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Implications of Using Rainwater Harvesting as Supplementary Water Supply Source for Urban Bangladesh

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Abstract

The scarcity of safe water affects more than one-third of the current world population. Sustainable water supply management is vital for sustainable development in Bangladesh. Rainfall being abundant throughout the year, urban rainwater harvesting (RWH) has untapped potential in Bangladesh. The main purpose of this paper is to provide an in-depth look into the practicality of using RWH as a dual water supply system alongside the existing municipal water supply to mitigate the non-potable water demand of urban Bangladesh, where Dhaka city was chosen to test out the hypothesis and calculate possible rainwater collection. Secondary data analysis was done for projections and calculations of available water savings, adjusted to monthly variations of rainfall. It was found 28% to 81% of the non-potable water demand can be supplemented by RWH from April to October and a maximum of 103% can be fulfilled in the month of July for Dhaka city in 2030. For economic feasibility analysis, Net Present Value for two types of storage designs was calculated and the payback period was found to be between 2.5-3.6 years. This paper implies that RWH method is a viable option to meet non-potable water demand and demonstrates the water savings impact, design considerations, and economic analysis of the project.

Keywords: Rainwater harvesting, Non-potable use, Dhaka city, Urban Bangladesh

Introduction

Water is indispensable for the survival of all life forms on earth. One of the fundamental prerequisites of sustainability is the availability of clean and safe water for all. The United Nations announced the adoption of the "2030 Agenda for Sustainable Development", with 17 sustainable development goals (SDGs) at its core, at the UN Sustainable Development Summit in September 2015 (UN, 2017). Among them, "SDG 6 is set to ensure the availability and sustainable management of water sources and sanitation for all; while SDG 11 is to build cities that are inclusive, safe, resilient, and sustainable" (UN, 2017, p. 30 & p. 40). Efficient urban water supply management helps to satisfy both goals simultaneously. "It is estimated that almost half of the worldwide population may already be living in potential water-scarce areas for at least a month every year and by 2050 it could increase to some 4.8–5.7 billion. In 2010, 73% of the scarcity affected people resided in Asia, and this number is expected to be at 69% in 2050" (Burek et al., 2016, p. 66). Urban areas, especially with high population densities would face severe problems from higher water, energy, food deficits, and a higher concentration of resource consumption. Urban flooding, water stress, and lack of proper wastewater management hinder socio-economic development. Thus, urban development decisions should be taken considering "water" in the path of achieving the goals and targets of the SDGs and the Paris Agreement, as it directly affects future urban security and climate (Matthews et al., 2017).

Providing safe and constant water supply to people of all levels of the socio-economic sphere of urban Bangladesh by 2030 will become a huge challenge as urbanization rates are ever increasing in this region. It is estimated that the population of Dhaka will double by 2030 and Chattogram, Bangladesh's second-largest city, will reach a population between 5-10 million (UNDESA, 2018). The total urban population is expected to soar to a staggering 80 million by 2030 (UNDESA, 2018). Aside from the challenge of overpopulation, Bangladesh also faces uncontrolled and unplanned urbanization, arsenic contamination, insufficient water treatment infrastructure, lack of proper pipelines across the cities, and illegal and unmetered water pumping (Arfanuzzaman & Rahman, 2017; Sharma & Alipalo, 2017). The urban water management systems of Bangladesh already fail to meet the demands of the existing population. Almost all cities of Bangladesh use groundwater as the primary source for piped water provided by the municipal water supply system. India, Bangladesh, Pakistan, along with northern China, utilize almost half of the world's total available groundwater and it is estimated that these regions will soon experience shortages (Shah, 2007).

