other important considerations may include the local zoning regulations, the availability of skilled labor and resources, and the overall economic and demographic trends in the area. Ultimately, the goal is to find a location that offers the best mix of these various factors while also being a good fit for the specific needs and target of the project itself. In this study, a rainwater harvesting system is designed for Khulna University of Engineering and Technology (KUET), Khulna-9203, Bangladesh. A part of the roof area of the administrative building at the KUET campus, shown in Figure 1, is chosen for analysis. The nearest meteorological station to this study location is the Bangladesh Meteorological Department, Khulna. The rainfall data collected from this station and from the Weather and Climate website is used to analyze the water balance model.

Figure 1: Roof top in the administrative building at the KUET campus.

2.2 RWH System Design to Produce Drinking Water

Rainwater harvesting systems range from simple barrels to more elaborate structures with pumps, tanks, and purification systems. For official purposes, the requirement for portable water is nearly 5 liters of potable water per day to meet their demands for drinking (75%), washing their hands, and bottle (25%). This assumption was used to build the hypothetical RWH system. From the design of the administration building on the KUET campus, we get that the area that can be used for collecting rainwater from the roof is approximately 420 m^2. But there are also some assumptions, as there is already some equipment and it will need some space for monitoring and extra activity in the future. However, based on the pattern of rainfall, two different roof sizes, i.e., 200 m^2 and 300 m^2, were chosen for analysis. It can be suggested to use a 1500-liter or 2000-liter tank in multiple quantities if needed. In this study, it is expected that a basic filtering chamber, made of fine-pore ceramic and conventional charcoal, is coupled to the RWH system and can deliver drinkable filtered water. The filter system should have the following characteristics: in the initial stage, water would pass through the tiny pores of the ceramic wall, filtering away germs and suspended pollutants. The water is then passed through a bed of activated charcoal to remove any contaminants the rainwater may have contained. Also, a thin layer of silver is anticipated to be applied to the filter cartridges inside the surface in order to protect them from any bacterial build-up. A piezometer is also incorporated into the design since it can be used to show the tank's water level. The diagram of the proposed system is shown in Figure 2. According to the Water Quality Parameters Bangladesh Standards and WHO Guide Lines recommended by the Department of Public Health Engineering (DPHE), the filtration and disinfection processes chosen in this section are fully satisfactory. The authors recommend that gravel, cheesecloth, sand, limestone, charcoal, and small gravel be placed from the bottom to the top of the filter chamber. The gravity-fed filtration unit's design is shown in Figure 3. Filtration materials details of the proposed gravity-fed filtration chamber are shown in Table 1. The author, Alim et al. (2021), concluded that in this filtration system, the quality of filtered water is good enough that it does not require extra minerals to be added. Thus, this proposed system does not require extra provision for adding minerals.

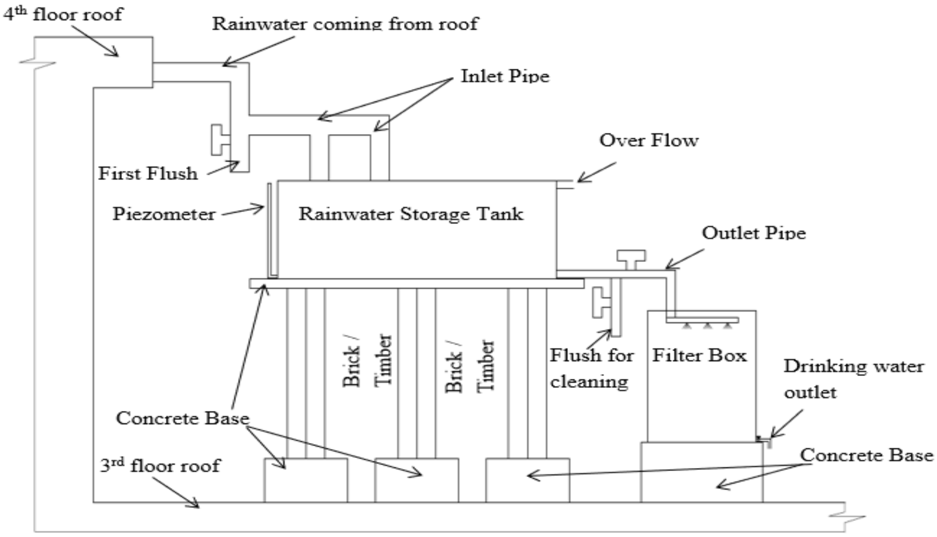

Figure 2: Diagram of the proposed rainwater harvesting system.

