SUSTAINABLE WATER SUPPLY: RAINWATER HARVESTING FOR

MULTISTORIED RESIDENTIAL APARTMENTS IN DHAKA, BANGLADESH

A Thesis

by

FARZANA SULTANA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2007

Major Subject: Construction Management

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Approved by:

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	Mohammed Haque
Committee Member,	Charles Culp
Head of Department,	Joe Horlen

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ABSTRACT

Sustainable Water Supply: Rainwater Harvesting for Multistoried Residential Apartments in Dhaka, Bangladesh.

(December 2007)

Farzana Sultana, B. Arch., Bangladesh University of Engineering and Technology

Co-Chairs of Advisory Committee: Dr. Ifte Choudhury
Dr. Mohammed Haque

Rainwater harvesting is a familiar term for Bangladesh. People in areas that lack drinking water, particularly the coastal areas and the rural areas in the country, practice rain water harvesting. The high annual rainfall in the country makes rainwater harvesting a logical solution for the arsenic contamination of ground water in Bangladesh (Rahman et al. 2003). Also, the increasing population in the urban as well as rural areas is putting increased load on underground aquifers which is evident in the fact that the piezometric level in Dhaka has decreased by more than 65 feet in the last decade. The annual rain fall that the city receives may be an effective answer to the recharge of aquifers. Rain water harvesting during the rainy season can reduce the increasing load on groundwater levels.

This study aims to provide some guidelines for economic rainwater harvesting system, especially for urban areas for specific user groups. These guidelines were formulated through literature review, analysis of some case studies on rainwater harvesting, and, to a certain extent, practical experience of the researcher. Data from secondary sources have also been used for the purpose. 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 solution is applied to a typical plan of an apartment house in Dhaka (multistoried) using programming and visualization so as to demonstrate the scope and benefit of integration of rain water harvesting technique with the architectural design.

The harvested rainwater definitely does not meet the basic domestic requirement, but supplements it during the rainy season which, most importantly, is usable for individual household use. Large-scale rainwater harvesting also, hopefully, results in a decrease of seasonal flooding in the urban areas. The products of this research are a) a computer program for sizing cisterns and b) an animation of the proposed rainwater harvesting system that may be used as a tool to demonstrate the benefits of the technique.

DEDICATION

To my parents

Mrs Kamre Jahan
Mohammed Showkat Ali

ACKNOWLEDGEMENTS

My first and most earnest gratitude goes to the Almighty Allah for materializing my dream.

I would like to express my gratitude to my Co-Chair, Dr. Ifte Choudhury, for his support, patience, and encouragement throughout my graduate studies. It is not often that one finds an advisor that always finds the time for listening to the little problems that unavoidably rise in the course of performing research. His technical and editorial advice was essential to the completion of this dissertation and has taught me innumerable lessons and insights on the workings of academic research in general. My thanks also go Dr. Mohammed Haque and Dr. Charles Culp for reading previous drafts of this dissertation and providing many corrections and valuable comments that improved the presentation and contents of this dissertation.

The friendship of Mohsin Reza, Bhajan Biswas, Aaron Cooper and Sameh Alathirah is much appreciated and has led to many interesting and good-spirited discussions relating to this research. I am also grateful to my colleague Manisha Singh and Lilian Kalyanapu for helping considerably with realizing the detail procedure of research. In particular, Lilian trained me for programming with great diligence and ingenuity. My thanks go to Mahmudur Rahman Masum who helped with collecting data from Bangladesh and to Architect Nahas Khalil for igniting the interest for rainwater harvesting in me. I also owe a huge debt of gratitude to Dr. Shahana Rahman and her family who were instrumental in the development of my professional career.

Last, and most heartfelt acknowledgement must go to my brother Mohiuddin Ahmed for being a mentor, in all possible ways. His image, support and encouragement were in the end what made this thesis possible. My parents receive my deepest gratitude and love for their dedication and the many years of support during my undergraduate studies that provided the foundation for this work. Their support, encouragement, and companionship have turned my journey through graduate school into a pleasure. And upon whom lies my everlasting love.

NOMENCLATURE

GPPD	Gallon Per Persons Per Day
DC	Daily Consumption
MC	Monthly Consumption
ROF	Runoff Factor
CRF	Critical Rainfall
ARF	Mean Annual Rainfall
MFI	Monthly Factor of Insufficiency
YFI	Yearly Factor of Insufficiency
TS	Total Storage
LF	Leakage Factor

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INTRODUCTION AND BACKGROUND

Fresh water, a renewable but limited resource, is scarce in many areas of the developing world because of unplanned withdrawal of waters from rivers and underground aquifers causing severe environmental problems like arsenic contamination (Rahman et al. 2003). In many countries, the amount of water being consumed has exceeded the annual amount of renewal creating a nonsustainable situation (Choudhury & Vasudevan, 2003). In addition to that, rainwater run-off during rainfall from roofs and other sealed surfaces during heavy rain is leading to accumulated flooding in the urban areas of many countries like Bangladesh where the drainage system was not designed including the volume of rainwater runoff. As ancient as the early days of civilization, rainwater harvesting, the system of collecting and using the precipitation from a catchment area is considered as an alternative option for water supply in Bangladesh (Yusuf, 1999). Unless it comes into contact with a surface or collection system, the quality of rainwater meets Environmental Protection Agency standards(Choudhury & Vasudevan, 2003) and the independent characteristic of its harvesting system has made it suitable for scattered settlement and individual operation (Rahman & Yusuf, 2000).

This thesis follows the style and format of Journal of Construction Education and Research.

THE PROBLEM AND ITS SETTING

Problem Statement

The purpose of this study is to assess a sustainable rainwater harvesting solution for multistoried residential apartments in Dhaka, Bangladesh using interactive tools like programming, visualization etc.

Research Objectives

1. To identify and analyze the rainwater harvesting methods of Bangladesh.
2. Analyze the significance of rainwater harvesting in the urban residential areas of Bangladesh
3. Develop a solution for rainwater harvesting solution for a typical multistoried residential apartment in Dhaka, Bangladesh.
4. Utilize programming and visualization to assess the efficacy of the solution and its details.

Delimitations

1. The research will be confined only to the urban area of Dhaka, Bangladesh.
2. The study will be confined to residential apartments of Dhaka, Bangladesh.
3. The study will be confined to six storey apartment buildings of Dhaka, Bangladesh.

Assumptions

1. No environmental or other contamination other than those from the catchment area will be present in the harvested rainwater.

2. The rainwater harvesting method is socially accepted in the study area.
3. The per capita water consumption is assumed to be 25 gal/day or 94.75 lpcd (MH and PWD, 2002).
    a. 1.5 gal/flush; frequency of use/day=4, total 6 gal
    b. 2.5 gal/ shower, duration per shower= 5 minutes, total=12.5 gal
    c. Cooking and drinking: 1.5 gal
    d. Cleaning and miscellaneous: 5gal. grand Total: 25 gal/person/day

Definitions

Catchment Area

Catchment area is the net roof surface, in square feet/square meters, from which rainwater is collected (Choudhury & Vasudevan, 2003).

Cistern/Storage Tank

A cistern or a storage tank is a receptacle built to catch and store rainwater. They range in capacity from a few liters to thousands of cubic meters. Cisterns are usually built underground (Pacey and Cullis, 1986).

Potable Water

The water of sufficient quality which is fit for human consumption is called potable water (Choudhury & Vasudevan, 2003).

Aquifer

An aquifer is an underground layer of water-bearing permeable rock, or unconsolidated materials (gravel, sand, silt, or clay) from which groundwater can be usefully extracted using a water well (Pacey and Cullis, 1986).

Ground Water

Groundwater is the water located beneath the ground surface in soil pore spaces and in the fractures of geologic formations (Pacey and Cullis, 1986).

Alternative Technology

Alternative technology refers to technologies that are more environmentally friendly than the functionally equivalent technologies dominant in current practice, aims to utilize resources sparingly, with minimum damage to the environment, at affordable cost and with a possible degree of control over the processes.

Filtration

Filtration is the method of separating solid and suspended contaminants in rainwater achieved by the interaction between the rainwater and a porous interface i.e. the filter (Pacey and Cullis, 1986).

First Flush

First flush is the first part of the rainwater runoff after a dry period, which contains higher concentration of contaminants than a subsequent flush (RHPT, 2007).

Visualization

Visualization refers to the creation of two and three dimensional graphic of any architectural/construction design with the aid of digital computers and 3D software.

REVIEW OF RELATED 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, in Mexico, Africa as well as in Australia and United States. As the population of the world increased, irrigation, the most water consuming human activity, as well as domestic water usage increased, leading to a consequence of crisis of water supply in different region. Among other available alternative sources for water supply, rainwater harvesting has become the most economic solution for the water crisis (Boers and Ben-Asher, 1982).

Rainwater and Community

Domestic Rainwater Harvesting (DRWH) is a sub set of rainwater harvesting whereas policies and legislation mostly refer to the generality. The popular means of water harvesting is surface run-off providing water in large quantity, of low quality mainly for agriculture. In water policies of the African countries, such as Kenya, RWH as a means of poverty alleviation refers to harnessing water by constructing appropriate dams and pans for collection of water for small-scale agriculture and livestock. In Kenya, DRWH can mean both surface run off and roofwater harvesting while in Sri Lanka and Thailand it means only roofwater harvesting. Due to recent rapid development of roof water harvesting in some countries, some policy documents now distinguish between roof water harvesting and rainwater harvesting. Although the one of the largest development of roof water harvesting took place in Thailand in the 1980's, neither rainwater harvesting nor roofwater harvesting are mentioned in the local Water Act (Ariyabandu, 2003). Bangladeshi water policy clearly identifies the problems associated with over-use of surface and ground water, which has been causing depletion and pollution of ground water resulting in salt-water intrusions and arsenic threats. While the policy recognizes sustainable development of surface, ground and *rainwater* as a possible solution, it does not refer to roofwater harvesting. Therefore, interpretation is crucial for the implementation of policies, depending on the need of the hour.

As shown in table 1, most countries of the world, state owns the water resources, while the current debate in the water sector reforms is the Community Verses State Ownership in Water Resources Development. Although the presumption of most activists is that water resources development should be transferred to community ownership for it to serve the communities and attain sustainable development, all water policies (contributing to this view) are still engrossed in the conventional state ownership of water resources.

Table 1

Ownership of water and its impact. (Ariyabandu, 2003)

Country	Status	Description
Sri Lanka	Public Ownership	No restriction on development of DRWH
India	Not specified	Water is a state object. No potential threat to development of DRWH
Bangladesh	State ownership	No constraints on development of DRWH
Thailand	State ownership including atmospheric water	Storage of water requires a license as decided by the river basin committees
Kenya	State ownership	Requires a permit to construct water works. Not clear whether this includes DRWH. No restriction on water for domestic use.
Uganda	State ownership	Requires a permit to construct water works. Not clear whether this includes DRWH. No restriction on water for domestic use.
Ethiopia	Public Ownership	No permit is required. But large scale water development is practiced without permission. Status of DRWH is not clear. No restriction on water for domestic use.