Therefore, considering all the current and future challenges of urban Bangladesh, the country needs to incorporate a culturally acceptable, cost-effective, and sustainable method to supplement its existing water supply system. The age-old approach of rainwater harvesting (RWH) could be one such option. In recent years, research on various aspects of RWH has gained traction and pilot projects have been conducted in various locations in Bangladesh. Various NGOs, domestic and international, have come forward to implement and pilot projects all over the country, especially in coastal areas. Recently, the government has made an amendment to the Building Construction Rules 2008 that all new residential buildings in Dhaka City Corporation area must install rainwater harvesting facilities (*Dhaka Imarat-Nirman-Bidhimala*, 2008). Bangladesh National Building Code (BNBC) has also included the provision that every proposed residential building that is built on a plot area ranging from 300 m^2 to 1,000 m^2 should have arrangements for artificial recharge to aquifer through a single percolation well. Rooftop sizes exceeding 1,000m^2 should construct an additional percolation well for every extra 1,000m^2 space. Rainwater harvesting, use, and artificial recharge to aquifers should be carried out as per building code, and specification of relevant authority included in BNBC 2014 (BNBC, 2014). RWH for direct potable and non-potable use such as toilet flushing, washing clothes, cleaning, and other household activities may benefit both urban homeowners and the municipal water authority (Ara, 2017). Homeowners can supplement their water use and the authority can use the saved water for aquifer recharge. Despite these rules being included in the building code, we still do not observe a significant number of implementations of these provisions in urban areas, likely due to lack of knowledge and information. In addition, the idea of building aquifer recharge pits may be highly complex and unattractive to the urban residential homeowners.

This paper aims to identify the effectiveness of rainwater harvesting methods as a dual water supply system for non-potable water use to mitigate the future water demands of urban Bangladesh and supplement the knowledge gap. The paper uses Dhaka city as a case study and includes monthly rainfall variability in harvested water supply calculation and projection. Economic analysis for two different storage system designs for a typical building size has been done using Net Present Value and Payback Period calculations.

Background and Literature Review

In conducting the study reported in the present paper, a wide-ranging literature review was carried out on water scarcity, groundwater depletion, and rainwater harvesting. Papers on rainwater harvesting have explored the potential, feasibility, cost-benefit analysis, system modelling, and spread of knowledge of RWH for many different regions of the world including Bangladesh. Though global RWH literature has been reviewed, to be concise this section only mentions studies that are relevant to Bangladesh.

Groundwater depletion and simultaneous surface water pollution have been harming freshwater availability in Bangladesh in recent years. South Asian countries including Bangladesh use groundwater as the primary source of water, especially for irrigation purposes and urban supplies. The Indian and Bangladeshi governments took the policy of overly subsidizing electricity for irrigation purposes in the rural areas which in turn backfired because the mass of the population has little awareness regarding the economic or monetary value of water (Hanasz, 2014). Intensive and irresponsible use of groundwater for irrigation and urban supplies, particularly in northern India and central and northwestern Bangladesh, has caused the rapid depletion of groundwater level in various degrees across the subcontinent (Mukherjee et al., 2015). "Natural resource shortages such as water shortages happen because of three reasons according to Thomas Homer-Dixon; these are- human-induced environmental change (decline in the quantity or quality of a resource), population growth (reduction in per-capita availability), and inequality of access (the majority of access of resources lies in the hands of the few in power)" (Dixon, 1991, p. 39-40; Hanasz, 2014). This is true in most cases, but there are other socio-political reasons behind the water shortage issue typically faced by most South Asian countries (Hanasz, 2014).

On the other hand, Bangladesh receives abundant rainfall every year for almost eight months between February and October (Bashar, Karim, & Imteaz, 2018). Most of the urban areas of Bangladesh are located in regions with heavy rainfall. Consequently, most of the cities in Bangladesh face problems of waterlogging on the streets and flooding during the monsoon (IWM & DWASA, 2016). One of the direct benefits of the RWH systems in urban areas could be the mitigation of floods. Different types of structures can be designed in public places, for example - recharge pits that would directly recharge groundwater, thus simultaneously preventing water logging. It has been found that RWH system improves the quality and quantity of groundwater in some parts of India (Jebamalar, Ravikumar, & Meiyappan, 2012). According to a study by the Institute of Water Modeling and Dhaka Water and Sewerage Authority (IWM & DWASA, 2016), RWH is a feasible solution for groundwater recharge in Dhaka, where the groundwater level is depleting at a rate of 2.81 meters per year since 1991 (Uddin & Baten, 2011). It can also considerably reduce the runoff and waterlogging throughout the monsoon season in Dhaka city (IWM & DWASA, 2016).