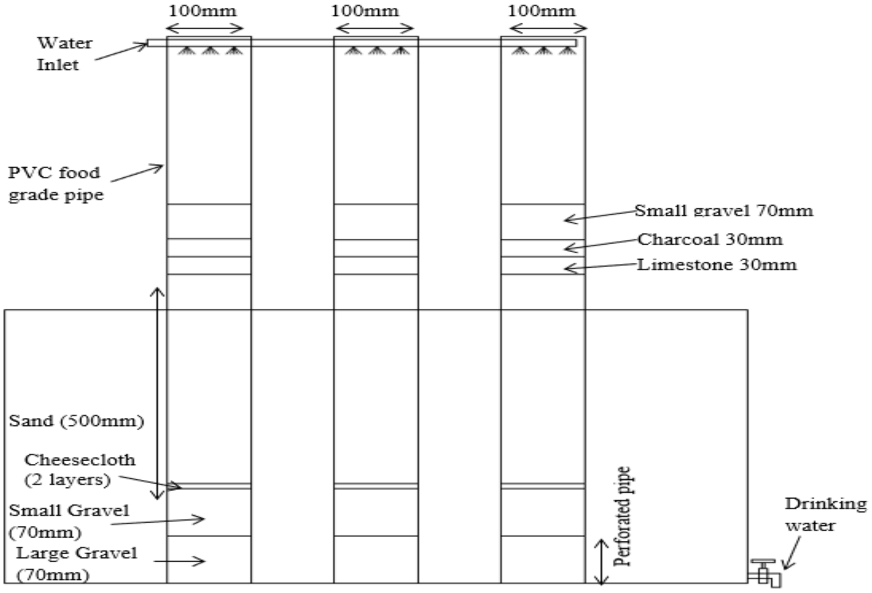

Figure 3 : The design of gravity-fed filtration unit's.

Table 1: Filtration materials details of the proposed gravity fed filtration chamber.

Materials	Size	Layer Thickness
Small gravel	5 mm	70 mm
Charcoal	2-3 mm	30 mm
Limestone	20-30 mm	30 mm
Sand	d_{50}=0.36	500 mm
Large gravel	15-20 mm	70 mm

2.3 Water Balance Modeling

In Excel, a daily WBM is developed. The daily rainfall data used for modeling is taken from the "Weather and Climate: The Global Historical Weather and Climate Data" website. The WBM model was created to explore the impact of roof size, tank size, and water filter capacity on system reliability and annual drinking water production. The WBM model has a number of established assumptions. According to different reports, the first flush can eliminate the majority of impurities from the roof. Meanwhile, it is presumed that the first 1 mm of rainfall will be used for the first flush. When the amount of rain falls is greater than 1 mm, the rainwater tank is used to store the residual water. Based on the previous studies, it is assumed that 20% of the total runoff would be lost due to evaporation, leakage, and spillage (Khastagir and Jayasuriya, 2010; Vander Sterren et al., 2012). After that, the collected rainwater is sent to the filtering chamber to produce drinking water. The rate of filtration determines how much drinking water is generated. When determining the filtration rate, it is important to focus on tank capacity and precipitation. It must be estimated how much of the total runoff will enter the tank and how much will overflow. One of the developed WBMs is presented in Table 2.

2.3.1 System Reliability

System reliability in this study refers to the system's ability to deliver water at any given time. For example, a system with a reliability of 100% means that its water supply would be available at all times throughout the year, but a system with a reliability of 90% means that its water supply would be unavailable on 10% of the days of the year. Due to the variability in the number of typical wet days and the average monthly rainfall distribution data, it is necessary to analyze the system's reliability. One must exercise extreme caution when choosing parameters that may increase the reliability of the system, but also take into consideration that the result should be affordable and economically feasible. For instance, individuals might believe that constructing a larger tank would boost the system's reliability, but if the roof catchment is insufficiently large, the rainwater tank would remain mostly empty. As a result, the cost of the system would increase significantly, while its reliability might only slightly improve. Similarity aside, how much drinking water is generated in a single day depends in part on the daily filtration rate. Thus, a number of variables, including the size of the rainwater tank, the pattern of the rainfall, the length of the dry season, the size of the roof catchment area, the rate of filtration, and water losses, affect how reliable a RWH system is.

