ROOFTOP RAINWATER HARVESTING: REVIEW AND PRACTICE

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ABSTRACT

Water is one of the most essential resources for life on Earth, along with food, air, and groundwater, which is the main source of freshwater. Despite this, very little is done to protect these key resources. The water table is dropping due to excessive subsurface water pumping and massive water waste. Water scarcity is already an issue in many parts of the world, and because artificial water cannot be produced, the situation will only worsen if attention is not given to it. Since rainfall is the main supply of water, it should be collected on a personal basis to reduce water scarcity. Utilizing rainwater harvesting (RWH) is a great way to restore groundwater and save water for later use. Bangladesh is steadily losing its surface and groundwater supplies due to a number of factors, including its remarkably high population density, fluctuating temperatures, irregular rainfall patterns, and abrupt changes in meteorological parameters. Therefore, in order to meet the demands, it is now essential for individuals, institutions, and communities to implement various water conservation strategies. The purpose of this study was to evaluate and review the overall design of a rooftop rainwater collection installation in Bangladesh. In regions with a shortage or scarcity of water, this is the most effective method of reducing the problem. The analysis of the annual precipitation statistics of the last 12 years of the Khulna region is presented in this paper. One of the significant findings of this paper is the assessment of the rainwater quality in Khulna through laboratory testing. In this paper, an attempt has been made to investigate the significance, need and various benefits of having a rainwater collecting system. The purpose of this study was to evaluate and review the overall design of a rooftop rainwater collection system on the rooftop of the Civil Engineering building of KUET in near future.

Keywords: *Rainwater, rainwater harvesting, rwh design, rooftop rwh*

1. INTRODUCTION

Higher demand for clean drinking water is a result of the growing global population. Resource utilisation for surface and groundwater is being employed more quickly than they can be replenished. As a practical decentralised water supply, rainwater collection is an ancient technique that is gaining popularity in many countries. Studies have indicated that this technology possesses some beneficial qualities, and with appropriate management, it has the potential to replace around 50% of clean rainfall with drinking water (Akoto *et al.*, 2010). One method to address the increasing demand for water is to install individual rainwater collection systems. A sustainable way to solve the problems caused by large-scale projects that use centralised water management techniques is through rainwater gathering. Concerns about how to provide everyone with clean water are being brought on by population expansion on a global scale. Research conducted globally demonstrates that Rainwater Harvesting (RWH) is a cost-effective and secure alternative water supply (Kim and Yoo, 2009; Islam *et al.*, 2010; Matos *et al.*, 2013; Zhang and Hu, 2014). Directly collecting rainfall and storing it for later use or restoring it is known as "water harvesting." The process of collecting runoff for use in agriculture is known as water harvesting. (Julius *et al.*, 2013). The technique of gathering and storing rainwater for use in productive projects later on is known as rainwater harvesting. Rainwater harvesting is a small-scale water resource initiative that uses structural methods to collect, store, and control rainfall before using it for home and industrial purposes. The phrase "rain water harvesting" describes the process of gathering and storing precipitation that occurs naturally, as well as other surface and hydrological studies, engineering interventions, and conservation and efficient use of the limited water resources of a physiographic unit, such as a watershed. It can also refer to the procedure of gathering and holding on to water from the treated area in order to boost precipitation runoff (Patel *et al.*, 2014). Rainwater collection and storage is not a modern technique; rather, it has long been a feature of human society (Jain *et al.*, 2015). Rainwater harvesting (RWH) has been practiced since 4500 B.C. all over the world (Verma and Tiwari, 1995). Rainwater collecting is already common in several regions of Asia, Africa, Northeast Thailand, Sri Lanka, Botswana, and Uganda (Barry *et al.*, 2009)