Instead of strong policies, special reasons and circumstances led the success of DWRH in the past. Still, it is strongly assumed that enabling policies and legislation will be vital for the sustainability of DRWH in future. At present, the NGOs and special projects are working to foster DRWH. Without state commitment, this trend can't continue. Also, the ownership of water should be handed over to the water user communities, along with that, demand responsive approaches should be adopted in selecting water supply options. This will naturally pave the way for development and promotion of DRWH based on need (Ariyabandu, 2003).

Community operation and maintenance, along with community participation and control, is essential to the successful implementation, operation and maintenance of any rainwater project, eventually which encourages demand management. Demand management strategies are unlikely to succeed without strict individual self-discipline and community control / recommendations agreed by the community themselves regarding efforts to promote water conservation. Evidences show that combined public-private sector approaches for rainwater harvesting initiatives can work effectively in certain circumstances (Gould, 2007).

In a case study in the semi-arid region of Brazil (an initiative developed by NGOs with the support of Brazilian Federal Government Institutions and international funding organizations), instead of focusing on short-term, top-down, palliative measures based on the construction of dams and wells, it focused on low cost, bottom-up, long-term measures and, most importantly, it involves an educational component. So, the provision of water is closely related to the empowerment of the most destitute population which leads to the sustainability of the actions. This case illustrates the relevance of the partnership between grassroots organizations and governmental institutions in the context of mitigation through the combination of educational and technical components. The educational component of this project is thus the basis for any needed social transformation of the area. It is important, at this stage, to assess the impact of the project on the quality of life of the beneficiary population. The avoidance of the political manipulation of the construction of cisterns by local politicians should also be monitored. Looking at the socio-economic and political implications of the problems, in order to properly mitigate the scarcity of water, the social implications have to be addressed and the consciousness-raising of the population is the only way through which this can be done (Branco et al. 2005).

Figure 1: Flood in Urban Slum

Figure 2: Arsenic in Tube Wells

In Bangladesh, in 1989, the Ministry of Environment and Forest was established to address the emerging environment related issues. In the consecutive years, the National Environment Policy, 1992 was adopted; a new law called the Bangladesh Environment Conservation Act, 1995 was enacted repealing the earlier law of 1977 and restructuring the Department of Environment. The national environment management action plan (NEMAP) has also been finalized and is being implemented. Eventually, other laws were framed including the followings:

1. The Environment Court Act, 2000,

2. The Environment Conservation Rules, 1997,
3. The Environment Pollution Control Ordinance, 1977,
4. The Water Pollution Control Ordinance, 1970.

And so on. Although all these acts and rules are specific about water pollution and wetland conservation, little has been done from the part of the government for water conservation specially relating rainwater groundwater and groundwater recharge. The Ministry of Housing and Public Works Department, Government of Bangladesh, had published a rainwater-harvesting manual applicable for the rural and urban areas in 2002. The guidelines were applied in the installation of rain water harvesting system in one governments housing (Member of Parliament Hostel) as a study. However, after the change of Government the study was left incomplete as well as the publication of the manual. To make the rain water harvesting a practice for any target area, examples should be the first step. With that, Government should frame appropriate policies regarding tax incentive to individual households for the rain water harvesting practice, which will encourage the citizens to adopt it. All the existing public buildings and new building constructions can be a good place to start installing and study the output of rain water harvesting. Promotional and educational activities from local government will also be necessary to realize the following issues that could be solved or improved by rain water harvesting:

- Water shortage, i.e. of safe drinking water
- Seasonal flooding (Figure 1)
- Ground water recharge i.e. water management
- Health and sanitation
- Alternative water supply (Arsenic contamination: Figure 2 & 4)

Bangladesh Water Development Board (BWDB), Water Resources Planning Organization (WARPO) are institutions under the Ministry of Water Resources, the

Government of the People's Republic of Bangladesh. They are among the key organizations dealing with nation - wide macro level water resources planning and management. At present, they are helping the government with tasks such as monitoring implementation of the National Water Management Plan (NWMP) and its impact, upkeep of water resource assessments, maintenance and updating of the National Water Resources Database (NWRD) and MIS etc. But these organizations can help the government in planning large scale rain water harvesting project through local government and monitor the application and out come. The Bangladesh Environmental Lawyers Association (BELA), Participatory Review International Network, BRAC are some private organization and NGO’s that are working hand in hand with the government with the energy conservation issues. Through the recent activities, BELA has become a true pressure group against environmental violations, and its research has played a significant role in popularizing the environment amongst the general public. In the implementation phase of the government plans, these NGO’s can work directly work with communities under local government to educate and involve them in water conservation practices. Including female citizens will definitely improve the outcome which was successful in similar projects in several parts of India. All these practice has already started in Bangladesh in different areas starting with small residential communities and aiming at huge commercial buildings areas where catchment area is larger (MoEF, 2003).

Irrigation & RWH

In Tanzania, the vast majority of farmers depend on rain-fed agriculture. Therefore, future food security depends upon developing improved dryland cropping systems. An important step towards tapping the potential of these systems is be to use the available rainfall, known as ‘green water’, more efficiently. The challenge is to select and apply appropriate RWH interventions that capture the unproductive green water flows. *In-situ*, microcatchment and macrocatchment rainwater harvesting systems were tested against the local practice of flat cultivation as control. All were managed according to local extension recommendations, and the benefits were measured in terms of grain yield. *In-situ* rainwater harvesting provided no benefit. Microcatchment rainwater harvesting resulted in increased yield per unit area cultivated. On a total system area basis (i.e. including the uncropped catchment), however, production decreases were observed. A cost-benefit analysis does show a benefit in the short rainy season. Macrocatchment rainwater harvesting provided increases in grain yield in both the short and the long rainy seasons (Hatibu et al. 2003).

Along with economic justification, the promotion of rainwater harvesting projects requires an analysis of the eco-hydrogeology and human dynamics. Based on the case from Tanzania, rainwater harvesting for crop production showed the potential for poverty reduction which is evident in the results from two-seasons (2002 to 2003) yield monitoring for maize and lablab. According to the results obtained from the yield monitoring exercise, Rainwater harvesting for crop production has a great potential of poverty reduction given impressive returns to land and labor even during b-average seasons. Interventions to improve productivity of rainwater (more crop out put per drop) while maintaining the integrity of the eco-hydrology and other natural systems in the watershed would result in tremendous economic benefits. This would result into tremendous financial earnings too. Such efforts could be in empirical knowledge of which best agronomical and runoff management practices could optimize physical yields for the intercrop (Mutabazi, et al. 2004).

Hatibu et al. (2006) also presents an analysis of economics of rainwater harvesting by poor farmers in Tanzania. Results show that rainwater harvesting for production of paddy rice paid most with returns to labor of more than 12 US$ per person-day invested. These benefits are very high due to the fact that without rainwater harvesting it is not possible to produce paddy in the study area. The results also show that contrary to expectations, improving rainwater harvesting systems by adding a storage pond may not lead to increased productivity. Another finding that goes against the widely held belief is that rainwater harvesting results in more benefits during the above-average seasons compared to below-average seasons. It is therefore, concluded that there is a potential for combining rainwater harvesting with improved drainage of roads. The construction of rural roads in semi-arid areas can beneficially be integrated with efforts to increase water availability for agricultural needs. (Hatibu et al. 2006).

He et al. (2007) evaluates the determinants of farmers' decisions, using a binary logistic regression model, to adopt rainwater harvesting and supplementary irrigation technology (RHSIT) and its elasticity of adoption in the rain-fed farming systems, based on a survey of 218 farmers in the semiarid areas of Loess Plateau in 2005. The result shows 12 variables to be significant in explaining farmers' adoption decisions. Farmers' educational background, active labor force size, contact with extension, participation in the Grain-for-Green project, and positive attitudes towards RHSIT are some of the variables having significantly positive effects on adoption of RHSIT, while farmer's age and distance from water storage tanks to farmers' dwellings have significantly negative correlation with adoption of the technology. Variables such as family size, off-farm activity, level of family income, risk preference, and land tenure do not significantly influence adoption. This information will help prioritize the factors that affect adoption decisions and provide insight on pathways to increase the adoption of RHSIT.

In Gansu and other provinces in northwest China, the preliminary implementation of Rainwater Harvesting Agriculture (RHA) suggests that RHA has the potential to improve performance in rainfed farming systems and to address environmental problems; example: soil erosion. The small-scale, low cost RHA systems make application by household farmers simple. Successful RHA needs to be integrated in a comprehensive agricultural-management system; i.e. with other agricultural technologies and management practices. Also, the spread of RHA over large areas entails consideration of a range of technological, agro-hydrological, ecological, social, cultural, economic, and political factors. In particular, training and extension services to farmers is required to develop and disseminate more effective and affordable types of RHA technologies as alternatives and to design and develop alternative policy instruments and social institutions that facilitate adoption of RHA practices (Li et al., 2000). Also in a time period of 2002 to 2004, the influence of different in situ rainwater harvesting and moisture conservation methods on soil moisture storage and growth of Tamarix ramosissima was studied in the semiarid loess region of China. Rainwater harvesting and moisture conservation treatments increased growth of T. ramosissima, tree height was significantly higher for the rainwater harvesting and moisture conservation treatments than the controls. (Li et al., 2005)

Benefits: Poverty Alleviation and Socio Economic Development

Composed in a comprehensive system, the basic three components of rainwater harvesting; a collection surface, guttering and a water store, yields several benefits. According to Krishna (2003), the most important benefit of rainwater harvesting is that the water is totally free; the only cost is for collection and use. Also, the end use of harvested water is located close to the source, which eliminates the need for complex and costly distribution systems. When groundwater is unacceptable or unavailable, rainwater provides a water source, or it can supplement limited groundwater supplies. A superior solution for landscape irrigation, rainwater harvesting reduces flow to stormwater drains and also reduces non-point source pollution while reducing the consumers' utility bills. Having lower hardness than groundwater, rainwater helps prevent scale on appliances and extends their use (Li et al., 2005).

Studies carried out on a global basis indicate that in the past fifty years, the world's population has doubled, as did the per capita water consumption rate (from about 400 m3/year to about 800 m^3/year) having only a small percentage of the available water is of good enough quality for human use. The countries of Africa have been experiencing an ever-growing pressure on their available water resources, with increasing demand and costs for agricultural, domestic and industrial consumption. These pressures have caused both environmental deterioration like pollution of freshwater systems and overexploitation of important water catchments, resulting in lowered groundwater levels. Water stress has several consequences including Social, Economical, and Environmental etc. A large proportion of Africa's population is affected by water shortages for domestic use. As a response to the 1971–74 droughts with the introduction of food-for-work (FFW) programmes, government-initiated soil and water conservation programmes promoted the application of rainwater-harvesting techniques as alternative interventions to address water scarcity in Ethiopia. These also intended to generate employment opportunities to the people affected by the drought. Issues like poverty, drought, sanitation etc strongly support the need to focus on development and promotion of rainwater-harvesting technologies as one of the alternatives to enhance water availability for different uses including domestic water supply, sanitation and food production (Seyoum, 1994).