A significant number of research papers have explored the potential benefits, economic feasibility, technical reliability, and acceptance of RWH in different residential, commercial and educational institutions and socio-economic structures in Bangladesh. A study analyzing the architectural design considerations of 21 residential buildings in Dhaka city for RWH concluded that harvested rainwater fulfills 12%-30% of the total restricted water demand. For larger rooftops, having rainwater catchment area >700m^2, groundwater recharge is more viable than storage (Ara, 2017). Rahman et al. (2011) used a mass curve (rainwater availability vs. time) analysis for Dhaka city in their paper and determined that a maximum water deficit of 0.38m^3 occurs in April and 0.25m^3 of maximum surplus water is available during October. They also estimated that 33% of water demand can be satisfied through RWH using individual harvesting systems and 10% of such demand can be satisfied using community-based RWH systems in residential buildings of Dhaka city. Sultana (2007) concluded that harvested rainwater does not meet the total domestic requirement of residential buildings in Dhaka but supplements it during the rainy season, and that the quality of the water harvested would be acceptable for individual household use. Ashraful and Islam (2015) investigated the potentiality and cost-effectiveness of RWH of a rooftop of an educational institution in Gazipur, and found that it was feasible for short term water supply, but not for long term dry spells. A book by Water Aid Bangladesh compiled several studies about RWH in Bangladesh that includes pilot projects in several educational institutions such as Bangladesh University of Engineering and Technology (BUET), Military Institute of Science and Technology (MIST), Ahsanullah University of Science and Technology (AUST), and found them to be economically feasible and implementable (WaterAid, 2013).

The daily water balance model, using the parameters YBS (Yield Before Spillage) and YAS (Yield After Spillage) to calculate different reliability and economic cost-benefit factors, is a typical method utilized in recent studies. A detailed methodology can be found in Sakib et al. (2019, pp. 110-11). This study by Sakib et al. (2019), using the daily water balance model for commercial buildings in Dhaka, established that a 18%-25% reliability is attainable and 200-2,900 KL of rainwater harvesting is possible yearly in the wet climate for catchment areas ranging from 120m^2 to 1,242m^2. They also estimated the energy savings and water savings from this process to calculate their benefit-cost ratios. The authors had considered different aspects and different estimations of the lifetime of the RWH projects for commercial buildings in Dhaka, and found the cost-benefit ratios to be greater than 1 for all attributes they tested. Karim et al. (2015) investigated the technical reliability and economic cost-benefit utilizing the same model. They found the maximum reliability achievable was 15%-25%, and that RWH is economically feasible for average and wet climatic conditions for residential buildings in Dhaka city. Also using the same model, Bashar et al. (2018) compared between six different regions of Bangladesh and found Sylhet and Chittagong to have the highest reliability of 30%-40%. The payback period for RWH in Dhaka city was determined to be between 4.3-7.6 years.

Several studies have also been conducted in the coastal areas of Bangladesh where salinity is the primary challenge for the safe drinking water supply. Utilizing the same model for the residential buildings in the coastal areas, Karim et al. (2013) reported that the maximum reliability achievable under the average climatic condition ranges from 70%-90% and the percentage of reliability does not increase considerably beyond a 3,000 L storage tank capacity.

Health Considerations for RWH

Because of health consideration, an assessment of the quality of rainwater is essential before designing an RWH system for both potable and non-potable uses. A pilot project by IWM and DWASA examined 25 parameters, such as - levels of pH and sulfate, chloride, arsenic, lead, nitrate - to examine the quality of rainwater in the BUET laboratory for six samples taken from six different areas of Dhaka city (see Appendix A). They concluded that almost all the parameters were within the permissible limits, and suitable for groundwater recharge and other non-potable uses without any negative health impacts (IWM & DWASA, 2016). Haque & Rinkey (2019) did a similar investigation of samples of rainwater from Dhaka city and checked the physical (turbidity) and chemical (pH, electric conductivity, total dissolved solids, nitrate, nitrite, sulfate, chloride, and fluoride) characteristics of water quality. The outcomes revealed only the pH, nitrate, and fluoride values to have considerable difference with the World Health Organization (WHO) standards, but all other parameters were within the permissible limits. The study concluded that rainwater of Dhaka city needed proper filtration for utilization in potable uses, but was suitable for non-potable uses (Haque & Rinkey, 2019). According to the "Rainwater Harvesting Manual" of the Public Works Department, almost all residential apartment buildings in Dhaka city are facilitated with water pumps and underground storage tanks (PWD, 2002). Because of the interrupted municipal water supply, this storage tank is filled when the water supply is available and then pumped into the overhead storage tank to supply individual units during interruptions. PWD (2002) maintains that no extra cost is needed to construct a separate tank for RWH or buy a water pump. Masudul Islam (Personal Communication, May 9th, 2020) pointed out that since the tank is constructed underground or overhead of toilets with a manhole attached for cleaning and maintenance, there is little to no chance of mosquito breeding. As labor is cheap in Bangladesh, the manual chlorination of the tanks is likely to be more economically feasible than using an automated system (Sultana, 2007).