With an annual average of 2,200 millimetres (mm) of rainfall, Bangladesh is a very rainy nation. The majority of areas receive at least 1,500 mm of rain annually, but others, like the border regions in the northeast, receive as much as 5,000 mm (World Bank, 2022). For this reason, rainwater collecting is a viable alternative supply of water (Karim et al., 2015). There are several problematic areas in Bangladesh (Hassan *et al.*, 2011) where the water sources are contaminated with high salinity (Anwar *et al.*, 2019), arsenic (Bari *et al.*, 20009; Hasan *et al.*, 2012; Shafiquzzaman *et al.*, 2023) and manganese. Rainwater collecting has already gained popularity in those areas where comparatively the more rainfall occurs (Brojen & Bari 2023). While rainwater collecting systems are prevalent in rural regions impacted by arsenic and along the country's coast, they are not widely used in Bangladesh's urban areas (Akter and Ahmed, 2015; Brojen *et al.*, 2023).

Rainwater harvesting systems are made up of parts for filtering, storing captured water in tanks, and moving rainwater through pipes or drains (Patel *et al.*, 2014). RWH systems and technologies can be categorised in a number of ways, mostly according to the catchment area's size, storage type, and runoff generating method. There are two sorts of systems that result from runoff generation criteria: in-situ water conservation, which conserves rainwater where it falls, and runoff based systems, which concentrate runoff from a catchment. Storage in the soil profile and storage structures are the two categories that result from the runoff storage criteria. There are two types of catchments based on size: macro catchments and micro catchments inside the field (Julius *et al.*, 2013).

Macro-catchment technologies: These are systems that gather runoff from sizable regions that are significantly remote from their point of usage. Large runoff flows that are redirected off surfaces like highways, slopes, and meadows are handled by these devices. Examples include the use of rock catchments, sand and earth dams, and hillside sheet/rill runoff.

Micro-catchment technologies: these gather runoff near the crop in growth and replace the moisture content of the soil. The primary use of micro-catchment technology is the cultivation of medium-water-demanding crops including millet, sorghum, maize, and groundnuts.
Rooftop harvesting technologies: Rooftop harvesting devices have the benefit of collecting water that is reasonably pure. (Malesu *et al.*, 2006)

Out of all these techniques, the rooftop rainwater gathering approach was the most widely approved. Those that use it argue that it is far less expensive than ground catchment systems. This is mostly because the roof is already established and its height offered some degree of pollution protection.

Additionally, it was implied that the roof systems were closer to the residences, which was advantageous (Stoler *et al.*, 2012). The majority of towns with widespread rainwater collection used thatch, aluminium, asphalt, zinc, and ceramic tiles as roofing materials. But industrialised nations also employ wood, slate, concrete, copper, shingles, and timber (Uba and Aghogho, 2000). In addition to being effective in collecting and storage, it is an ecologically beneficial method that substantially benefits the community. The benefits that come with rainwater collection include:

- less strain on the public water supply, which serves as the primary source of water for cities;
- emergency use (e.g., fires);
- because of its low installation costs and potential to lower water bill expenses, it is only financially advantageous;
- it increases soil moisture levels to support the growth of plants;
- rainfall greatly restores groundwater levels.

Water that has been collected and treated locally might simply be considered drinkable. Once more, rainfall might be recognised as non-potable sources when it comes to gardening, washing, toilet flushing, and other uses where purity is not as important (Rahman *et al.*, 2014). Despite the numerous benefits that this technology offers, policymakers in Ghana and most other developing nations have not established appropriate policy guidelines for its future use. Because of this, rainwater collection methods are still primitive and exclusive to isolated villages and rural areas (Singh et al., 2007).

In our study area, there is excess amount of chloride present in the water of regular use. This water is harmful for the equipment of various laboratories in the Civil Engineering department of KUET. It has been observed in the recent years that due to the problems in the supplied water into the laboratories, machinery have been damaged because of rusting. So, it is very necessary find an alternative water source for the laboratories in the department. Besides, there is no previous research work related to design and implementation of rain water harvesting system on the rooftop of Civil Engineering building of KUET campus. So, this research work will fill that void in this regards.