Kenya, having a population of about 25 million people, has current water supply coverage of 42% meaning millions of Kenyans with no access to an adequate and safe water supply, facing, severe social and economic consequences. The Kenya Rainwater Association (KRA), founded to bring together individuals and institutions wanting to face the challenge of low water coverage by utilizing rainwater, used low cost technical options and built local capacity through community based organizations (CBOs). This also built the village organization and management capacities. A combination of improved health awareness and benefits from clean and safe water and income from sale of surplus farm produce resulted in an increase in willingness to pay for improved housing and water supply. The lessons learnt in this study includes compulsory community involvement in RWH, use of motivation, mobilization and participation for achieving desired goal, observation at commencement, control of Quantity and quality of the output (Mbugua, 2000).

The conclusions from the study of He et al. (2007) indicate that the rainwater harvesting and supplementary irrigation technology (RHSIT) extension project should incorporate consideration of farmer age, farmer educational attainment, and active labor force members. The benefits of RHSIT must be clearly perceived by the users looking at their own socioeconomic conditions. The results also suggest the need for greater political and institutional input into RHSIT projects. there is a need to design and develop alternative policy instruments and institutions for extension, technical assistance, training, credit services that will facilitate adoption of the farmer participatory practices to better fit the needs of farmers in particular.

Also in Zimbabwe, the successful adoption of RWH technologies has the potential 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 assisted in improving environmental management through water conservation, reduction of soil erosion and resuscitation of wetlands in the study area. The major constraints facing technology adopters were water distribution problems, labor shortage, and water-logging during periods of high rainfall and risk of injury to people and livestock as a result of some of the technologies. However, the farmers who have adopted RWH have devised ways of dealing with some of the cited problems, for instance, formation of labor groups to mitigate against labor shortage. It was concluded that RWH technologies are suitable for smallholder farmers in semi-arid areas provided they properly tailored the conditions of the locality where they are promoted. Other benefits of adopting RWH include improvement of people’s standard of living (break out of the cycle of poverty) and reduction in environmental degradation (Mutekwa & Kusangaya, 2006).

The impacts of rooftop rainwater are greatest where it is implemented as part of wider strategies that considers people’s overall livelihood strategies. Water should be seen as a key productive as well as domestic resource, with different uses being made of it by men and women. By taking such an approach, and widening the role of potential benefits to include economic and health related issues, the overall benefit to households and communities of rainwater harvesting will be doubled. The most important impact in terms of women and the poor is the reduction in time spent collecting water, a vital issue (Ariyabandu, 1991), which can be as much as several hours per day. This time then becomes available for other purposes, both productive and 'social'; more time to spend on education, with children and friends etc. (Smet & Moriarty, 2001).

Research on appropriate technologies and infrastructures to support water reuse has progressed rapidly over recent decades presenting a wide range of source – treatment – reuse options for planners to choose from. Although the economics of water reuse schemes supports application to new developments than retrofit projects (table 2), there are few studies which seeking to address strategic option selection issues for large developments. The potential advantages of using treatment and reuse systems in new developments require an understanding of the relationships between a wide variety of factors, namely social, environmental, technological, and operational. Using a commercially available software package, Alegre et al. (2004) reports the design and implementation of a low resolution simulation tool to explore sustainable water management options for a live case study site in the south of England (a peri-urban development of 4,500 new homes) with particular reference to opportunities for rainwater harvesting, and water reuse.

Table 2

Strengths and weakness in recycling, rainwater and conservation. (Alegre et al. 2004)

Strategic option	Strength	Weakness
Recycling	Continuous supply available. Variety of reuse option available.	Frequent maintenance of system often required. Can be expensive to purchase and install (particularly if dual reticulation is required). Health impacts uncertain.
Rainwater	Lower Treatment Requirements. Cost effective Technology.	Storage tank space requirements. Intermittent and unpredictable supply.
Conservation	Low cost. No technology Dependent.	Sustained Impact often dependent on long term behavioral change. Incorrect installation of devices is a problem

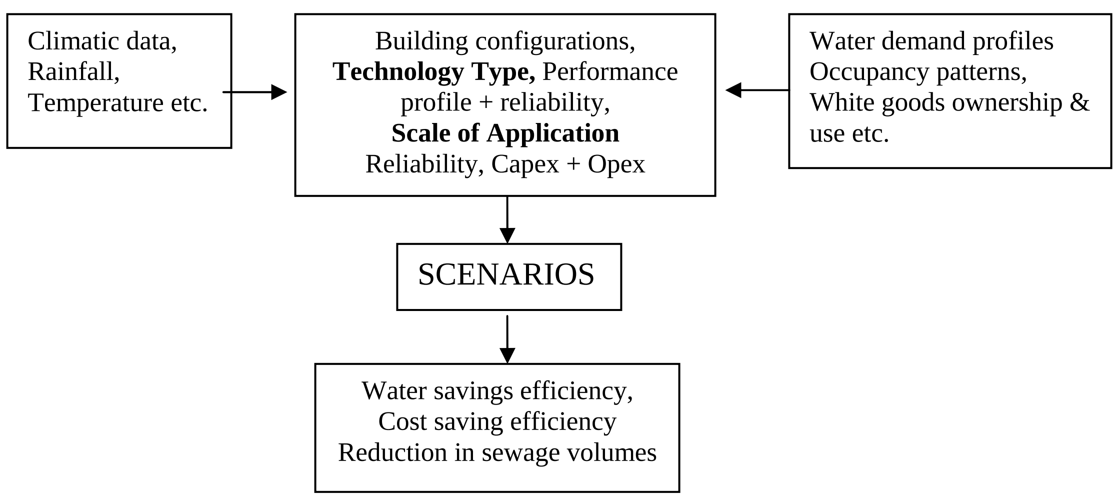


Figure 3: Model Design Template

The model in figure 3, proposed by Alegre et al. (*200*4), described above is capable of generating a set of data regarding water flows through the proposed development. It can be used to investigation of water saving and cost implications of supplying non-potable demand nodes with either recycled greywater or rainwater. It is suggested that:

- Commercially available simulation tools can be used to represent gross water flows through a new development and to explore different water management options.
- Future demand profiles will influence the financial and water saving performance of different management strategies and therefore, micro-component water demand prediction is a key element of strategic option assessment (Alegre et al. 2004).

Practice in Bangladesh

Bangladesh used the surface water as the principal source for drinking water up to the recent past. Although rainwater harvesting is a familiar term for Bangladesh, it is not a common practice as only 35.5 percent of the households in coastal areas use this method as source of drinking water due to high salinity problem (Ferdausi & Bolkland, 2000). Being a tropical country, Bangladesh receives heavy rainfall (figure 3) during the rainy season with an average annual rainfall of 95 inches (BBS, 1997). This amount makes rain water harvesting an obvious solution for the arsenic contamination whereas 50% area of the country is suffering from arsenic contamination making it a nation wide problem (Rahman et al. 2003). Moreover, the increasing population in the urban as well as rural areas is putting increased load on underground aquifers, which is evident in the fact that the piezometric level of Dhaka has decreased by more than 65 feet in the last decade. Dhaka receives an annual rainfall of 71-80 inches which can easily be an answer to the vertical recharge for the aquifers (Kabir and Faisal, 1999). Rainwater harvesting will also facilitate the urban users with some additional benefits: decrease in the street water logging etc. The economical condition as well as absence of water supply facility has prompted the low income groups to harvest the rain water for household and essential uses which is evident in the fact that 52 indigenous methods has been practiced by the tribal people of Bangladesh (Kabir and Faisal, 1999). Although these methods are small scale, area specific, labor intensive and paced with slow rural life, they involve significant low cost while maintaining ecological balance and sustainability. Thus these indigenous methods can facilitate the new harvesting techniques with their strength, screening them from their inherent limitations (Mbilinyi et al. 2005).

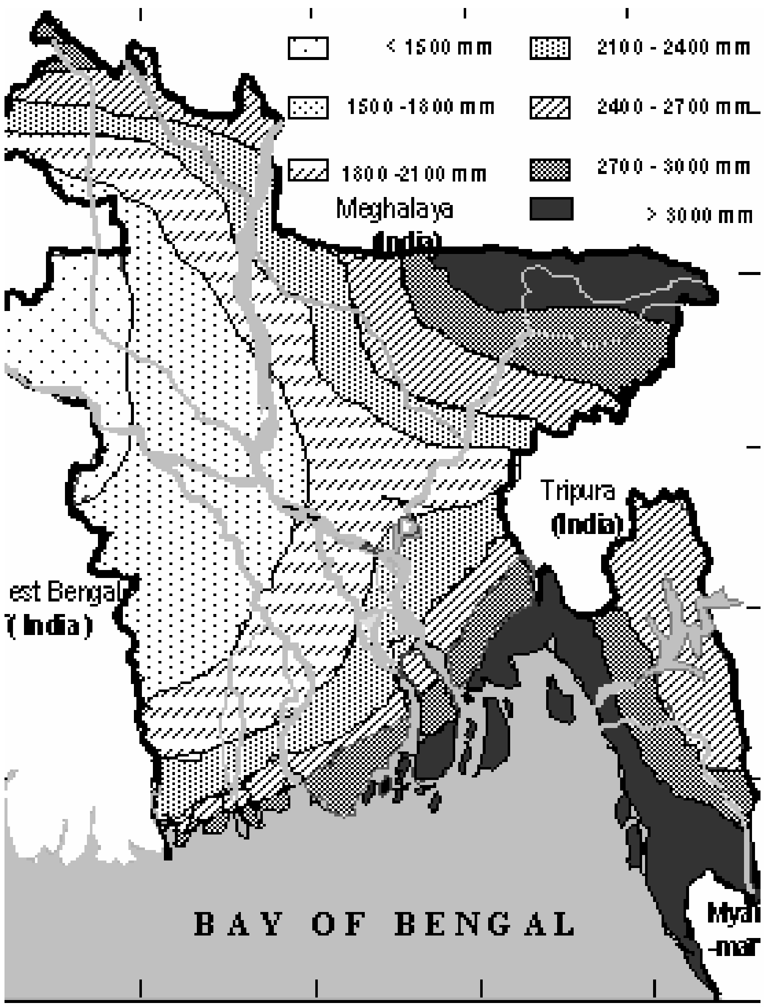


Figure 4: Annual Rainfall in Bangladesh. (Rahman et al. 2003)