Whether water should be considered a "human right" or an "economic good" has posed a debate in various studies. "Drawing examples from the tragedy of commons, a group of people, industries, farmers and governments have warned that unregulated, free access to water would lead to serious depletion of this essential life-sustaining resource" (Hardin, 1968). This perspective depicts water as an economic commodity. On the other hand, the rights discourse on water argues that "water is not a commodity"; The United Nations (UN) has acknowledged the "Right to Water" as fundamental to development. Accordingly, the UN Human Rights Declaration (2002) states, "*The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible, and affordable water for personal and domestic uses. An adequate amount of safe water is necessary to prevent death from dehydration, reduce the risk of water-related disease, and provide for consumption, cooking, personal, and domestic hygienic requirements* (UN Committee on Economic, Social and Cultural Rights, 2003)*"* (Uddin & Baten, 2011, p. 6). Inspired by the right-based approach, this paper has considered access to water as a basic human right, implying that everyone should have the right to harvest rainwater at their own free will, independent of the cost of the acquired water.

Needs & Benefits of Using RWH for Non-Potable Use

Catchment areas can be of various types in urban regions; catchments may be from rooftops, storm-water drains, terraces, or open spaces, among others. In developed countries, water requirement for gardens, toilet flushes, and laundry is estimated to be 30% of the total municipal water supply. In fact, only laundry accounts for 20% (UN-HABITAT, 2012) and this need can be mitigated by rainwater. Another use of stored rainwater can be in the case of usage for firefighting emergencies. From Haque (2019), we find that the non-potable water use for Dhaka city dwellers is 56% of the total water demand. Husna & Rahman (2017) found that the quality of rainwater of Dhaka is suitable for only non-potable use. They also calculated the groundwater recharge for use in toilet flushing and washing in a residential building, harvested rainwater could be useful for both these uses and would be promising in conserving water. Haque and Rinkey (2019) also suggested that rainwater in Dhaka city should be used for non-potable uses rather than drinking or cooking. Zaman et al. (2011) examined the utilization of rainwater as a secondary source for flushing toilets or water closets. The surplus water for flushing from harvested rainwater was estimated by them to be 472 m^3 / year. This water supply was found to be 293% of estimated demand. The results of another study by Ahmed & Nahar (2015) showed that rainwater from the rooftop of a residential building in Dhaka saved nearly 69% of total water required by the residents for toilet flushing, house cleansing, and washing clothes for the period of April-August.

Most of the literature explored RWH potential for a single residential building and did not adjust for seasonal variations. This paper aims to provide a comprehensive assessment of the potential of using rainwater available for non-potable uses for urban areas, adjusting for monthly rainfall variations. It also includes an economic analysis. Dhaka city is used as a case study and the methods can be replicated for other urban areas of Bangladesh.

Technical and Design Considerations for RWH Systems

Each RWH system consists of at least the following basic components:

i. Rainfall
ii. Rainfall catchment area or roof surface for collection of rainwater

iii. Conveyance systems (gutters) to transport the rainwater from the roof or collection surface to the storage tank or directly towards the groundwater recharge pit
iv. Storage reservoirs/tanks to store the rainwater until utilization
v. First flush device to get rid of the first 30 minutes of rainfall (Sultana, 2007)
vi. An infiltration or water treatment system if the intended purpose of the harvested water is for potable use (Nissen-Petersen, 2017)

Design of an RWH System

The design of an RWH system depends on several factors such as the purpose of water use, type of catchment area, and the rainfall pattern of the particular geographical area. The detailed design and engineering considerations are beyond the scope of this paper, and therefore it only provides a short general introduction to different designs according to the purpose of water use.

