AC 2010-345: RAINWATER HARVESTING FOR DOMESTIC CONSUMPTION IN BANGLADESH: SIZING AND CONSTRUCTION OF STORAGE CISTERNS

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Rainwater Harvesting for Domestic Consumption in Bangladesh: Sizing and Construction of Storage Cisterns

Abstract

Bangladesh has an emerging problem with water supplies not adequate to meet even the minimum requirements for potable water. Surface water is being continuously contaminated by both industrial and human pollutions; rapidly increasing demands due to population explosion results in withdrawal of ground water at a faster rate than it is replenished by recharge. This problem can easily be mitigated through rainwater harvesting, taking advantage of high quantities of rainfall in the country. This study proposes to provide some guidelines for economic rainwater harvesting for domestic consumption in urban areas of Bangladesh. The guidelines have been formulated using existing data on rainwater harvesting systems. Based on these guidelines, a mathematical model has been developed to figure out cistern sizes for collection of rainwater. The products of this research are a) computer program for calculating domestic water requirements and sizing storage cisterns and b) an animation of the proposed rainwater harvesting system. These can be used as teaching tools to demonstrate the construction methods of such a system and the benefits of the technique.

Key words: Bangladesh, Cistern sizing, Rainwater Harvesting

The Problem and its Setting

Problem Statement

Rainwater harvesting is the principle of collecting and using precipitation from a catchment area. The term is derived from a more general connotation of water harvesting that denotes the collection, storage, and use of water mainly for the purpose of irrigation. Nowadays the term generally comprises the collection of run-off on micro-catchment principles, such as roofs.

The purpose of this study is to assess a sustainable rainwater harvesting solution for multistoried residential apartments in Dhaka, Bangladesh through an extensive review of the literature and collection and analysis of secondary data. The objectives of the study were as follows:

- Identify and analyze the rainwater harvesting methods of Bangladesh,
- Analyze the significance of rainwater harvesting in the urban residential areas of Bangladesh,
- Develop a solution for rainwater harvesting solution for a typical multistoried residential apartment in Dhaka, Bangladesh, and
- Utilize programming and visualization to assess the efficacy of the solution.

Review of the Literature

Historical Background

Rainwater harvesting is a common practice in the countries and areas where the annual precipitation is high and pure drinking and usable water is scarce. All over the world, economical condition has prompted the low-income groups to harvest the rainwater for household and essential uses. Several countries of the world in different regions have showed the popularity of this method. Originated almost 5000 years ago in Iraq, rainwater harvesting is practiced throughout the Middle East, the Indian subcontinent, Mexico, Africa, as well as in Australia and United States. Demand of water both from surface and underground sources continually increases with the increase in world population, leading to a consequence of crisis of water supply in different regions. Among other available alternative sources for water supply, rainwater harvesting has become the most economic solution for the water crisis[1].

Rainwater Harvesting Around the World

Studies and experiments have been done to establish the potability of rainwater [2, 3, 4]. Composed in a comprehensive system, rainwater harvesting yields several benefits. Krishna[5] indicates that the most important benefit of rainwater harvesting is that it is totally free; the only substantial cost involves storage.

Increased awareness on water crisis has led rainwater harvesting to be proposed as a community facility. For example, small and medium residential and commercial constructions in the United States have shown increasing interest in rainwater harvesting since 1996[6]. Cities and states around the world are adopting rules related rainwater harvesting, especially in United States[4].

Kenya has successfully adopted rainwater harvesting systems[7]. Kenya Rainwater Association uses low cost technical options to build the systems through community based organizations. A combination of improved health awareness and benefits from clean and safe water and resulting income from sale of surplus farm produce gives rise to an increased willingness of people to pay for improved housing and water supply.

A study by Mutekwa and Kusangaya[8] indicates a successful adoption of RWH technologies in Zimbabwe that has contributed to alleviate problems faced by resource-poor subsistence farmers. Benefits of RWH technologies include an increase in agricultural productivity, enhancing household food security and raising of incomes. The technologies also have assisted in improving environmental management through water conservation, reduction of soil erosion and resuscitation of wetlands in the study area. The study[8] concludes that RWH technologies are suitable for smallholder farmers in semi-arid areas provided they are properly tailored the conditions of the region where they are promoted. Other benefits of adopting RWH include improvement of people's standard of living and reduction in environmental degradation.