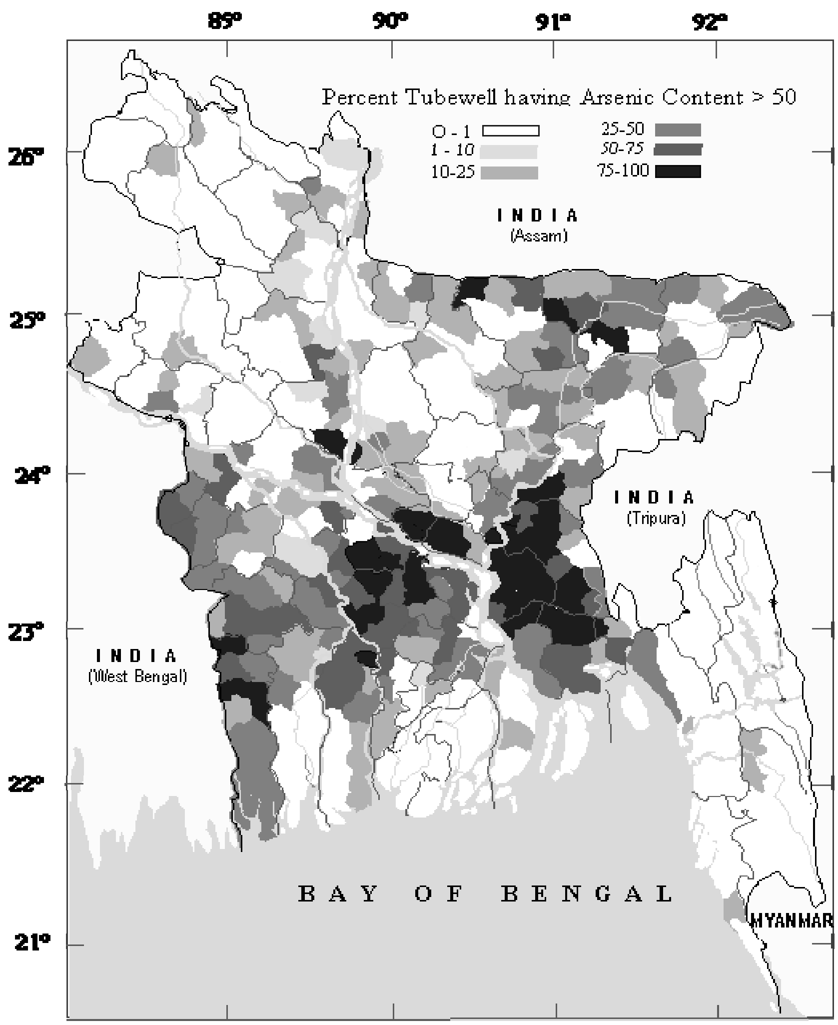


Figure 5: Arsenic Situation in Bangladesh (Rahman et al. 2003)

In the present context, rainwater harvesting is being seriously considered as an alternative option for water supply in Bangladesh. Although the cost of this method is burdensome for low income group, rooftops in buildings can be designed to collect rainwater solving the challenging issues of minimizing the storage cost and management and allocation the water use by water quality. In the case of a builder, at an initial stage of construction, investments in time, design and money are minimal for adopting rooftop rainwater harvesting (Thomas, 1998).

Present Situation

Studies and experiments have been done not only to establish the potablity of rainwater but also to design buildings installed with rainwater catchment facilities with optimum treatment facilities. Materials like ceramic tile and galvanized metal roofs has been recommended by Woods and Choudhury (1992) for quick transportation of precipitation and minimization of loss through evaporation. Studies on management and treatment of vegetation, surfaces and chemicals have been done to achieve economic solution for specific region. Additional attention is given to storage capacity according to duration of dry periods, affordability, robustness and durability of materials, safety and maintenance of the filtration system.

Increased awareness on water crisis has led rainwater harvesting to be proposed as a community facility. As for example, the small and medium residential and commercial construction of United States has shown increasing interest in rainwater harvesting since 1996 (Choudhury & Vasudevan, 2003). Cities and states around the world are adopting rules related rainwater harvesting, especially in United States (TWDB, 2005). The most universal and critical services to a building, water supply reaches building through one of the following three ways: piped supply, rivers and other water bodies and rainwater. It is almost the only way to upgrade ones household water supply without waiting for the development of community system. The acceptance of rainwater harvesting will expand rapidly if this method is treated like other building services and if designed into the structure instead of being retro-fitted (Thomas, 1998).

RESEARCH METHODOLOGY

Guided by the research objectives, the methodology of this research is divided into three parts, namely Data Collection Procedure, Data Analysis, Results.

Data Collection Procedure

Data was collected of chemical composition of groundwater and rainwater from secondary sources. Sources of these secondary data were research papers/govt. water reports on water chemistry of:

- China (Li et al. 2005 & Hao et al. 2006))
- Brazil (Piranha et al. 2006)
- USA (Kilmas, 2006 & US gov. doc)
- Palestine (Al-Ghuraiza & Enshassi, 2006)
- Portugal (Stigter et al. 2006)
- India (Sarin, 2005)
- Nigeria (Adeniyi & Olabanji, 2005, Yair et al. 1991, Yazlz et al. 1989)

Research reports and studies on water resource management and supply system, Rainwater chemistry etc. from countries around the world including Bangladesh provided the necessary qualitative and quantitative data for the rainwater quality analysis and its prospect for potability.

Data Analysis

Summarizing the rainwater chemistry data and comparing them to EPA standard, one-sample T-test was conducted having the EPA standard values as test value (except for two case where the rainwater values are compared with ground water values; because suitable value was unavailable in the EPA standard)

Results

The quality of rainwater does not meet the WHO guidelines for drinking water quality, particularly for bacteriological quality. Contaminants like bird droppings etc., and air pollution results in higher levels of chemical constituents. Also, acid rains have a serious effect on the water quality (sulphuric constituents). However, rainwater is a considerable improvement over unprotected traditional sources and stored rainwater maintains a good water quality provided proper maintenance of the tank. The direct/ indirect health impacts include:

- Water-related illnesses are reduced (although household-based treatment is recommended), particularly compared to water from surface sources. The result is less sick days, increased economic activities, and savings in medical expenses.
- Probable reduction in Malnutrition as rainwater used for vegetable and other crop growing contributes to an improved diet.
- Improved sanitation and hygiene resulting from increased availability of water can contribute to improved health.
- Reduced transportation of heavy loads over long distances from an early age leads to reduced physical problems and growth reduction.
- Increased income streaming from productive uses of additional water that can lead improved nutritional status, and a reduction in communicable diseases due to improved home environmental conditions (better housing, ventilation etc.) (Smet & Moriarty, 2001).

Collection and artificial infiltration of roof runoff water has become very popular in many countries including Switzerland to prevent overloading of sewer systems and to ensure sufficient groundwater recharge underneath sealed urban areas. However, lack of knowledge concerning the quality of roof runoff, with respect to the presence of pesticides is still a concern. Study shows that in rain and roof runoff, maximum pesticide concentrations originating primarily from agricultural use occurred during and right after the application periods. Moreover, it is revealed that a major portion of the compounds washed out from the atmosphere may actually penetrate to the groundwater, particularly when the roof runoff is infiltrated directly into highly permeable zones of the subsurface. However, although in some cases rain and roof runoff waters does not meet European Union and Swiss drinking water standards (100 µg/L), the groundwater contamination potential of the pesticides originating from the atmosphere can be considered of equal or even smaller importance as compared to their direct use in agriculture. The investigations also show that leaching of pesticides used as construction chemicals on roofs, may be a much more significant source of organic pollutants present in roof runoff. (Bucheli et al., 1998).

The analysis of the T-test, reported in Table 3, 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. To use it as potable water, the total coliform i.e. microbiological contaminants has to be purified. Comparing different purification methods used home and abroad several options were found: Evaporation, Solar disinfection, Chlorination etc. Considering the cost, availability and effectiveness, chlorination seems to be the most appropriate one to use for this purpose.

Table 3

Rainwater chemistry

Parameter	Test type	Degree of Freedom	Mean	Test value	Significance (2-tailed) P<=0.05	Conclusion
pH value	One sample T test	6	6.4986	6.5	0.996	pH value of rainwater is not significantly different than the EPA standard value
Total Coliform	One sample T test	1	805.00	0	0.023	Total coliform in rainwater is t significantly higher than the EPA standard value
Fecal Coliform	One sample T test	1	175	0	0.197	Fecal coliform in rainwater is not significantly different than the EPA standard value
Total Dissolved Solids	One sample T test	4	48.656	500	0.00	TDS in rainwater is significantly lower than the EPA standard value
Hardness	Paired sample T Test	1	10.15500	Compared with Ground water	0.00	Hardness in rainwater is significantly lower than groundwater
Iron	One sample T test	2	0.1893	0.3	0.362	Iron in rainwater is not significantly different than the EPA standard value
Sulphate	One sample T test	4	19.136	250	0.00	Sulphate in rainwater is significantly lower than EPA standard
Sodium	One sample T test	4	4.05	200	0.00	Sodium in rainwater is significantly lower than EPA standard
Chloride	One sample T test	5	15.1283	250	0.00	Chloride in rainwater is significantly lower than EPA standard
Carbonate	Paired sample T Test	4	349.384	Compared with Ground water	0.02	Carbonate in rainwater is significantly lower than groundwater
Nitrate	One sample T test	2	4.6967	10	0.330	Nitrate in rainwater is not significantly different than the EPA standard value

Cost Benefit Analysis

Review of the related literature provided the first step to understand the various methods or rainwater harvesting practiced all over the world including all indigenous practices of Bangladesh. Similar cases with sustainable solution from countries with similar context were the key literatures as well data sources so as to provide better understanding to project a suitable solution. In addition, these literatures provided the comparative images of the rainwater harvesting solution practiced in different places so as to choose the user friendly solution and their detail elements for the urban areas of Bangladesh. Feedback from the local municipality water supply authority and related government supplied information about the cost of rainwater harvesting tools, materials and installation for the residential apartments of Dhaka Bangladesh.

At present the WASA (Water and Sewerage Authority) charges taka 5.25 per 1000 ltr i.e. 19.89 taka per 1000 gal. For the chosen building the water consumption of the building is 50% dependent on Rainwater. So the monthly savings in water bill will be:

MC (gal) X Cost (taka/gal) X Dependency (%) X Tax (%).
60880 gal X 19.89 taka/1000 gal X 50% X 15% = 90.85 taka/ month

This number becomes 181.71 taka/month when the building becomes totally dependent on rainwater. Needless to mention that rainwater will also save the additional taxes and fees charged by the city authority with the water bill. It becomes economic to install the system during the construction of the building as it saves material and labor cost. The total cost of RWH system comprises three major elements be it for a new building or for an old one:

1. Gutters and Downpipes
2. Storage Tank
3. Devices

The construction of an underground cistern is strongly facilitated by the foundation construction of a multi storied residential building, so it almost adds a minimum amount of cost for the construction of the storage tank. To be specific, the basement slab and foundation walls are already there for the building itself; all it needs for the storage tank is to construct walls to define the volume and boundary of the tank, the cost of which is very negligible comparing to the total construction cost. Still, to calculate the cost per gallon of the rainwater, the following detail is done:

Minimum construction Cost/Sqft = Taka 1000.
Volume of the harvestable rainwater = 255,178.52 gal = 34,064.69 cuft

Assuming a ceiling height of 9.33 ft, the minimum floor area for the storage tank is 3651.09 Sqft. So, for 3651.09 Sqft, the construction cost will be Taka 3,651,092 i.e. $ 52158.45 ($1 = Taka 70.00). The unit cost becomes TK 14.28/gallon or US$ 0.20/gallon. Also for the gutters and pipes, the quantity of the rainwater gutters and downpipes are less than 5% of the total plumbing and sanitary pipes. The only cost to handle is for the devices required for the purification of the water which are: Chlorinator with price ranging from $1000-$2500 (RHPL, 2007), and De-chlorinator All these prices are in US dollars which is much less in the local currency of Bangladesh. Suggested by (MH and PWD (2002), 1% chlorine solution is required to add with harvested water after each rainfall incidence with an aimed concentration of 50 mg chlorine per liter of rain water. Since labor cost is cheap in Bangladesh, this method is more suitable compared to the price of the Chlorinator devices.