2. METHODOLOGY

Previous selected research works from different sources are thoroughly studied in this paper. To understand the proven methods on the rain water harvesting in the different countries of the world the previous research works is then explored and drawn a number of effective steps for future application of the systems in our country.

This background study is done to emphasize and consider the context of Bangladesh, specially an practical application for the building of Department of Civil Engineering, KUET which is located in Khulna. For this, average annual rainfall data of Bangladesh collected and analysed.

In order to assess the quality of rainwater, the rain water from the rooftop of the building at winter is collected on 7/12/2023 and properly stored in the Environmental Engineering Laboratory of Department of Civil Engineering, KUET for further quality monitoring. Then the some parameter of the stored rainwater which is one week old. After testing these ten parameters of at least 4 days, the change of those parameters were analysed.

So the previous research works are studied, annual mean rainfall data are analysed, rainwater of the study area is monitored through tests and theoretical equations for the design of the rain water harvesting system are observed as a part of the methodology of this paper.

2.1 Study Area

The old civil engineering building rooftop at the KUET campus is the subject location for this research project. The campus, which is around 117 acres, is located in the Khulna district. The campus is located in the northwest of Khulna in Fulbarigate. The campus is around 15 km from Khulna City's zero point, which is closely connected to the city's important centre districts via broad, open roadways. It is located around 14 kilometres from the Khulna Railway Station and about 12 km from the Inter-District Bus Terminal. The location of Civil Engineering building of KUET on map is shown in Figure 1.

Figure 1: Location of Civil Engineering building of KUET on map.

The mechanical engineering building is located to the west, central field is to the south-east, rokeya hall canteen is to the north, and the electrical engineering building is to the south of the study area.

2.2 Process Flowchart

Process followed to carry out the research work are mainly theoretical observations, annual rainfall data analysis of the study area and rain water quality monitoring. From the previous literature review, the definition, classification and benefits are found out and added to this paper. The annual rainfall data of last 12 years for Khulna region has been analysed in this paper. Then the theoretical observations are done from the previous research works. Rainwater quality was also monitored by performing tests conducted in the Environmental Engineering laboratory. At least 11 parameters of water quality was determined and change was observed through these tests. Flowchart presenting the methodology followed to write this paper is shown in Figure 2.

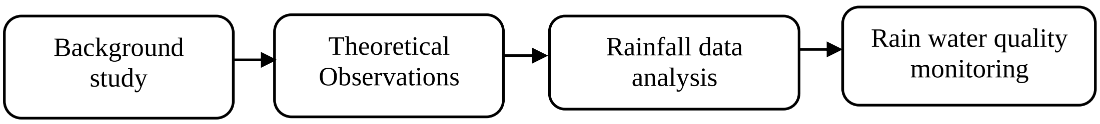

Figure 2: Methodology flow chart.

3. THEORETICAL OBSERVATIONS

3.1 Potential Rainwater Harvesting Flow Rate

Rainfall potential on rooftops (catchments) is determined upon the size of the interception surface, the amount of precipitation, and the composition of the catchment material.

Equation used to determine the amount of rainfall available is-

$$Q= (C \times I \times A)/1000 \qquad (1)$$

where A is the catchment area in square metres, I is the monthly rainfall in millimetres, Q is the quantity of water yielded every month, and C is the efficiency of the catchment, or coefficient of available runoff. (Ahmed and Rahman, 2000)

The minimal potential catchment area A needed to collect rainwater for N individuals, with each person receiving q litres per capita per day (lpcd) depending on the amount of rainfall. It can be determined from the formula.

$$A = 0.365\, q\, N / (f\, I) \qquad (2)$$

Assume that around 25% of the precipitation evaporates and is used to cleanse the catchment region with first-rain water, which results in lower-quality precipitation. (Ahmed and Rahman, 2000)