Practice in Bangladesh

Bangladesh used the surface water as the principal source for drinking water up to the recent past. But nowadays, withdrawal of groundwater has become norm. One of the major problems with groundwater is arsenic contamination. Almost 50 percent of the country suffers prom this contagion[9]. Figure 1 shows the alarming scale of the problem in Bangladesh.

Being a tropical country, Bangladesh receives heavy rainfall during the rainy season with an average annual rainfall of 95 inches[10]. This amount makes rainwater harvesting an obvious solution for the country.

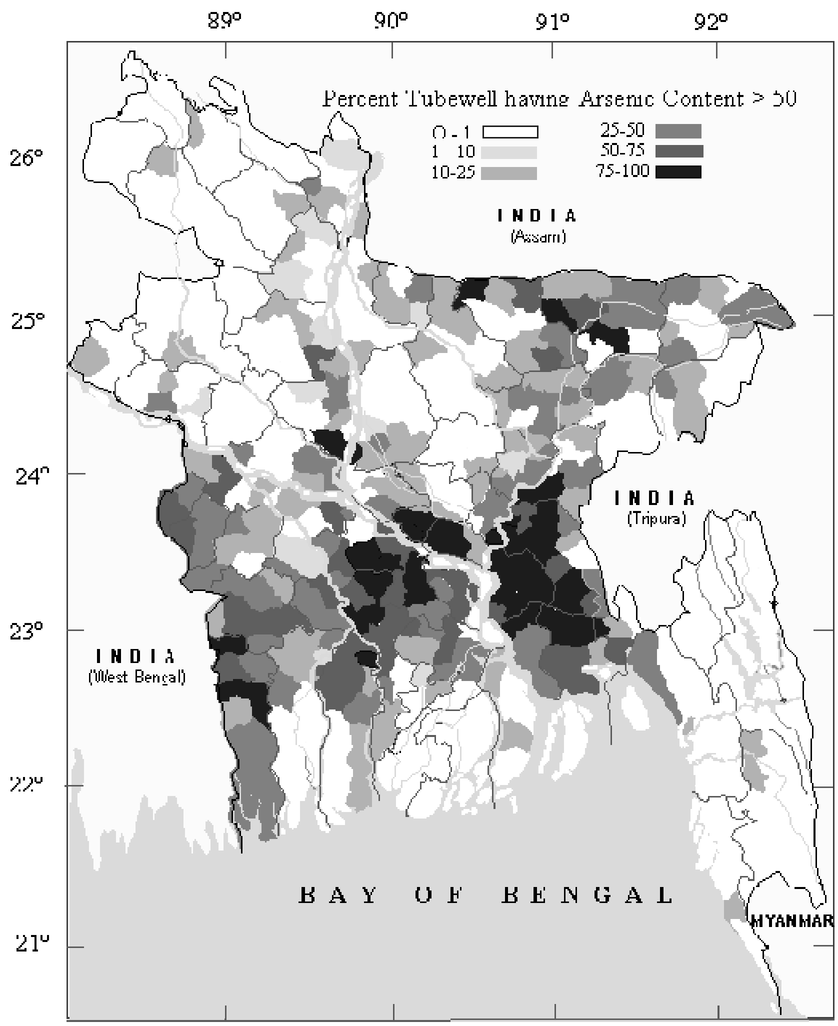

Figure 1: Arsenic Contamination of Groundwater in Bangladesh

The ever-increasing population in Dhaka, the capital of Bangladesh, is putting increased load on underground aquifers. Dhaka receives an annual rainfall of about 100 inches which can easily be an answer to the vertical recharge for the aquifers[11]. Rainwater harvesting has also the promise of facilitating the consumers with some additional benefits such as reduction in the scale of seasonal flooding and water logging.

Rooftops in buildings may be designed to collect rainwater solving the challenging issues of minimizing the storage cost and management. If the system is incorporated in the design and construction process of buildings, cost of such a system could be very minimal[12].

Rainwater Harvesting Technology

Catchment Surfaces

Unlike conventional water supply system, which is either dependent on groundwater or on stream flow, rainwater harvesting is totally based on the availability of water from precipitation. It has to be intercepted first in order to make it available for consumption. The quantity of water that can be harvested depends on the amount of rainfall and the size of the catchment area. Some of the methods of interception include the use of the roof, courtyard, and ground catchments.

Use of roof is the most commonly developed practice for rainwater harvesting. Under satisfactory conditions, roof run-ff can supplement or even replace the conventional supply system. Rainwater can be collected from any type of roof. The only type of roof that is unsuitable for drinking is one with lead flashings or coated with lead-based paint[13].