The integration of the RWH installation task in the construction schedule will take place in several stages. Figure 7 explains that most of the additional gutter and piping works will take place in an early and mid stages depending on the type of building and its construction. For the selected case, the storage tank is located in the semi-basement, which is involved in the foundation task. The later stages are self explanatory:

1. Foundation: Construction of storage tank in case of underground storage.
2. Plumbing Rough-in: installation of rainwater down pipes and gutters.
3. Roofing: Installing appropriate finish material and down pipes.
4. Plumbing Trim: Connecting the RW supply pipes to appliances and outlets
5. Exterior Landscaping: Connecting catchment area to the gutters and filtration devices.

Proposed RWH System

Guided by the literature review, a rainwater harvesting system in urban environment consists of:

- Roof Catchment
- Gutters and Downpipes
- First flush device
- Filter chamber
- Chlorination chamber
- Dechlorinator
- Storage tank(underground /overhead)
- Water Pump/Supply system

Roof Catchment

Catchment includes rooftops, compounds, rocky surface or hill slopes or artificially prepared impervious/semi-pervious land surface. For the selected building, rooftop is considered as the catchment area as there is no other effective catchment area. Rooftop of different materials like aluminum sheets, plastic sheets, concrete, shingles etc. can be used. The runoff coefficient depends on the rooftop material as shown in table 4. General values are tabulated below in table 4, which may be utilized for assessing the runoff availability (Pacey & Cullis, 1989).

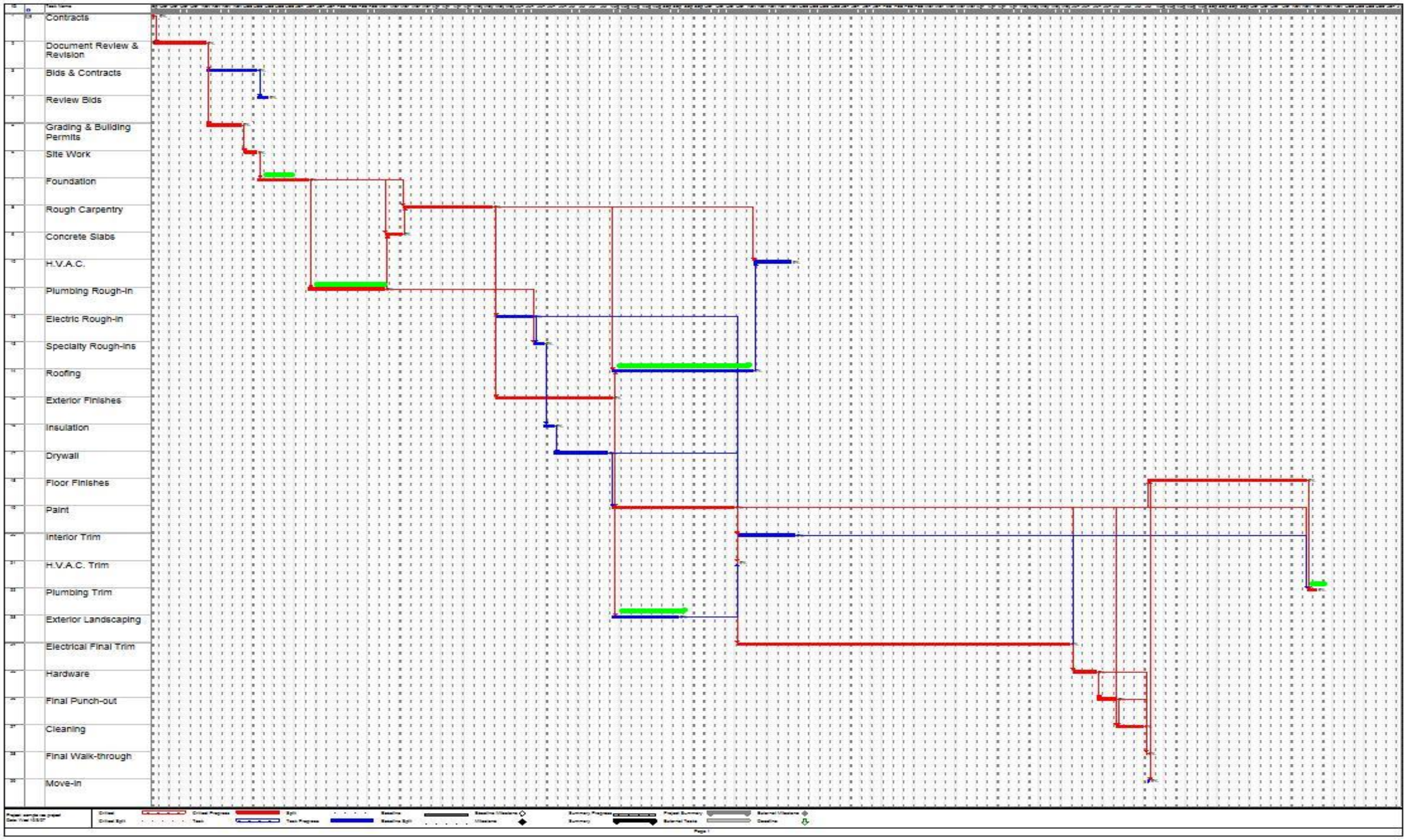


Figure 6: Schedule of a Residential Project

Table 4

Runoff coefficients

Type of catchment	Runoff coefficient
Roof Catchments • Tiles • Corrugated Metal Sheets	0.8-0.9 0.7-0.9
Ground surface coverings • Concrete • Brick Pavement	0.6 - 0.8 0.5 – 0.6
Untreated ground catchments • Soil on slopes less than 10 percent • Rocky natural catchments • Green area	0.0 - 0.3 0.2 – 0.5 0.05 - 0.10

Gutters and Downpipes

Gutters and down pipes of different materials like PVC pipes, G.I pipes, ferocement pipes, wooden pipes can be used for gutters. Depending on the intensity of the rainfall (inch/hr), the sizes of the pipes are determined. Table 5 illustrates the dimesions depending on rainfall intensity. It is recommended to keep the dimension 10-15% more than the required one (MH and PWD, 2002).

Table 5

Piping dimensions (Stein & Reynolds, 2000)

	Highest rainfall (inch/hr)					
Pipe	1	2	3	4	5	6
diameter	Area (sqft)					
2	2176	1088	725	544	435	363
3	6440	3220	2147	1610	1288	1073
4	13840	6920	4613	3460	2768	2307
5	25120	12560	8373	6280	5024	4187
6	40800	20400	13600	10200	8160	6800
8	88000	44000	29333	22000	17600	14667

First Flush Device

In a first flush device a separate vertical pipe is fixed to the rainwater down pipe using a "T" junction or similar as shown in the figure below. The initial flush of rainfall (containing the majority of the contaminants) running off the roof washes into the ‘first flush down pipe’ or into lower chamber where it is retained. When this chamber becomes full, the floating ball seals the chamber and the continuing water flows down the collection pipe into the storage tank. The water containing contaminants in the first flush pipe or chamber can be used for other purposes besides drinking (e.g. outdoor cleaning, washing, gardening etc) depending on its quality.

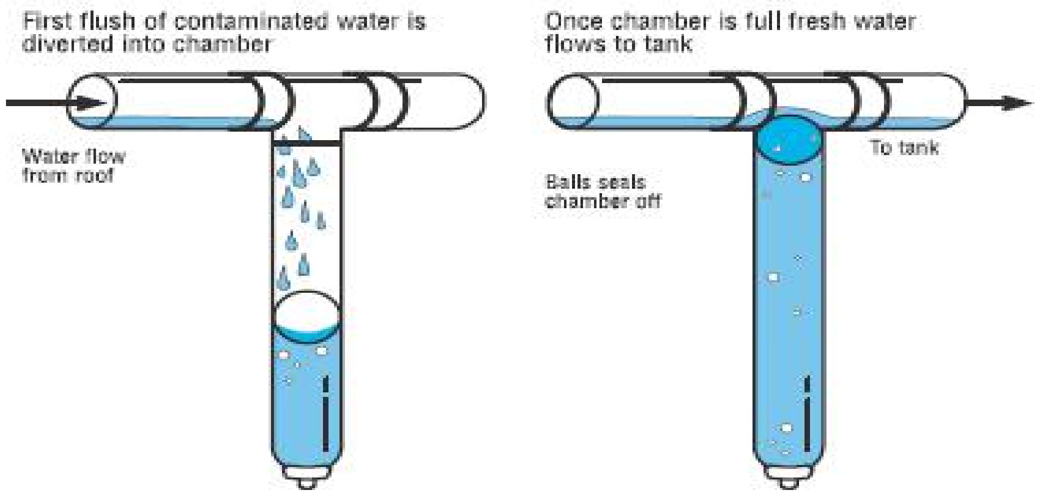


Figure 7: First Flush Device (RHPL, 2007)

Filter Chamber

To get rid of solid particles (leaves etc.), wire mesh filter at down pipes are used. But the best way to clean the rainwater from solid particles is to use the multilayered filter, proposed by Dr. Hussam, composed of five layers of aggregates. The detail Components of the filter is explained in next chapter. The SONO filter, invented by Abul Hussam (an associate professor in the department of chemistry and biochemistry at George Mason University, Fairfax, Varginia), is now manufactured and used in Bangladesh. Other than the filter, locally produced installation materials and equipments are available all over the country.

Chlorination Chamber

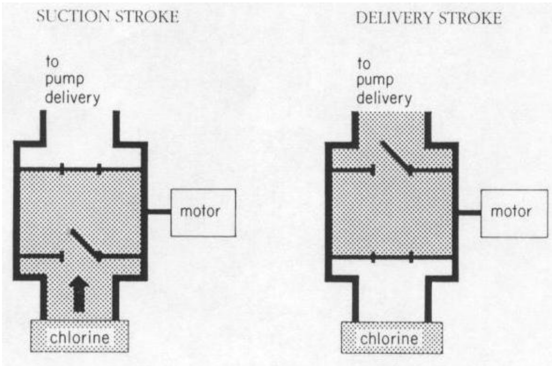
After each consecutive rainfall all the stored rainwater should be chlorinated. But for this a separate storage tank is required which requires extra cost of construction which can easily be invested in a pump type chlorinator. Various methods are available for continuous chlorination of a private water supply (Mosely, 2005). Adding small quantities of chlorine manually to the water tank is the cheapest and most effective means of disinfection. Chlorine can be added in various forms such as common household bleach. Different bleaches have different levels of active ingredient. The amount of bleach to add, based on a 4% active ingredient, is shown in the table 6 relative to the amount of water in the tank.

Table 6

Chlorine composition

Volume of water in Litres	Amount of bleach to add (mL with 4% active ingredient)
1000	125
2000	250
3000	375
4000	500
5000	625
6000	750
71000	875
8000	1000
9000	1125
10000	1250
11000	1375
12000	1500

As shown in the figure 8, the injection device should operate only when water is being pumped, and the water pump should shut off if the chlorinator fails or if the chlorine supply is depleted. A brief description of common chlorination devices follows. A positive displacement or chemical-feed device, it adds small amount, of chlorine to the water, the dose of which is either fixed or varies with water flow rates. Chlorine is drawn into device then pumped to water delivery line.