Groundwater Recharge

This usually requires the construction of bore wells, recharge pits, or recharge wells. PVC pipes are installed to go at least 40/50 ft beneath the surface or as low as the groundwater level. After the collection of rainwater from roofs and other catchment areas, the water is conveyed through the pipes to the bore wells. Then the water goes through the bore wells to the ground, to directly recharge the groundwater levels. RWH systems designed for groundwater recharge were found to be economically feasible as the rainwater quality was deemed suitable for this purpose (IWM & DWASA, 2016).

Potable Domestic Use

To use rainwater for domestic purposes, a separate tank or reservoir is constructed or the existing tank is used to store the harvested water. In residential areas of urban Bangladesh, especially in Dhaka, almost all buildings have underground storage tanks that can be used for rainwater storage (PWD, 2002). Direct use in cooking or drinking would require sophisticated water treatment systems. Ghosh et al. (2015) found that in coastal areas of Bangladesh RWH was feasible and would be suitable to meet drinking water demand throughout the year with proper filtration. This paper focuses only on non-potable use of the harvested rainwater, so it elaborates the design considerations for non-potable use a bit further.

Non-Potable Use

Water that is not suitable for direct usage in drinking and cooking is referred to as non-potable water. There are various types of RWH system designs for directing rainwater to use for non-potable usage only, such as direct pumping, indirect pumping, and gravity-fed systems (Zaman et al., 2011). Each design has advantages and disadvantages of their own. As most residential and commercial buildings in urban Bangladesh already have existing underground storage tanks and water pumps, the indirect pumping design would be the closest replica (see Appendix B for the figure of indirect pump design). Water from the catchment area goes through conveyance pipes and then through a filtration device to the storage tank. Then the water is pumped to an overhead tank which then goes through the internal plumbing system to point of use to toilets and bathrooms of the house or apartments (Roebuck et al., 2011) (see Appendix B figure).

There are also various architectural and engineering considerations for different tank sizes and storage designs. As mentioned, the underground storage tank is more popular in Bangladesh and it is the more traditional way of urban rooftop RWH around the world. Therefore, this type of catchment-storage design (see Appendix C for figure) has been considered for the cost calculations (scenario 2) for this study. One disadvantage of this design (scenario 2) is that many multi-storied apartment complexes in the city areas may not have a big enough underground storage tank for the total water needed for all non-potable uses for all the inhabitants of the particular apartment complex. It might also be costlier to construct additional bigger storage tanks. These limitations can be overcome by a new approach. Building a storage space over the toilet area (OTS) is typical for buildings of Dhaka city; this space can be used for installing rainwater storage tanks if the internal plumbing system is considered carefully at the design phase of a building (Ara, 2017). From Ara's (2017) analysis, it was found that instead of a single large storage structure, it is more economical to plan the OTS as rainwater storing space from the very beginning of the building design and construct it accordingly (see Appendix D figure). Such innovation can reduce and distribute the water in multiple smaller tanks, which reduces tank sizes significantly (Ara, 2017). The chances of overflow will also be less as the households use the water directly for their everyday use like toilet flushing, showering, or washing clothes. This can be designed either as a gravity-fed system with an overhead rainwater storage tank that pours into the smaller tanks, or it can be designed as an indirect pumping design with an underground rainwater storage tank. Therefore, this paper also examines this innovative storage design for the cost calculations (scenario 1).

Rainwater Harvesting Potential and Storage Tank Capacity Determination

The most important component of the RWH system design is the determination of the size of the storage tank. We have discussed two different storage tank designs in the previous section. Another important information needed for the calculation is the runoff coefficient of the rooftop that is being used for RWH. The runoff coefficients for different roof materials vary. According to Narain et al. (2005) "Runoff efficiency is highest (85%) for corrugated iron sheet roofs, followed by stone slab roofs (80%), paved surface (68%), and clay tile roofs (56%). The lowest (39%) is for thatched straw roofs" (p. 12). Typical methods of determining storage tank capacities for rooftop RWH systems for general use are the demand-side approach and the supply-side approach (see Appendix E for details). The supply-side approach is more widely used around the world for urban rooftop RWH as the catchment area is limited and the user number is higher in urban areas. Literature regarding Bangladesh has used both approaches. This study follows the supply-side approach.