2.4 Economic Analysis

The proposed RWH system's economic viability is assessed using life cycle cost analysis (LCCA). All forms of cash flows from the past, the present, and the future are taken into account and valued in the present. To conduct the analysis, we used the nominal cost and discount rate method. The cost of producing drinking water from the RWH system is estimated, and the payback period of the proposed system is determined based on the assumed anticipated selling price of the produced water. The difference between the market value of the produced water and all costs is the system's revenue. Mathematically shown in equation (1).

$$R = \sum WS_i - E_i \tag{1}$$

Where R, WS_i, and E_i represent the revenue in a given year, the monetary value of produced water in the same year, and production expenses in the year, respectively. When the value of revenue is positive ($R>0$), the system is regarded as economically viable; nevertheless, when the revenue is negative ($R<0$), the system is not economically viable. All the costs are expressed in BDT (Tk) in this study. The costs of the rainwater tank (made of food-grade polyethylene), concrete slab, timber, and accessories are provided by different local contractors in Khulna. The expenses related to materials are found at the local market. Local plumbers are consulted for plumbing costs and charges related to the RWH system and accessories. To make the decision-making process easier, an economic analysis of the proposed RWH system is being conducted. If a system has a net present value (NPV) that is greater than zero, it is seen as being economically desirable. The NPV of a system can be calculated by using equations (2) and (3), shown below:

$$NPV = \sum_{i=1}^{n} \frac{CF_i}{(1+r)^i} - E_{CP} \tag{2}$$

Where, $$CF_i = \sum R - \sum E \tag{3}$$

Here, CF_i represents cash flow in the *i*th year, which is the difference between the revenue (R) generated and expenses (E) in the year. E_{CP} denotes expenditures related to the initial installation of the plant. In this case, E_{CP} refers to capital costs, which include costs for the rainwater tank and its accessories, the concrete base, the initial piping cost, and the cost of the filtration chamber. Here n represents the life span of the system, taken as 20 years, and r is the inflation rate. The annual amount of produced water is multiplied by the unit price to estimate the RWH system's annual revenue. Also, some assumptions have been made about ensuring benefits. Every two years, an extra amount is added for filter changing or improving maintenance and operating costs. Different margins from the unit water production cost are taken into account when determining the unit price of water.

2.4.1 Sensitivity Analysis

The RWH system is technically possible since construction materials are easily available from nearby marketplaces. To build a system, we almost always make a lot of assumptions and approximations, so there are uncertainties that must be taken into account. The generated WBM is used in a sensitivity analysis to determine the impact of various input parameters on economic outcomes. Since inputs including the price of construction, materials, labor, capital, and maintenance are quite likely to have uncertainties, this analysis depicts a variety of scenarios with favorable or unfavorable results that could occur during the practical implementation of the project. The profit from the RWH system, which is the money made from selling the produced drinking water, is subjected to a sensitivity analysis in this study. To evaluate the system's performance under various circumstances, a number of input characteristics are taken into account, including the capital cost, maintenance cost, and cost of the produced drinking water.

3. RESULT AND DISCUSSION

3.1 System Reliability

One of the most crucial elements that must be taken into account while creating a RWH system is its technical reliability. The impacts of roof size, rainwater tank size, and daily filtration rate on the RWH system's reliability are depicted in Figures 4 and 5. As can be seen from Figure 4, the impact of the roof size on annual drinking water production with respect to a fixed filtration rate and a fixed water tank. If the range of roof area increased from 200 square meters to 300 square meters, the amount of drinking water production also increased significantly. This means that for the same filtration rate and storage tank size, the production of drinkable water increased significantly when the roof size was larger. Thus, a roof size of 300 square meters is more reliable for this RWH system at the KUET campus.