3.2 Calculation of number of rainwater pipe

Equation used to determine the number of rainwater pipe is-

$$Q= n \times \pi/4 \times d^2 \times v \qquad (3)$$

where,
Q = discharge
I = The amount of rainfall
A=Catchment area
n=The least number of pipes
d=The rainwater pipe's diameter
v=The water's velocity on the roof when it is about to enter the pipe because of the roof's available slope. Given that the roofs are level or have a 0-2% slope,
v=0.1m/s

So, no. of pipes are calculated as:

$$n=Q / (0.785 \times d^2 \times v) \qquad (4)$$

Using the above formulae the total number of required RWP can be calculated (Mishra et al., 2020)

3.3 Calculation for the Diameter of the Discharge Pipe

The main building, which is the chosen catchment area, was taken into consideration while designing the discharge pipe. First, the formula is used to determine the water velocity entering the horizontal discharge pipe.

$$v^2=u^2+ 2as \qquad (5)$$

where,

v= velocity of Water entering the horizontal discharge pipe
u = Rainwater entering the R.W.P. at a speed of 0.1 m/sec.
Building height =s
acceleration due to gravity (a) = g = 9.81 m^2/sec.
The equation mentioned above may be used to determine the water's velocity within the building.

We know,

$$Q = \pi/4 \times d^2 \times v \qquad (6)$$

After entering every value into the equation, the value of d is obtained. (Mishra *et al.*, 2020)

3.4 Deign of recharge well

In this investigation, the length of the drain and the roof top area were taken consideration while calculating the concentration time.

$$T_C = 0.0195\ L^{0.77}\ S^{-0.385} \qquad (7)$$

where, T_C= Concentration period, minute
L= Length of overland flow
S= average overland area slope

$$\text{Volume of recharge well} = Q * T_C \qquad (8)$$

Using the above formula the volume of recharge well can be calculated (Mishra *et al.*, 2020)

So from the above theoretical observations, necessary equations for the design of RWH system are obtained. By applying these formulae, rain water harvesting flow rate, potential catchment area, number of discharge pipes, diameter of pipes, concentration period, volume of recharge well etc can be calculated for the design purpose.

4. RESULT & DISCUSSION

4.1 Rainfall Data Analysis

Bangladesh's climate is defined by high temperatures, substantial amounts of rainfall, high humidity, and a rainfall pattern that is determined by the average rainfall intensity. Average rainfall is required for necessary calculation for the design of RWH.

The yearly mean rainfall data of the past consecutive 12 years is shown in Figure 3. It is observed from the figure that the Khulna region receives an annual rainfall height in between 1400 mm to 2000 mm.

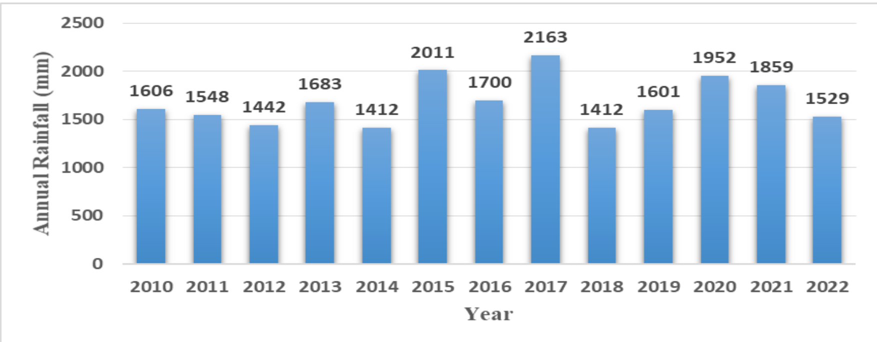

Figure 3: Average rainfall data of Khulna from year 2010 to 2021 (Source: World Bank)