Separation of Sediments

When rainwater is collected from roof, the first consignment of water contains dust, debris, bird droppings, or other sediments. This should be separated from the supply before it is stored. Simple, automatic systems are available for diverting this water (called first flush diverter) that can be easily installed with a rainwater catchment system (see Figure 2).

It consists of a ball float and a pipe chamber. When the rain starts to fall, it drains through a screen and accumulates together with any debris in the pipe chamber. As the chamber fills, the ball floats on the surface of collected water. Eventually the ball becomes stuck at the intersection between the first flush device and the pipe that leads to the storage tank. Thus water is redirected subsequent toward the storage tank.

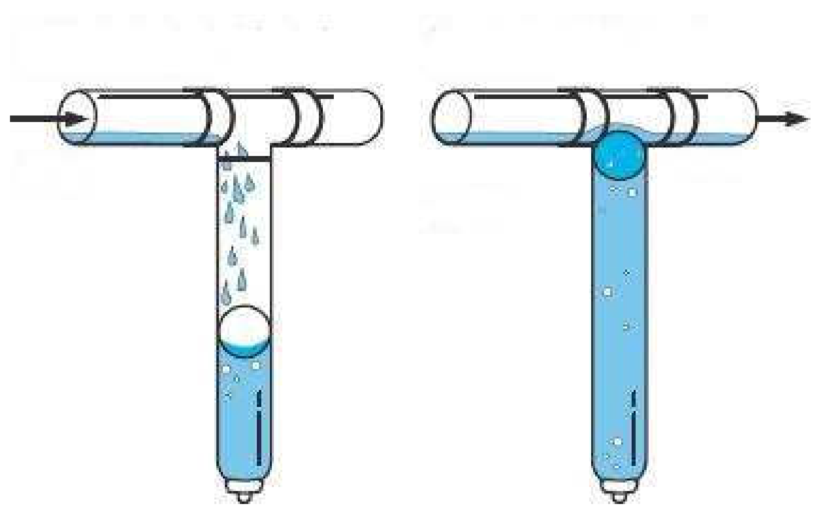

Figure 2: First flush device

Storage of Rainwater

Quantity runoff from a catchment area is dependent upon the amount of precipitation. Since it is intermittent in nature, storage must be an integral part of a rainwater harvesting system. Storage facilities can either be below or above ground depending on site conditions and other factors. The cistern or tank selected should be completely covered in order to prevent health hazards and loss of water due to evaporation.

Methodology

In order to provide a rationale for adopting rainwater harvesting systems for Bangladesh, it was necessary to find out (1) the extent of treatment required to make the water potable and (2) overall savings, if any, to the consumers when they switch either partially or completely to supply from this source.

Data Collection and Analysis for Treatment of Rainwater

One of the major costs involved in water supply is treatment. Before installation of a rainwater harvesting system, one should find out the extent of treatment that would be required for this type of supply water. It was, therefore, decided to find out the quality of harvested rainwater and the levels of its contamination.

Test reports of rainwater from different countries were collected from secondary sources. The data was then analyzed, comparing it to existing EPA standards. A one-sample t-test was conducted to analyze the data. Variables tested were pH value, total coliform content, total dissolved solids, and minerals such as chloride, iron, nitrate, sodium, and sulfate.

Findings

The analysis of the data, reported in Table 2, strongly suggests that except for the amount of total coliform, chemical composition of rainwater is within the safe range to be used as potable water. It is therefore only logical to conclude that treatment of rainwater for domestic consumption in Bangladesh would not be expensive compared to the cost of treatment for groundwater. Only major treatment would be the removal of total coliform. Comparing different purification methods currently used, several options such as distillation using solar energy, deionization, reverse osmosis, and chlorination. Considering the cost, availability and effectiveness of the various, chlorination seemed to be the most appropriate method for this purpose.

Table 2: Comparison of rainwater quality against EPA standards

Variable	Mean value	EPA standard	p-value ($p<=0.05$)	Findings
pH value	6.50	6.50	0.996	pH value of rainwater is not significantly different than the EPA standard
Total coliform	805 ppm	5 ppm	0.023	Total coliform count of rainwater is significantly higher than the EPA standard
Total dissolved solids	48.70 ppm	500 ppm	<0.000	Total dissolved solids in rainwater are significantly lower than the EPA standard
Chloride	15.128 ppm	250 ppm	<0.000	Chloride in rainwater is significantly lower than the EPA standard
Iron	0.19 ppm	0.30 ppm	0.362	Iron in rainwater is not significantly different than the EPA standard
Nitrate	4.70 ppm	10 ppm	0.330	Nitrate in rainwater is not significantly different than the EPA standard
Sodium	4.05 ppm	200 ppm	<0.000	Sodium in rainwater is significantly lower than the EPA standard
Sulfate	19.14 ppm	250 ppm	<0.000	Sulfate in rainwater is significantly lower than the EPA standard

Domestic water requirement

Daily water consumption was calculated by developing a program for the purpose, using Java Script (see Figure 3). It was based on following variables:

- Total number of residents in an apartment
- Daily per capita use of different plumbing fixtures such as lavatories, showers, water closets, etc.