When designing or selecting a suitable filtration unit for the desired RWH system, it is crucial to consider the impact of the daily filtration rate on the system's reliability and how much drinking water is produced in a single day. If an RWH system owner intends to produce drinking water for an administration building only (assumed to be 70 people and 5L/day/person), a RWH system with a 300-square-meter roof area and a 6kL tank with 1000L/day would serve the purpose with approximately 70–75% reliability. Moreover, if the owner intends to produce a significant amount of drinking water, then this system also needs to improve the filtration rate with tank size. From Figure 5, it can be seen that by increasing the daily filtration rate from 1000 L/day to 1500 L/day with a 6 kL rain storage tank for a 300 m^2 roof area, there has been a significant increase in drinking water production from 185 kL to 234 kL. In this condition, reliability would also increase with the increased rate of filtration. Figure 6 also represents monthly drinking water production and monthly need if the roof area is 300 m^2 with 6 kL rainwater tanks and a daily filtration rate of 1000 L/day and 1500 L/day.

Since the cost of the storage tank adds significantly to the capital investment, choosing the best tank size is also important. I found that, after looking into a number of RWH system study reports, the choice of a large rainwater tank was typically to blame for the low economic return. The ideal size of the rainwater tank is established in this study using a daily water balance model. Figures 4 and 5 present the performance of a small-scale RWH system in terms of monthly drinking water production with respect to tank size, roof size, and daily filtration capacity. As can be seen, when the roof size is 300 m^2 and daily water filtration is 1500 L/day, the annual drinking water production for this RWH system using 4.5 kL and 6 kL rainwater tanks is 220 kL and 234 kL, respectively. That indicates the total volume of drinking water per year might increase if the rainwater storage tank was increased from 4.5 kL to 6 kL. So a 6 kL rainwater storage tank is more suitable for this study. From all figures, it is clear that, if we increased the roof area, filtration rate, and storage tank size, the amount of monthly drinking water production also increased significantly, which also made this proposed RWH system more reliable. So, for a roof size of 300 m^2 with a 1500 L/day daily filtration rate, the optimum water storage tank is 6 kL.

Table 2: Daily water balance model considering 300 m^2 area, 6 kL tank & 1500 L/day filtration rate.

Date	Precipitation	Total runoff	Runoff coefficient	First flush	Net runoff	Water in tank	Tank overflow	Daily filtration	Filtered water	Water in tank after filtration
01/09/2020	19.5	5850	0.85	300	4672.50	6000.00	3051.00	1500	1500	4500.00
02/09/2020	5.9	1770	0.85	300	1204.50	5704.50	0.00	1500	1500	4204.50
03/09/2020	6.5	1950	0.85	300	1357.50	5562.00	0.00	1500	1500	4062.00
04/09/2020	1.0	300	0.85	300	0.00	4062.00	0.00	1500	1500	2562.00
05/09/2020	2.9	870	0.85	300	439.50	3001.50	0.00	1500	1500	1501.50
06/09/2020	2.7	810	0.85	300	388.50	1890.00	0.00	1500	1500	390.00
07/09/2020	12.0	3600	0.85	300	2760.00	3150.00	0.00	1500	1500	1650.00
08/09/2020	17.5	5250	0.85	300	4162.50	5812.50	0.00	1500	1500	4312.50
09/09/2020	8.3	2490	0.85	300	1816.50	6000.00	129.00	1500	1500	4500.00
10/09/2020	2.3	690	0.85	300	286.50	4786.50	0.00	1500	1500	3286.50
11/09/2020	2.4	720	0.85	300	312.00	3598.50	0.00	1500	1500	2098.50
12/09/2020	4.4	1320	0.85	300	822.00	2920.50	0.00	1500	1500	1420.50
13/09/2020	2.9	870	0.85	300	439.50	1860.00	0.00	1500	1500	360.00
14/09/2020	12.4	3720	0.85	300	2862.00	3222.00	0.00	1500	1500	1722.00
15/09/2020	9.5	2850	0.85	300	2122.50	3844.50	0.00	1500	1500	2344.50
16/09/2020	15.3	4590	0.85	300	3601.50	5946.00	0.00	1500	1500	4446.00
17/09/2020	5.3	1590	0.85	300	1051.50	5497.50	0.00	1500	1500	3997.50
18/09/2020	14.1	4230	0.85	300	3295.50	6000.00	1293.00	1500	1500	4500.00
19/09/2020	0.0	0	0.85	300	0.00	4500.00	0.00	1500	1500	3000.00
20/09/2020	17.3	5190	0.85	300	4111.50	6000.00	1111.50	1500	1500	4500.00
21/09/2020	14.7	4410	0.85	300	3448.50	6000.00	1948.50	1500	1500	4500.00
22/09/2020	10.7	3210	0.85	300	2428.50	6000.00	928.50	1500	1500	4500.00
23/09/2020	9.4	2820	0.85	300	2097.00	6000.00	597.00	1500	1500	4500.00
24/09/2020	20.8	6240	0.85	300	5004.00	6000.00	3504.00	1500	1500	4500.00
25/09/2020	6.4	1920	0.85	300	1332.00	5832.00	0.00	1500	1500	4332.00
26/09/2020	1.0	300	0.85	300	0.00	4332.00	0.00	1500	1500	2832.00
27/09/2020	11.5	3450	0.85	300	2632.50	5464.50	0.00	1500	1500	3964.50
28/09/2020	3.4	1020	0.85	300	567.00	4531.50	0.00	1500	1500	3031.50
29/09/2020	9.1	2730	0.85	300	2020.50	5052.00	0.00	1500	1500	3552.00
30/09/2020	2.2	660	0.85	300	261.00	3813.00	0.00	1500	1500	2313.00