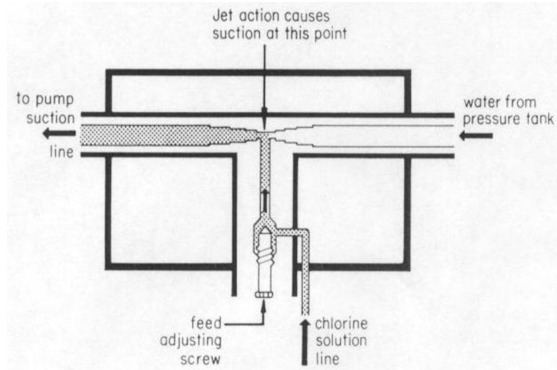


Figure 8: Pump Chlorinator

Figure 9: Injector Chlorinator

In figure 9, an injector or aspirator chlorinator is shown which is simple and inexpensive in mechanism. It requires no electricity and it works by the vacuum created by water flowing through a tube which draws chlorine into a tank where it mixes with untreated water

Figure 10: Electric Chlorinator

Figure 11: Dechlorinator

Dechlorinator

This device removes the excess chlorine and improves the taste. It can be installed with the pipe that goes to apartment from the storage tank. Different varieties are available in the market.

Storage Tank (underground and overhead)

Both overhead and underground storage tank can be constructed using different materials. Different types of overhead tanks are available in the market of different standard sizes. For both the type, most commonly used materials are:

- Cement concrete storage tank
- R.C.C storage tank
- Precast R.C.C storage tank
- Ferocement storage tank
- G.I storage tank etc.

Sizing of Storage Tank

Detail Information of a residential apartment building was collected for the research. Following are the details of the chosen case:

- Site area: 7331 sqft
- Built area: 5614 sqft
- Total no. of floors: 6
- 1 Semi-basement
- 1 Elevated Groundfloor
- 4 typical Apartment Floor with 4 units/floor.
- Household size: 5 persons/ unit (Ferdausi & Bolkland, 2000).

- Parking area 7145 sqft

Sizing Formula

Following the procedure proposed by Choudhury (2007), the size of the storage tank is determined for the chosen case:

Step 1: Determine monthly water consumption:

Daily requirement in gallons/person, GPPD= 25 gal/ person/day

No. of persons, N = 80

Total daily consumption in gallons, DC = N*GPPD = 2400 gal/day

Total monthly consumption in gallons, MC=DC*30.44= 60880 gal/month

Step 2: Determine critical rainfall

Determine catchment area in sqft., A = 5452.53 +585.74 = 6038.27 sqft

Determine runoff factor, for concrete roof ROF= 0.9 (Pace & Cullis, 1989)

Determine critical rainfall in inches per month,

CRF=MC*12*8.33/ A*ROF*62.4= 17.95 inch

Step 3: Determine total amount of rainwater available in a year

Find out mean annual rainfall, ARF= 7.7 inch

Find out monthly factors of insufficiency for 5 years, MFI

Add the MFI's to determine yearly factors of insufficiency, YFI= 6.85, 7.42, 8.08, 8.29, 8.30.

Determine maximum factor of insufficiency, YFImax

Determine monthly supply required, TS=YFImax = 8.30

Step 4: Determine storage factor, SF

Use 1 if water supply is completely dependent on rainwater. Here the dependency is assumed to be 50%. There fore, SF = 0.5

Step 5: Determine leakage factor, LF. Use LF = 0.01 if the material used for the cistern is concrete.

Step 6: Calculate storage volume in gallons, Vgal = MC*TS*(1+LF)*SF

= 60880 gal*8.30*(1+0.01)*0.5 =255178.52 gal

Step 7: Calculate storage volume in cubic feet, Vcft = Vgal*8.33/62.4 = 34064.6967 cft.

So, for an apartment building with a typical floor height of 9’-4”, the dimension of the underground storage tank would be:

3651.09 sqft (area) X 9.33 ft (height) = 34064.69 cubic feet.

For the chosen building, the available area for the cistern is on the basement floor, which consists of 4732.62 sqft area with 9.33 ft height, and 868.62 sqft are with 4.33 ft height. So the maximum storable volume of water:

(4732.62 X 9.33) + (868.62 X 4.33) = (44164.6 + 3761.12) cft = 47925.80 cft

Computer Program

To create an application that can be used by user group for calculation of the RW volume and water conservation, a program is created using Microsoft Visual Basic. The detail steps of the RW cistern volume calculation provided the basis of the logic for the calculating controls of the program. Example of logics for a specific control is provided in figure 12:

```
Private Sub Button5_Click(ByVal sender As System.Object, ByVal e As System.EventArgs) Handles
Button5.Click
        MC = TextBox4.Text
        TS = TextBox8.Text
        SF = TextBox9.Text
        LF = TextBox10.Text
        storagevolume = MC * TS * (1 + LF) * SF * 0.01
        SV = (storagevolume * 8.33) / 62.4
        TextBox11.Text = storagevolume
        TextBox12.Text = SV
```

Figure 12: Programming Logic

Also the cost benefit analysis is used to get the amount of saving per month and per annum. This programm can be used in any context to assess the pheasibility of RWH, choose appropiate material etc. using the local monthly rainfall information, User preferences and water supply cost. Further reasearch will guide to add more controls to make the program user friendly and educative. The final result is shown in figure 13 and 14.

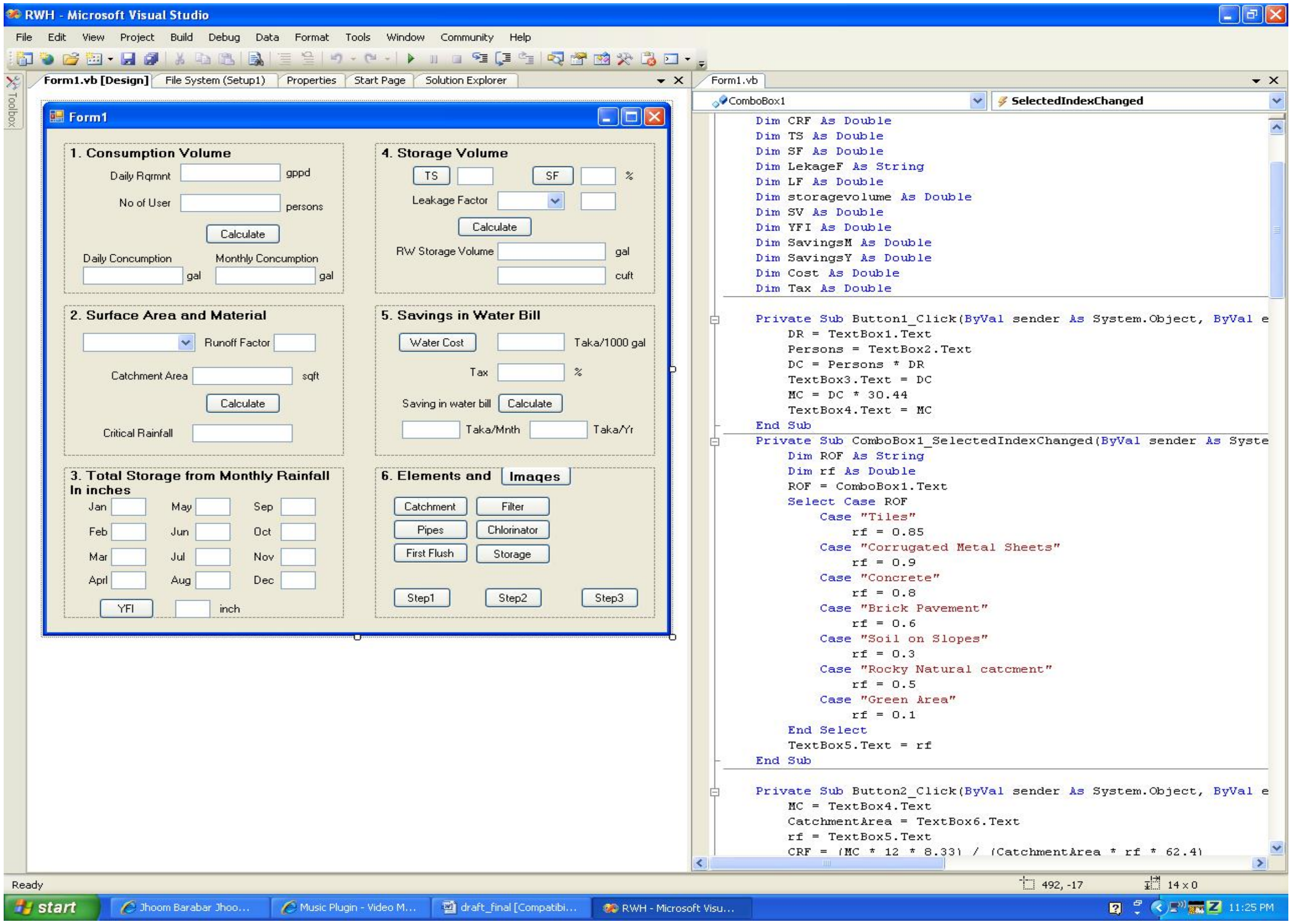


Figure 13: Visual Basic Interface

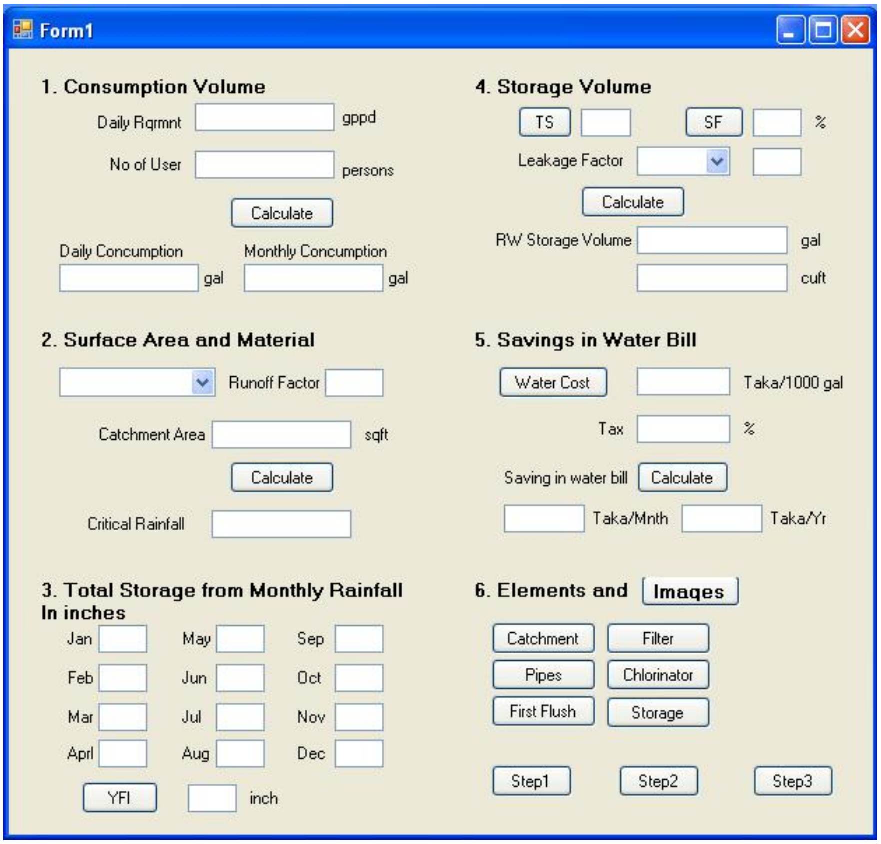


Figure 14: Rainwater Calculator

Development of a Teaching Tool

Visualization

A rainwater harvesting is composed based on the data analysis including the details of materials, installation techniques and maintenance as described in the texts below. The plans of the multistoried apartment house was obtained form the responsible Architectural firm on which the solution was applied and a 3D model of this plan along with the solution was developed using Sketchup. An animation was also developed using the same software to show the details of rainwater harvesting process.