Required Data Entry	
Number of People in Residence	
Indoor Water Use	
Bathroom Water Use	
Daily Showers in The Residence	
Average Shower Time in Minutes	
Shower Head Flow Rate (3.8 std. 1.6 res.)	
Total Weekly Baths in Residence	
WC Water Use	
Average Number of Flushes Daily Per Person	
Gallons Per Flush (5 std. 1.6 res.)	
Faucet Water Use	
Average Number of Times Each Person Uses Faucet Daily	
How Many Minutes Each Use	
Calculated Results	
Bathrooms	
WCs	
Faucets	

Figure 3: Water consumption calculator (partial view)

Based on the data for water demand by different fixtures, it was calculated that per capita water consumption in an urban area in Bangladesh is 25 gallons per day. The daily consumption of water for a family of 5 living in an apartment would be 125 gallons.

It was now critical to figure out whether adequate quantity of rainwater is available round the year to meet the demands of all the residents of a typical apartment complex in Dhaka, Bangladesh (see Figure 4). Usually such a complex consists of 10 to 20 apartments with a total number residents ranging from 50 to 100.

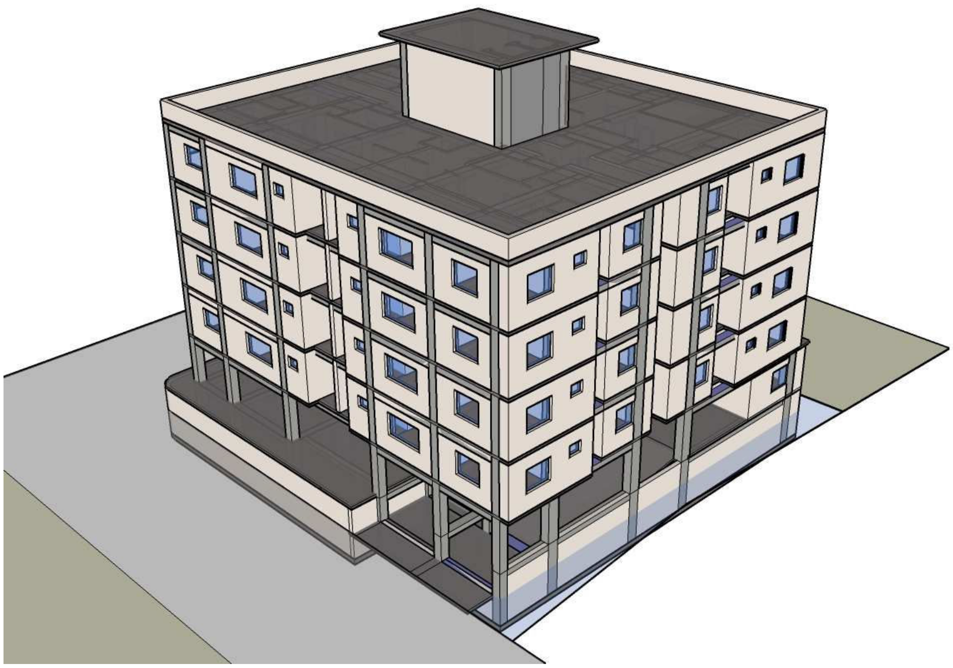

Figure 4: A typical apartment complex in Dhaka

Projects concerning collection of rainwater using roof as the catchment area can be initiated from the available rainfall data. Mean annual rainfall in Dhaka is about 100 inches. The volume of rainwater collected everyday and consequently used for consumption was found out using the following algorithm for different catchment areas and annual fall:

Water available in gallons = (62.4 lbs. per cft./12inches per ft./8.33 lbs. per cft)*annual rainfall in inches*catchment area area*runoff coefficient Eqn. (1)

A runoff coefficient of 0.9 has been used for the catchment area surface. Table 3 shows quantities of water available for domestic consumption. Assuming a conservative estimate of a rainfall of 80 inches and a catchment area of 8,000 sft., the total quantity of water available would be about 400,000 gallons.