The catchment area and storage capacity must be sized to accommodate water demand over the longest anticipated period without rain in order to provide a year-round water supply. If the rainwater collecting system be the only supply of water, the designer needs to make sure it can withstand the longest predicted period of time without rain or else make plans for a backup water source, such a well backup or transported water. In addition, precipitation from intense, short rainstorms might overflow storage tanks or splash out of the gutters. Even though these instances of heavy rain are included in the yearly rainfall total, it is uncommon to record the whole amount of precipitation that falls during an extreme storm. The fact that most rainfall happens periodically and isn't spread equally throughout the course of the year's twelve months is another factor to take into account. When sizing a system, the monthly distribution of rainfall is a crucial consideration (Patel *et al.*, 2014).

4.2 Rainwater Quality Assessment

4.2.1 Tests Performed on Rainwater Sample

Rainwater of late winter was collected on the rooftop of the old building of civil engineering of KUET. The rainfall height was measured which is 27 mm.
Parameters such as pH, Color, Turbidity, Arsenic, Iron, Manganese, Chlorine, Hardness, DO, EC, TDS are tested for monitoring on 07, 10, 12 and 13 December, 2023 in the environmental engineering laboratory of civil engineering building of KUET and the results of these parameters are presented on the Table no. 1.

Table 1: Water quality parameters montitored on laboratory tests

Parameters (unit)	**7/12/23**	**10/12/23**	**12/12/23**	**13/12/23**	**Mean value**	**Standard deviation**
pH	7.84	7.65	9.3	9.0	8.44	0.82
Color (PtCo)	21	9	16	0	15.33	9.11
Turbidity (NTU)	6.52	3.72	3.68	4.48	4.6	1.33
As (mg/L)	0	0	0	0	0	0.00
Fe (mg/L)	0.12	0	0.04	0.123	0.09	0.06
Mn (mg/L)	0	0	0.1	0.1	0.1	0.06
Cl^- (mg/L)	25	10	35	45	28.8	14.93
Hardness (mg/L)	129	-	69.45	92	96.8	30.07
DO (mg/L)	8.33	7.43	7.9	6.6	7.6	0.74
EC (μ/cm)	280	39.4	59.9	78.1	114.4	111.56
TDS (mg/L)	147	20	30	33	57.5	59.92

4.2.2 Analyses of Water Quality Data & Effect on RWH System Design

After testing these eleven parameters, the change of the values of these 6 days are observed and noted. From these values, it is observed that values of pH and Cl- have increased over the days.

The most crucial indicator of water quality for operational management is pH, which also establishes the treatment's efficacy. A pH level below the acceptable range might have negative effects on the user, such as steel corrosion, while using this water in the laboratory. From Table 1, the highest pH value is 9.3 which is very close to the standard value and the average pH value is 8.44 which is under the standard range which is 6.5 to 8.5. So the collected rainwater will not have adverse effect due to its pH value.

Excessive levels of chlorine can destroy pipes, pumps, and other laboratory equipment in addition to giving water a salty flavour. From Table 1, the highest Cl- value is 45 and the value is increasing day by day. But the maximum and average chloride readings from the test result demonstrate that it is much below the standard value of Bangladesh which is 150 to 600 mg/L.

Other parameters such as Color, Turbidity, Arsenic, Iron, Manganese, Hardness, DO, EC, TDS shows overall slight change over days which are shown in Figure 4,5,6 & 7.