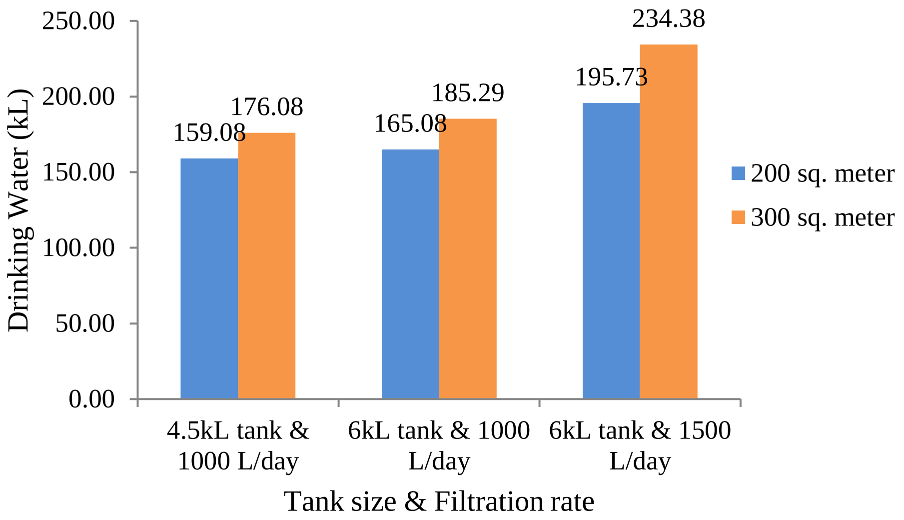

Figure 4: Annual drinking water production for different catchment area & Tank size.

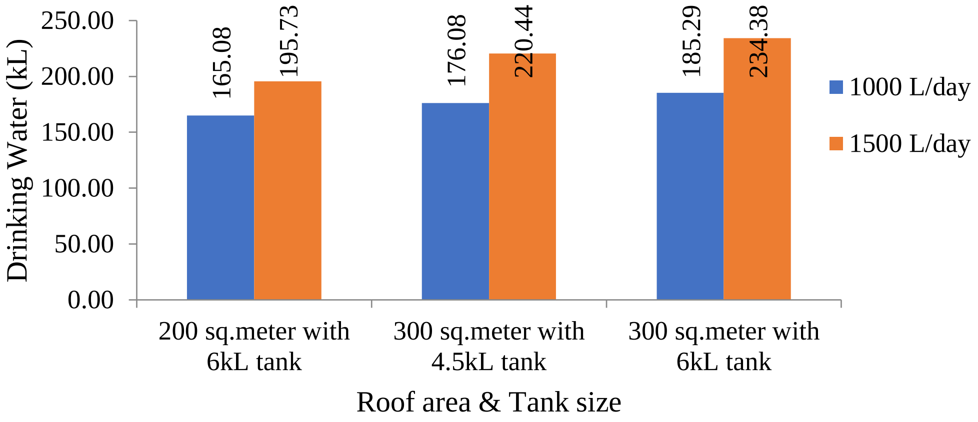

Figure 5: Annual drinking water production for different filtration rate& Tank size.