Table 3: Annual gallons of water available from catchment surface

Catchment Area in Sft.	Annual Rainfall in Inches					
	50	60	70	80	90	100
6000	168547	202257	235966	269676	303385	337095
7000	196639	235966	275294	314622	353950	393277
8000	224730	269676	314622	359568	404514	449460
9000	252821	303385	353950	404514	455078	505642
10000	280912	337095	393277	449460	505642	561825
11000	309004	370804	432605	494406	556206	618007

It was now necessary to find out whether the available quantity of water would be adequate to meet the daily demands of the residents of a typical apartment complex. The following algorithm was used for the purpose:

Persons served = Water available in gallons per year/(daily per capita consumption*days in a year) Eqn. (2)

Table 4 shows the number of persons served at the rate of 25 gallons per person per day at different quantities of rainfall. Assuming a conservative estimate of a rainfall of 80 inches and a catchment area of 8,000 sft., the total number of people served by the water available would be 45 .

Table 4: Number of persons served by available water from rainfall

Catchment Area in Sft.	Annual Rainfall in Inches					
	50	60	70	80	90	100
6000	50	60	70	80	90	100
7000	21	25	29	34	38	42
8000	24	29	34	39	44	49
9000	28	34	39	45	50	56
10000	31	38	44	50	57	63
11000	35	42	49	56	63	70

Cost Savings from the Use of Rainwater

It is apparent from the above findings that there would a considerable reduction in the use of water from conventional supply systems by factor of 0.5625 if rainwater harvesting is introduced. If the total number of residents in an apartment complex is 80, then it appears that more than 50 percent of the domestic water needs can be met by rainwater harvesting. Since this water is available almost for free, except for the nominal cost of some basic treatments, the cost of water would be reduced to more than half if rainwater harvesting system were installed. Considering the present cost of municipal supply water in Dhaka, Table 5 summarizes the savings of a family of five when dependence on conventional supply is reduced:

Table 5: Cost benefits of rainwater harvesting

Cost of municipal supply per 1000 gallons	$0.50	Cost of rainwater	0
Water consumption (in gallons) per year for a family of five	1500	Percentage reduction of municipal supply	56.25%
Water cost per year for a family of five	$750.00	Reduction in water cost for a family of five	$421.88

Proposed Rainwater Harvesting System

Components

The proposed rainwater harvesting system for an apartment complex in Dhaka, Bangladesh consists of:

- Roof catchment
- Gutters and downpipes
- First flush device
- Filter chamber
- Chlorination chamber
- Dechlorinator
- Cistern
- Water pump and supply pipes

Sizing of Storage Cistern

One of the major elements in the system is rainwater storage cistern. Since most of the apartment complexes in Dhaka are multistoried using raft foundation below grade (see Figure 5), the space enclosed by the foundation wall can be utilized as a cistern without much additional cost.

Figure 5: Raft foundation

The size of rainwater storage cistern was determined for a typical apartment complex in Dhaka, Bangladesh, with a roof area of 8,000 sft. The variables used to figure out the size were:

Monthly water consumption (MC): It is the total quantity of water requirement. It was based on daily per capita consumption in gallons.

Critical rainfall (CRF): It is the minimum quantity of rainfall per month in inches required to meet monthly water consumption requirement only from rainfall. It was calculated to be 18 inches.

Monthly factor of insufficiency (MFI): This is a ratio of the difference between monthly rainfall and critical rainfall to critical rainfall. When the monthly rainfall is equal to or higher than critical rainfall, the factor is zero. Table 6 shows all the monthly factors of insufficiency.

Table 6: Monthly factor if insufficiency

Rainfall	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean	0	1	2	8	10	18	20	23	10	5	2	0
Critical	18	18	18	18	18	18	18	18	18	18	18	18
MFI	1.00	0.94	0.89	0.56	0.44	0.00	0.00	0.00	0.44	0.72	0.89	1.00

Yearly factor of insufficiency (YFI): It is the sum of monthly factors of insufficiency.

Total monthly supply (TS): It is the required quantity of rainwater required to meet monthly consumption, without any shortfall in month of the year. It is based on the yearly factor of insufficiency.

Leakage factor (LF): It is factor that accounts for water loss due leakage through cistern walls. For a concrete surface, the factor is 0.01.