Methodology and Data

Analysis of existing literature has been done to acquire secondary data to support the paper about the study area and to perform calculations and make projections using existing quantitative models. The data for the calculations and projections were collected from Dhaka Water and Sewerage Authority (DWASA) reports, Bangladesh Meteorological Department (BMD), World Bank Databank, and various other scientific papers.

Firstly, the potential harvestable water volume was calculated using the supply side formula (Appendix E.2), adjusting it to monthly variations for historical data of 2015 from BMD. After that, the projection of rainfall variations and catchment area was used to project the future amount of harvested water available in 2030 for Dhaka city, utilizing the same method. The rationale for calculating the historical and projected rainwater amount was to acquire a comprehensive picture of the overall appropriateness of the RWH system and to assess if it could supplement non-potable water demand scenarios in Dhaka city. Feasibility was further explored through economic analysis consisting of Net Present Value (NPV) and Pay Back Ratio (PB) calculations.

Study Area

The study area is Dhaka city, the capital of Bangladesh. Dhaka is among the "world's 20 fastest growing cities" (Satterthwaite, 2020). Dhaka city is mostly affected by in-country migration due to lack of jobs, opportunities, and basic facilities in the rural areas. The UN predicts that the urban population of Bangladesh will surpass the rural population by 2030, even though Bangladesh was previously understood to be primarily rural (UNDESA, 2018). The population of Dhaka city has steadily risen, from 10,285,000 in 2010 to 21,005,000 in 2020 (WPR, 2020). The population of Dhaka city is projected to be 28,075,660 by 2030 (WPR, 2020). The urban area of Dhaka city is also expanding in a somewhat unplanned way. Pramanik & Stathakis (2016) estimated that there will be a 20% increase in the built-up area of the Dhaka metropolitan by 2030 and majority of this expansion would be in towards the north and northwest (see Figure 1).

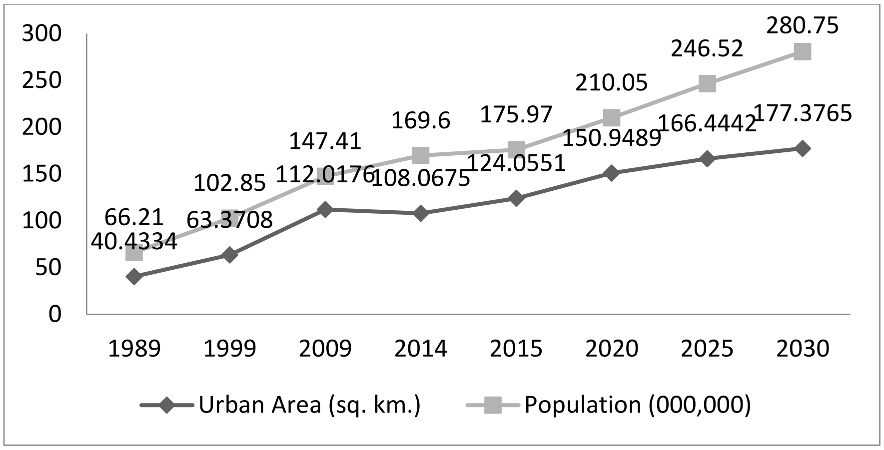

Figure 1: The increasing rate of urban expansion and population increase in Dhaka city
Source: Pramanik & Stathakis (2016), WPR (2020)

The Dhaka Water Supply and Sewerage Authority (DWASA) is the only municipal water authority for Dhaka city dwellers. DWASA provides 75% of the total demand for water, of which about 78% is accumulated from groundwater sources, and the remaining 22% is collected from different treatment plants (DWASA, 2015). Dhaka heavily relies on groundwater, with approximately 80% to 90% of demand coming from this source as there are only four surface water treatment plants (DWASA, 2015). The water supply system in Dhaka has been facing major problems for quite some time and is one of the worst in South Asia (ADB, 2016). According to the Groundwater Monitoring Survey Report of Bangladesh Agricultural Development Corporation (BADC) and the Institute of Water Modeling (IWM), the groundwater level of Dhaka city is falling by three meters per year (BWP, 2019). Groundwater has already receded by 50 meters in the past 40 years, bringing the current level to 65 meters below the surface (Haque, 2019; Sumon & Kalam, 2014).