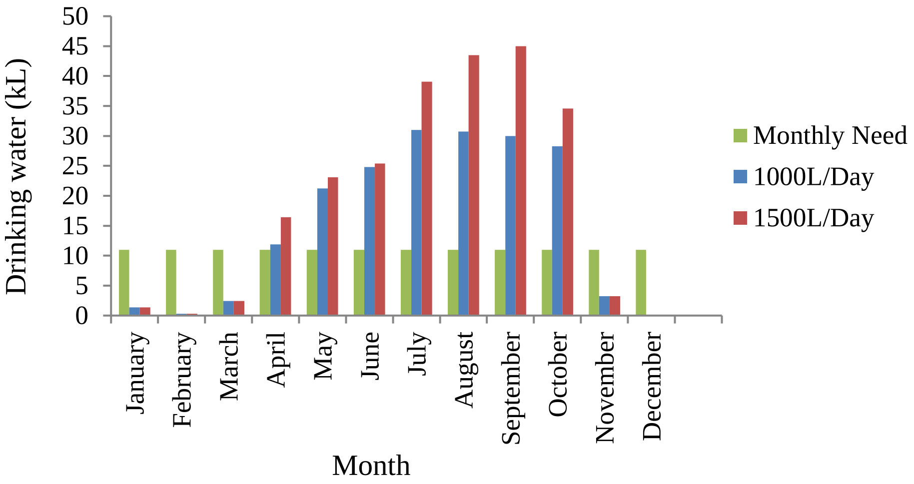

Figure 6: Monthly drinking water production for 300 sq. meter catchment area & 6kL tank different filtration rate.

3.2 Life Cycle Cost Analysis

It has been established that 6 kL is the ideal size for the rainwater tank in the proposed RWH system. Consequently, LCCA is carried out for a RWH system that produces 90% of its original capability (234 kL*90% = 210 kL) of drinking water annually and has a 6 kL rainwater tank, 300 m^2 of roof space, and a 1500 L/day filtration capacity. The capital cost of installing the RWH system in the administration building at the KUET campus is presented in Table 3. Since the proposed RWH system is meant to be installed on the KUET campus, where the main city water supply is not available, it is crucial to note that we did not use the water price that was selected from the central water supply system. In the present analysis, it was decided that the average water production cost is 2 Tk per liter that wholesalers use. This information was gathered by visiting the neighborhood wholesalers and requesting quotes from water production firms. Thus, we conducted the LCCA analysis considering the unit price of 2 Tk per liter and subsequently performed a sensitivity analysis for the prices between 5 and 7 Tk per liter to investigate different financial benefit scenarios. The LCCA analysis for this proposed system is presented in Table 4. Also, some assumptions have been made about ensuring benefits. As we can see, every 2 years, an extra amount is added for filter changing or improving with maintenance and operating costs, and different monetary values have been assigned as time passes. It is assumed that the production of drinking water will be reduced annually at the rate of 1000 liters per year. Further, it can be seen that the revenue starts to go in a positive direction significantly from the third year ending, and the total benefit at the end of 20 years is 1831109 Tk. That indicates this RWH system in the administration building at the KUET campus is economically feasible.

Table 3: Capital cost for RWH system in the study area

Item description	Cost (Tk)
Rainwater tank (1500 liters*4)	63000
Concrete slab & steel frame (1*4)	170000
Accessories	65000
Plumbing and Labor (1*4)	130000
Filter(1 unit*4)	210000
Extra cost (Transport, Electric energy and Miscellaneous)	75000
Total	713000

3.3 Sensitivity Analysis

When we build a system, we almost always make a lot of assumptions and approximations, so there are uncertainties that must be taken into account. There is no denying the uncertainty around these inputs, including the price of construction, materials, labor, capital, and maintenance. In order to analyze various RWH system scenarios and estimate the economic advantage, a sensitivity analysis is carried out in this study. Sensitivity analysis was performed on the RWH system's output, and the results are displayed in Table 5 for a 20–40% increase in capital expenditures, a little increase in maintenance (10–20%) and operating costs (10–20%), and a corresponding modification (profit). As we can see, the system output is significantly impacted by rising capital, maintenance, and operating costs. But any investment in the RWH system in the administration building at the KUET campus is supposed to return a profit to the owner. That indicates this proposed system is economically feasible. Since no direct energy input is needed for the treatment process, the suggested RWH system in this study is considered to be environmentally clean during the period when it operates. Also, construction materials are easily available from nearby marketplaces, and the maintenance is straight-forward and not too expensive (even a single person can do it by himself or herself), which ensures the technical sustainability of the new system.