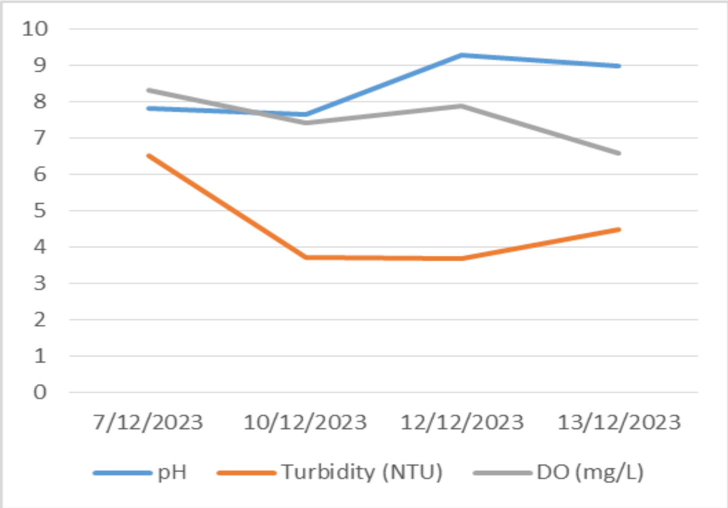

Figure 4: Change of pH, Turbidity and DO values of collected rainwater samples over days.

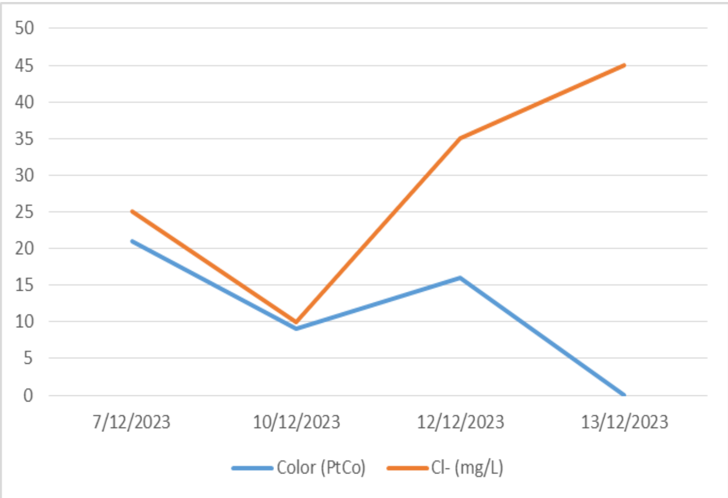

Figure 5: Change of Color and Cl^- values of collected rainwater samples over days.

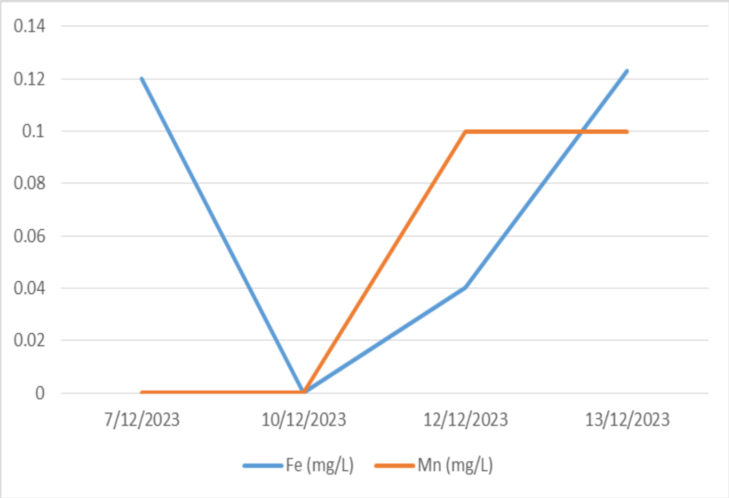

Figure 6: Change of Fe and Mn values of collected rainwater samples over days.