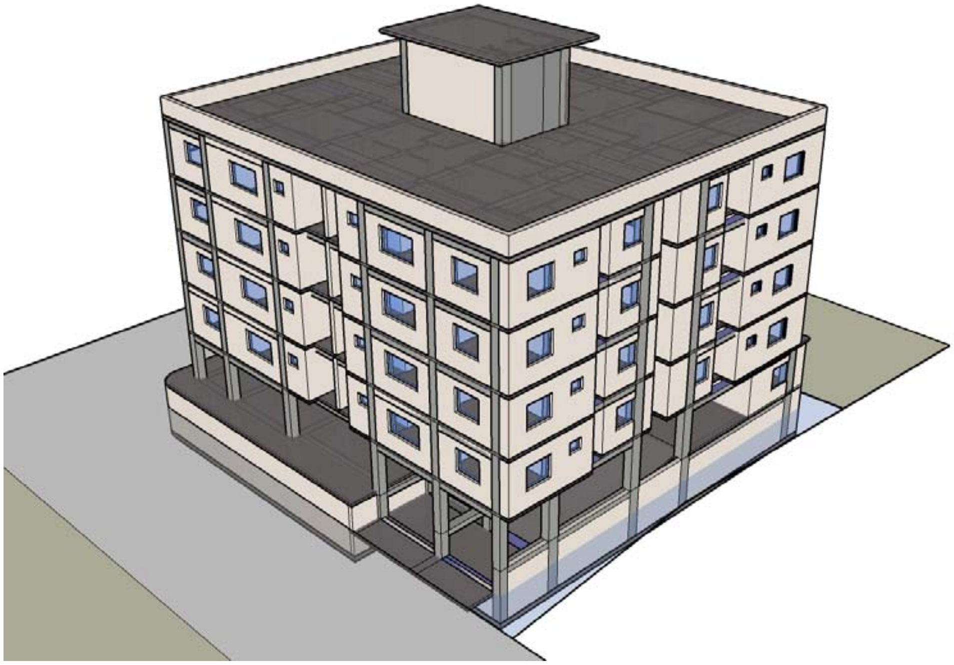


Figure 15: Residential Apartment

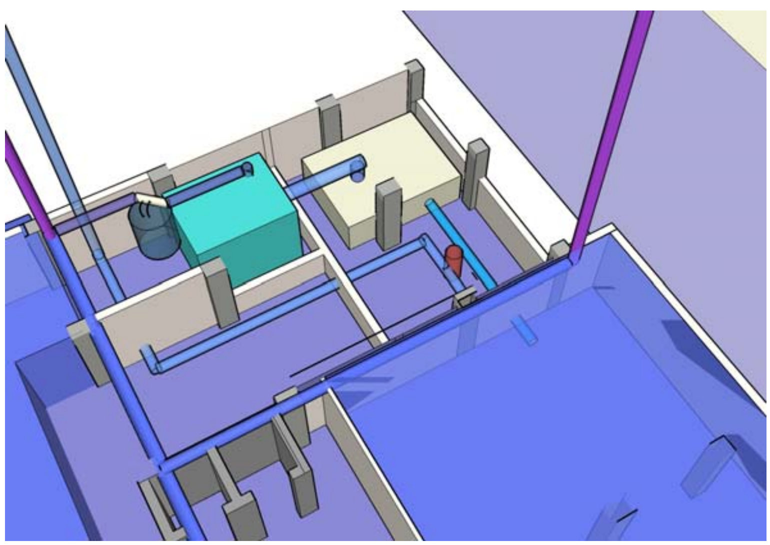


Figure 16: Rainwater Installation

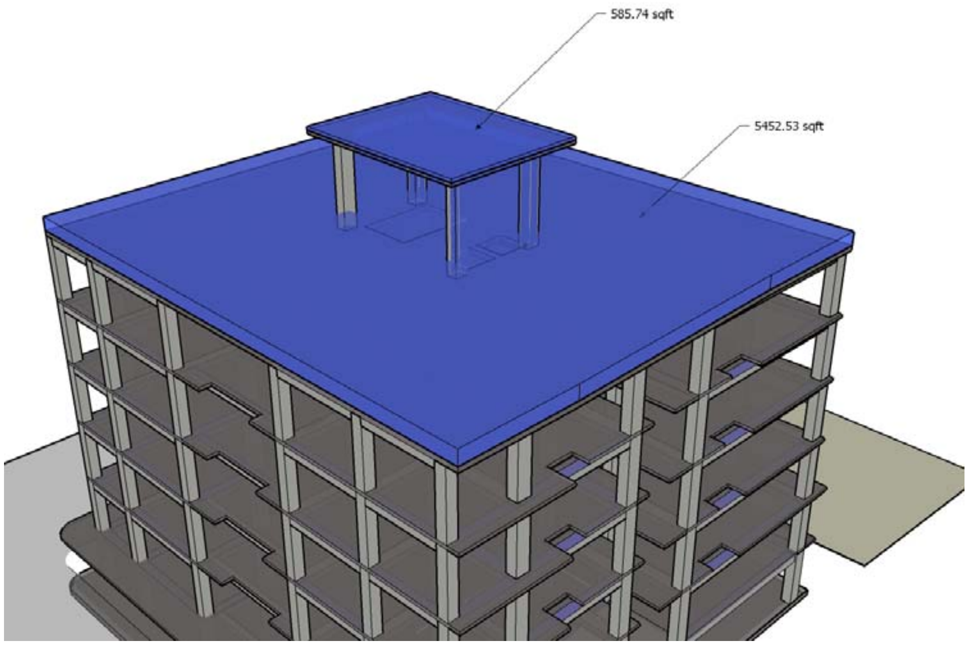


Figure 17: Catchment Area

Roof Catchment

The roof catchment of the building is 5452.53sqft and the roof top of the staircase is 585.74 sqft which makes it 6038.27 sqft in total. Assuming the concrete rooftop will be finished by paver block/tiles, the runoff coefficient of 0.9 is used here.

Gutters and Downpipes

It is assumed that it rains with an intensity of 4 inch/hr. the rooftop catchment area for the apartment building is 6038.27 sqft. So following the table 5, pipes with a radius of 5 Inches will be required. Estimating 15% more than the requirement, the dimension becomes: 5.75 inches i.e. 6 inches.

First Flush Device

For this device, a minimum design criterion is that the device should divert the first 0.5 mm of the rainfall (Mosely, 2005). To calculate the volume of water needed to be diverted, multiply the length and width of the house or collection surface (in metres) by 0.5 (mm):

Required volume of diverted water (L) = house length (m) * house width (m) * 0.5 (mm)

For the chosen building, (21.9m X 23.77m house size, diverting 0.5 mm rain), a first flush volume of 0.26 cubic meters i.e. 9.18 cft i.e. 68.70 gal should be diverted.

Filter Chamber

Following the model of Dr. Hussam, in a metal container, five layers are placed on top one another to form this filter. A metal sheet with holes of 1 cm diameter is placed at the bottom of the container. The materials that are used in different layers are:

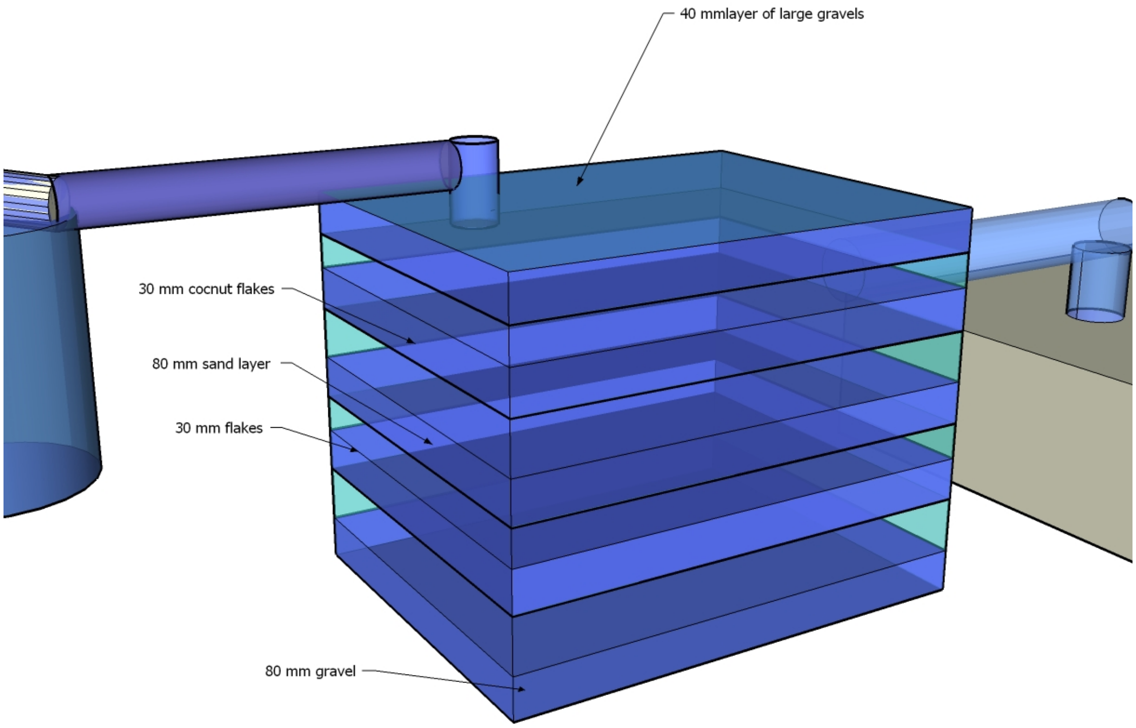


Figure 18: Filtration Device

Layer 1: large gravels in 40 mm layer, gravel size ranging from 12mm-14mm. Porous graves shouldn't be used

Layer 2: 30 mm thick layer of large strong flakes, dried skin of coconut etc. size ranging from 6-8 cm.

Layer 3: 80 mm thick layer of precleaned sand (grain size ranging from 1-3 mm).

Layer 4: a second layer of flakes, 30 mm thick.

Layer 5: last layer of large gravels of 80 mm size.

After passing through this filter, the rainwater is ready to be used for gardening, outdoor cleaning, toilet flushing, house cleaning etc. But to make this water potable, it has to purified by chlorination

Chlorination Chamber and Dechlorinator

Guidelines provided in the proposed RWH system is followed for the Chlorination chamber and Dechlorinator.