Table 4: The LCCA analysis for this proposed system

Year	Capital Cost (Tk)	Maintenance cost (Tk)	Operation cost (Tk)	Filter cost (Tk)	Total (Tk)	Present value	Net present value (Tk)	Per liter price (Tk)	Total water	Total (Tk)	Net present value (Tk)	Cumulative benefit (Tk)	Saving (Tk)
0	713000												0.00
1		15000.00	7000.00	0	735000.00	1.000	735000.00	2.00	210000	420000.00	420000.00	420000.00	-315000.00
2		16365.00	7637.00	210000	234002.00	0.870	203581.74	2.10	209000	439736.00	382570.32	802570.32	-136011.42
3		17670.93	8246.43	0	25917.36	0.756	19593.52	2.20	208000	457588.02	345936.54	1148506.86	190331.60
4		18883.15	8812.14	215000	242695.29	0.658	159693.50	2.29	207000	473239.29	311391.45	1459898.31	342029.55
5		20019.92	9342.63	0	29362.55	0.572	16795.38	2.36	206000	487153.90	278652.03	1738550.34	603886.20
6		21070.96	9833.12	220000	250904.08	0.497	124699.33	2.44	205000	499332.74	248168.37	1986718.72	727355.25
7		22029.69	10280.52	0	32310.22	0.432	13958.01	2.50	204000	509816.30	220240.64	2206959.36	933637.87
8		22893.26	10683.52	225000	258576.78	0.376	97224.87	2.56	203000	518681.10	195024.09	2401983.45	1031437.10
9		23678.50	11049.96	0	34728.46	0.327	11356.21	2.61	202000	526242.09	172081.16	2574064.61	1192162.06
10		24391.22	11382.57	230000	265773.79	0.284	75479.76	2.65	201000	532643.49	151270.75	2725335.37	1267953.05
11		25022.95	11677.38	0	36700.33	0.247	9064.98	2.69	200000	537837.42	132845.84	2858181.21	1391733.92
12		25583.47	11938.95	235000	272522.42	0.215	58592.32	2.72	199000	541998.14	116529.60	2974710.81	1449671.19
13		26084.90	12172.95	0	38257.85	0.187	7154.22	2.75	198000	545314.40	101973.79	3076684.60	1544490.77
14		26523.13	12377.46	240000	278900.59	0.163	45460.80	2.78	197000	547768.87	89286.33	3165970.93	1588316.30
15		26931.58	12568.07	0	39499.66	0.141	5569.45	2.81	196000	549784.21	77519.57	3243490.50	1660266.42
16		27270.92	12726.43	245000	284997.35	0.123	35054.67	2.83	195000	550917.44	67762.85	3311253.35	1692974.59
17		27576.36	12868.97	0	40445.32	0.107	4327.65	2.84	194000	551600.01	59021.20	3370274.55	1747668.14
18		27846.60	12995.08	250000	290841.69	0.093	27048.28	2.86	193000	551829.75	51320.17	3421594.71	1771940.03
19		28080.52	13104.24	0	41184.76	0.081	3335.97	2.87	192000	551605.59	44680.05	3466274.77	1813284.12
20		28296.74	13205.14	255000	296501.88	0.070	20755.13	2.89	191000	551147.07	38580.29	3504855.06	1831109.28

Table 5: Sensitivity analysis for accumulated NPV saving with respect to capital cost with maintenance and operating costs.