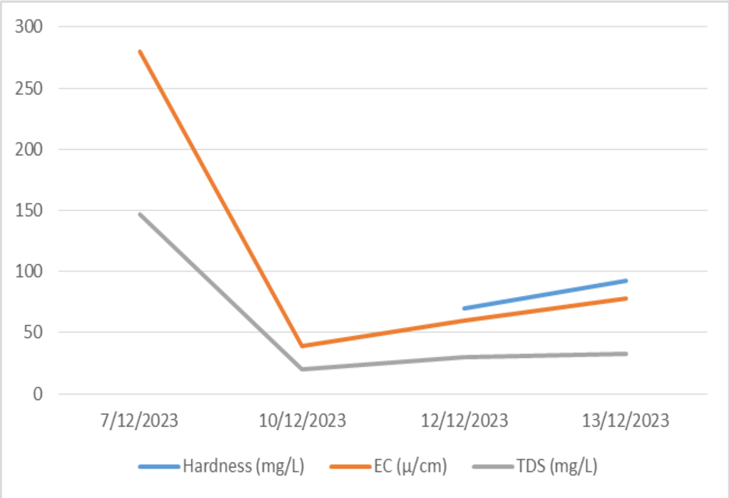

Figure 7: Change of Hardness, EC and TDS values of collected rainwater samples over days.

These slight variations of the values of the parameters are very significant for the future comparison of continuous quality assessment of rain water and designing RWH system. Because major change of pH, Cl^- and other parameters can affect the design of RWH system, as the stored water water quality will have significant effect on the laboratory equipments.

5. SIGNIFICANCE OF THE RESEARCH WORK

The main findings of this research paper are mainly the previous background studies, rainfall data analysis of the study area, quality monitoring of rain water and theoretical observations for required design of rain water harvesting system.

For design purpose in near future, existing roof area of old and extension building, drainage system and probable rainwater storage area are to be identified and selected. Then rainwater drainage system from rooftop are to be determined.

In next step, the rainwater storage area are to be calculated on the basis of water demand of laboratories of civil engineering building and annual rain water pattern in the area.

Different treatment systems of the harvested rain water are to be applied and finally a simple and user friendly treatment method would be adapted for the effective rain water use in the laboratories of civil engineering building. Probable systems for non-drinking purpose, simple filter and pH adjustment are to be required. If in the future the water is used for drinking, simple disinfection process are to be adopted in the treatment system. The step by step process flowchart to be followed for the design of rain water harvesting system is shown in Figure 8.

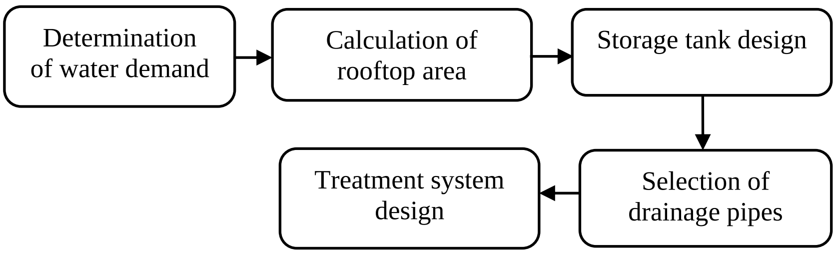

Figure 8: Process flowchart to be followed for the design of rain water harvesting system.

Besides, there is no previous research work related to rain water harvesting system on the rooftop of Civil Engineering Building of KUET. So, this research work will fill that void in this regards.

6. CONCLUSIONS

The overuse of groundwater is causing a daily increase in its scarcity and pollution from several sources. There is no doubt that the current situation requires for maintaining and recharging the groundwater in addition to making prudent use of the finite supply of fresh water. Rainwater collecting is a significant step towards appropriately consuming water at this rate. Because rainwater is devoid of iron, salt, and arsenic, it is a cost-effective and advantageous method of obtaining safe drinking water. A different source of safe water supply in metropolitan settings is rooftop rainwater harvesting equipment for multi storied building like civil engineering building of KUET which is very much needed for the laboratories in the present situation.

The major findings from this paper are:

- Yearly rainfall data of Khulna region are analysed and presented in this paper for designing the whole rain water harvesting system for further research.
- Assessment of the rain water quality of Khulna by performing some tests on the collected sample base on some specific parameters.
- From the results of performed tests, it is observed that values of pH and Cl^- have increased over 6 days.

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