Storage factor (SF): It is a ratio of water consumption from rainwater to total quantity of water requirement for consumption. For a typical apartment complex in Dhaka, Bangladesh the factor is calculated to be 0.5625.

Storage capacity (V_{gal}): It is the capacity of a cistern to store rainwater, measured in gallons. . It was calculated using the following algorithm:

$$V_{gal} = MC*TS*(1+LF)*SF \quad \text{Eqn. (3)}$$

Storage volume (V_{cft}): It is the size of the storage cistern in cubic feet. It was calculated using the following algorithm:

$$V_{cft} = V_{gal} * 8.33/62.4 \quad \text{Eqn. (4)}$$

A computer program using visual basic language was developed to calculate the actual capacity of such a cistern for a typical apartment complex (Figure 6). After entering data for all the steps identified for storage sizing, it was found that the space available in the basement (created by the below grade raft foundation) for a typical apartment complex in Dhaka was adequate for a rainwater storage cistern.

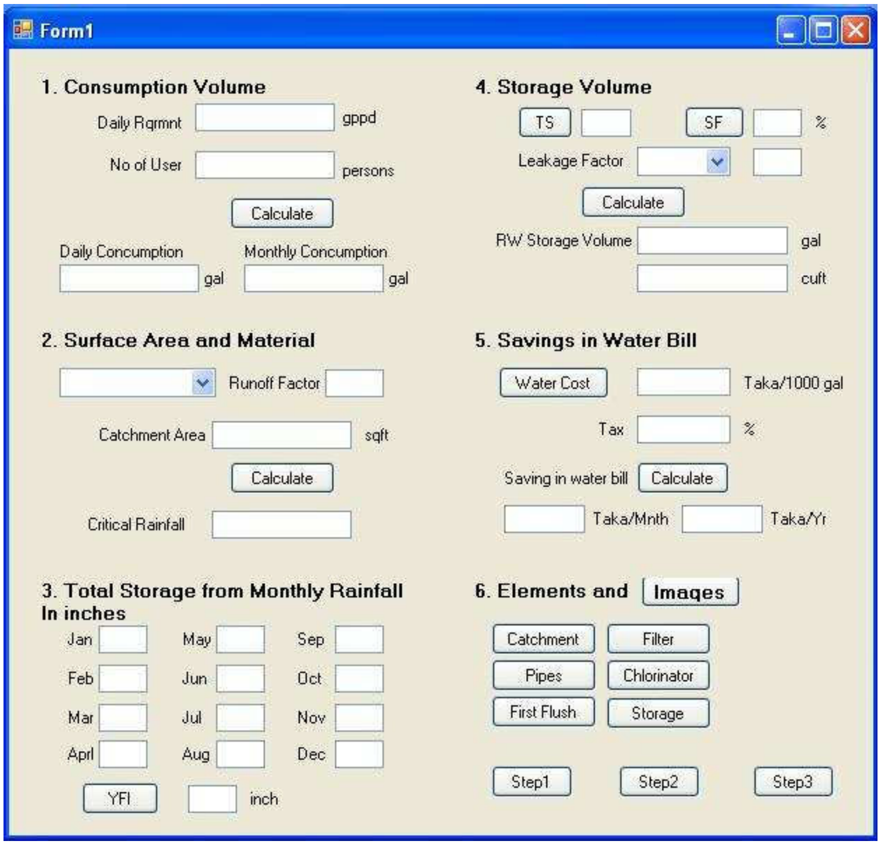

Figure 6: Storage tank calculator

Summary and Conclusions

The rainwater harvesting system that has been developed for a typical apartment complex in Dhaka, Bangladesh is composed of the standard components for such a system, adjusted to local requirements. A 3D model has been developed for the solution to make it easily comprehensible to the users. This model, along with the computer programs, forms the guidelines for design and installation of the system.

The solution developed and expressed in programming and visualization can be a comprehensive and effective tool for learning and designing rainwater harvesting solution both for the user and for the professionals in the building industry of Bangladesh. Under the guidelines, using the local water demand and rainfall, a rainwater water harvesting method can be designed even for a different location. The water conservation calculation in monetary terms will provide the owners, builders, as well as the users with the freedom to choose the option that suits most.

Further research can be done on the creation of animation with more details. The local bodies can use this research as a guideline to calculate the possible amount of supply water conserved by the rainwater harvesting as well as the decrease in load on the ground water to advocate this method to be included in housing policy. The results can be an effective teaching tool in the fields of sustainable construction, water conservation, and green building where alternative technologies such as rainwater harvesting are gradually getting serious attention.

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