Capital cost (Tk)	Initial Maintenance cost (Tk)	Initial Operation cost (Tk)	Filter cost (After1st 2year)	After 20 years Saving (NPV) (Tk)
713000	15000	7000	210000	1831109
855600 (20%)	16500 (10%)	7700 (10%)	231000 (10%)	1554536
998200 (40%)	18000 (20%)	8400 (20%)	252000 (20%)	1319964

4. CONCLUSIONS

This study assessed the economic and technical feasibility of installing small-scale rainwater harvesting (RWH) systems at Khulna University of Engineering & Technology (KUET), Khulna-9203, Bangladesh, as a source of drinking water. According to the water balance model (WBM), the ideal rainwater tank size for the administrative building under consideration, which has a catchment area of 300 m^2, is 6 kL. Also, a 1500 L/day filtration rate is determined to be ideal. Though we have suggested a water harvesting technique that boosts system reliability while also producing more drinking water, the system owner should be careful about water usage during November to March (the dry period), as the use of too much water may lead to a shortage or no water situation. We have proposed a water collection method that not only increases drinking water production but also improves system reliability. The LCCA analysis highlights a few interesting aspects. The planned RWH system can generate enough revenue at the end of three years. That means the proposed RWH system's payback period is between one and two years. The system might save 1831109 Tk throughout its 20-year lifespan at a capital cost of 713000 Tk, with additional costs for maintenance, operating, and filter changing. We have explored the sustainability of small-scale RWH systems in terms of quantity and quality of water, economic feasibility, and technical doability. The majority of the time, the RWH system was found to be sustainable when certain procedures were followed. If the system owner decides to install this system and sell the produced drinking water, it can be profitable.

It should be noted that the case study presented in this research is based on Khulna, Bangladesh's climate data. It is anticipated that the climate data for various locations will differ significantly. All of these analyses show that a small-scale RWH system for producing drinking water at the KUET campus is not only technically possible but also economically feasible.

REFERENCES

Alim, M. A., Rahman, A., Tao, Z., Samali, B., Khan, M. M., Shirin, S. (2020). Feasibility analysis of a small-scale rainwater harvesting system for drinking water production at Werrington, New South Wales, Australia. *Journal of Cleaner Production*. 270, 122437.

Alim, M. A., Ashraf, A.F.M. A., Rahman, A., Tao, Z., Roy, R., Khan, M. M., Shirin, S. (2021). Experimental investigation of an integrated rainwater harvesting unit for drinking water production at the household level. *Journal of Water Process Engineering*.44, 102318.

Hashim, S.M. (2018, October 16). How Safe Is the Water We Drink? *The Daily Star, Bangladesh.* https://www.thedailystar.net/opinion/no-frills/news/how-safe-the-water-we-drink-1647328

Macpherson, G. (2009). CO_2 distribution in groundwater and the impact of groundwater extraction on the global C cycle. *Chemical Geology*. 264 (1-4), 328-336.

Famiglietti, J.S. (2014). The global groundwater crisis. *Nature Climate Change.* 4 (11), 945.

McDonald, R.I., Green, P., Balk, D., Fekete, B.M., Revenga, C., Todd, M., Montgomery, M. (2011). Urban growth, climate change, and freshwater availability. *Proceedings Of The National Academy Of Sciences*. 108 (15), 6312-6317.

Yang, Q., Wang, L., Ma, H., Yu, K., Martín, J.D. (2016). Hydrochemical characterization and pollution sources identification of groundwater in Salawusu aquifer system of Ordos Basin, China. *Environmental Pollution*. 216, 340-349.

Zhai, Y., Zhao, X., Teng, Y., Li, X., Zhang, J., Wu, J., Zuo, R. (2017). Groundwater nitrate pollution and human health risk assessment by using HHRA model in an agricultural area, NE China. *Ecotoxicology and Environmental Safety*. 137, 130-142.

Naser, A. M., Martorell, R., Narayan, K. M. V., Clasen, T. F. (2017). First Do No Harm: The Need to Explore Potential Adverse Health Implications of Drinking Rainwater. *Environmental Science & Technology*. 51, 11, 5865–5866.

Khastagir, A., Jayasuriya, N. (2010). Optimal sizing of rain water tanks for domestic water conservation. *Journal of Hydrology*. 381 (3-4), 181-188.

Van der Sterren, M., Rahman, A., Dennis, G. (2012). Implications to stormwater management as a result of lot scale rainwater tank systems: a case study in Western Sydney, Australia. J. *Water Science & Technology*. 65 (8), 1475-1482.