Storage Tank (underground)

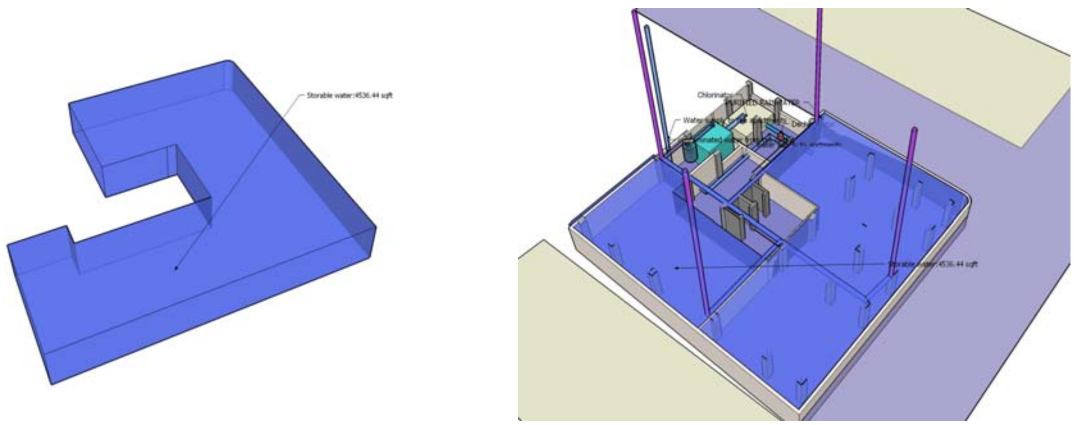


Figure 19: Storage Volume

For the selected building the foundation of the building is used for the purpose. The available storage tank area is 4536.44 sqft. Concrete slab and walls are used for the construction whereas other necessary elements are:

- Manhole for cleaning and maintenance
- Overflow pipe for the excess water connected to the drainage pipes.
- Should be connected to a power driven pump to supply water to the apartments. Because of the interrupted municipality water supply, all the apartments in the study area are facilitated with water pumps as the underground storage tank is filled when water supply is available and then pumpd into the overhead storage tank to supply to the individual units. So, the water pump does not add a cost into the rainwater installation (MH and PWD, 2002).

SUMMARY AND CONCLUSION

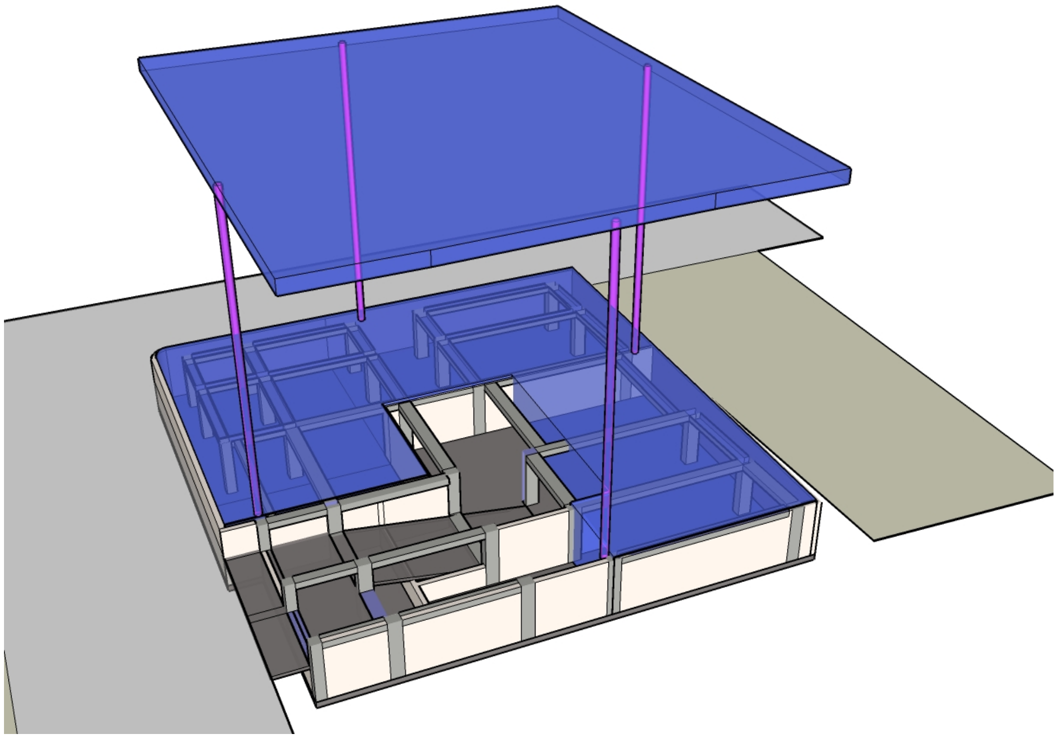


Figure 20: Catchment and Storage

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 as well as the estimate of the installation cost will provide the owners, builders as well as the users with the freedom to choose the option reviewing their own buildings to save more. This will serve more for the Industrial Projects where the buildings are associated with large tilted roof, which will harvests the rain water in huge amount. Further research can be done on the creation of animation with more details. Along with that, the City Government 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 for the fields like Sustainable Architecture, Water Conservation, Green building etc where alternative technologies like rainwater harvesting are getting more and more importance.

Recommendations

1. Further Research: Although data from secondary sources were used for this study to assess the potability of rainwater, physical experiments should be executed for the rainwater collected from the study area to have the respective chemical composition, which will feed into the decision making stage. Also, no research was done on the volume of First Flush with respect to intensity of rainfall, location and time. Determination of an effective First Flush volume will definitely increase the credibility of rainwater to be chosen as an alternative technology
2. Promotion and Education: providing the cost benefit scenario of rainwater harvesting system comparing the social, economic and environmental gains.
3. Formulation of Government policies such as Tax incentive for energy conservation (water, electricity etc.) in individual household, etc.
4. Pilot study through community involvement: execution through the local government and NGO participation.

At national scale, rainwater conservation plans and policies can be formulated to handle water crisis and flood issues of the nation. Feedback from different region and communities of the country is essential to make these plans comprehensive and need based. For an example, making the existing water bodies deeper to increase the storage capacity during the monsoon will not be suitable to areas where the existing water table is very high or all the water bodies are highly arsenic contaminated. Also application of local technology and material will be different depending on the regional production. To implement these policies, water management projects can be formulated (and awarded as professional assignment) at organizational level including rain water harvesting system. For implementation, private organizations can be engaged with projects to promote, educate, and involve communities for rainwater harvesting practice (this will also relieve the government from taking risk with public funds). Then with the help of these organizations, local government can develop cooperative system to maintain, monitor and ensure the aimed benefit of rain water harvesting. However, the achievement of sustainability starts forms individual household practice that adds up to the national level contributing the water consumption demand, alternatives to arsenic contamination, flood control and ground water recharge.

Rainwater harvesting at a household (be in the rural or urban area) improves the affordability of water consumption, irrigation and drainage facility of the site and structure. At the community level this practice contributes to the local/regional geography and water resources developing the socioeconomic condition of the area (through new job opportunities associated with rainwater harvesting technology, female citizen involvement etc). At national level, the output is much more visible in poverty alleviation (rain water harvesting for mass irrigation resulting in better agricultural production and thus national economy, development of public health and hygiene). The out come of the policies framed at national level can be compared to similar international cases for correction, up gradation and development. Also similar cases in different nation can be collaborated in a combined project where the socioeconomic development aims at a global perspective; individual economic development of each nation (through rain water harvesting) contributes to global water crisis, independence from foreign donations. End results as shown in figure 21 lead to global sustainability.

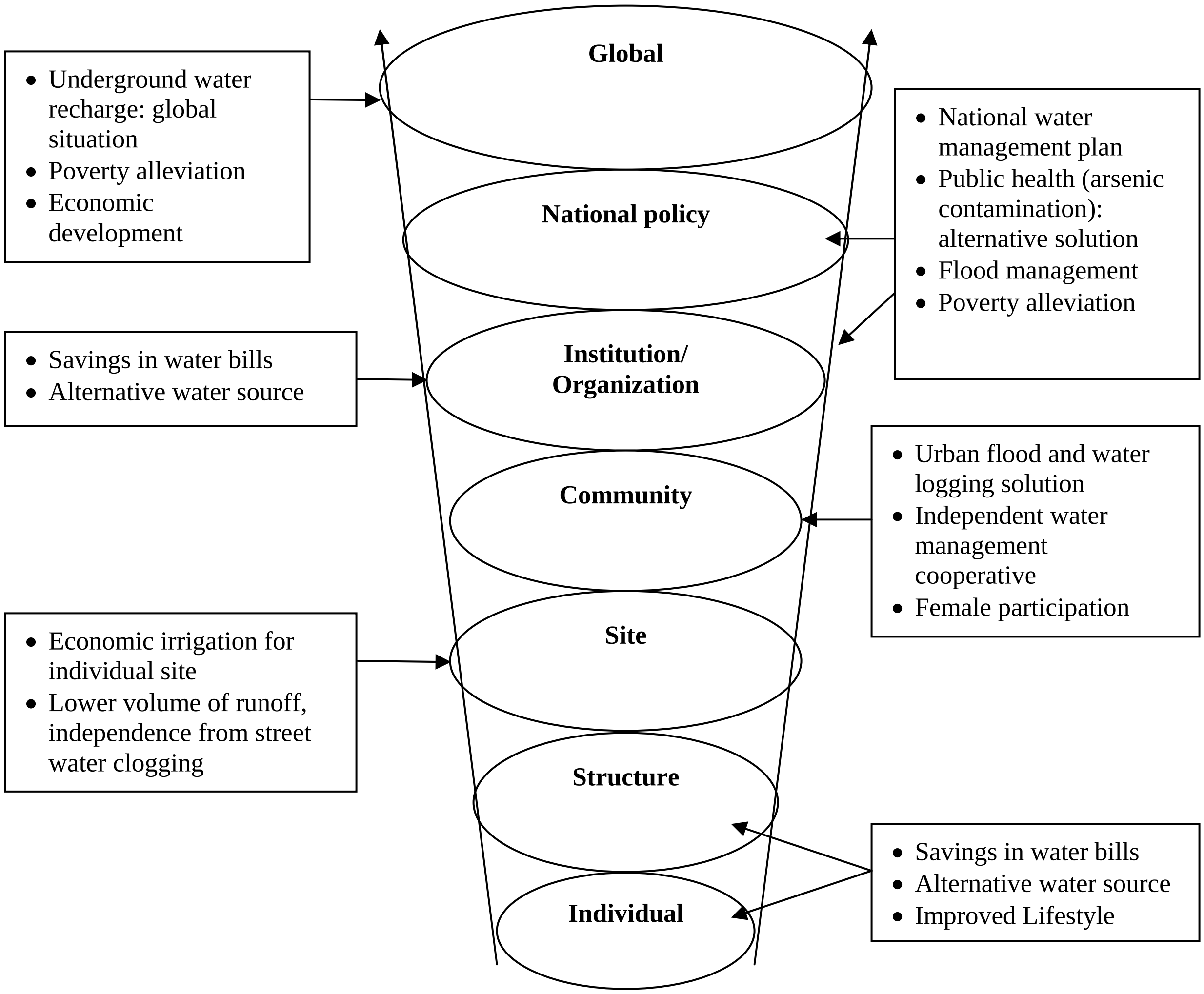


Figure 21: Scales of Sustainability

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