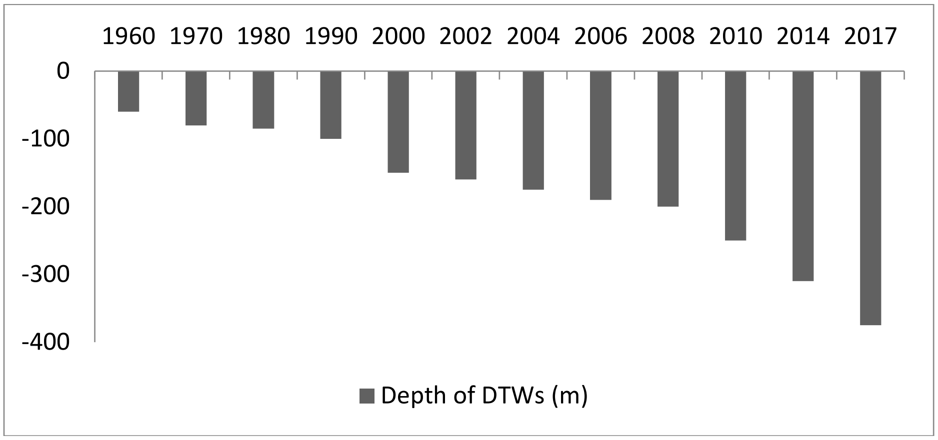

Figure 2: Gradual increase of mining depth of deep tube wells in Dhaka
Source: Haque (2019)

From Figure 2, it is evident that groundwater levels have declined at an alarming rate in Dhaka city, making the supply of water from groundwater sources increasingly difficult. From the annual report of DWASA (2015), we know that the annual supply capacity is 2,420 MLD for 2015. Holding this constant, if we plot the future demand estimates for Dhaka city up to 2035, we can see an increasing gap between supply capacity and projected demand (see Figure 3).

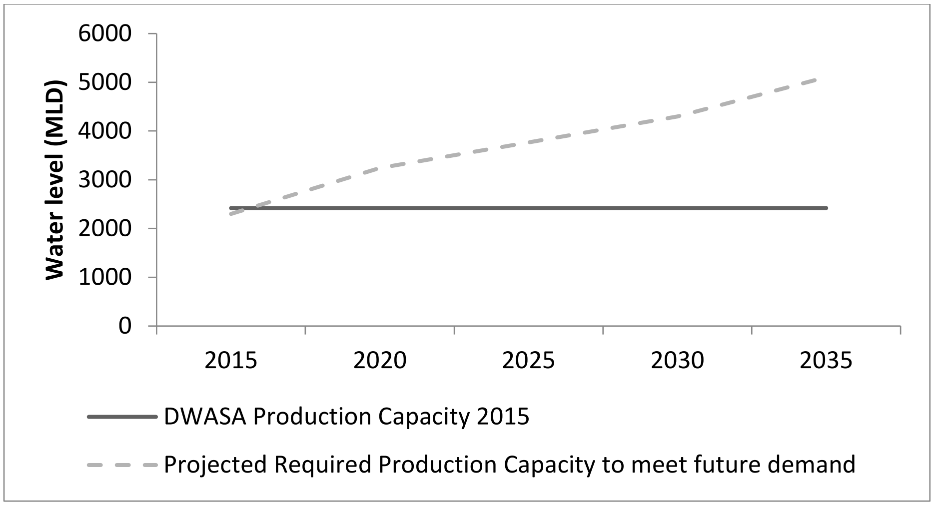

Figure 3: The projected demand-supply gap of Dhaka city
Source: DWASA (2015), Haque (2019)

To adjust for monthly variations of available rainwater, the average monthly rainfall data from 1980-2015 for Dhaka city was collected from the Bangladesh Meteorological Department website (BMD, 2020). Rajib et al. (2011) had provided a multi-model average in future rainfall projection and Shourav et al. (2016) used statistical downscaling model, while Hossain et al. (2017) used the Box-Jenkins approach. Noting the trend of all of the three papers, and using the data of Rajib et al. (2011) and the average monthly rainfall data from 1980-2015 for Dhaka city from BMD (2020), this study estimated the monthly rainfall in 2030 for Dhaka city. Below (Figure 4) we can see the 2015 and projected 2030 scenario for Dhaka city.

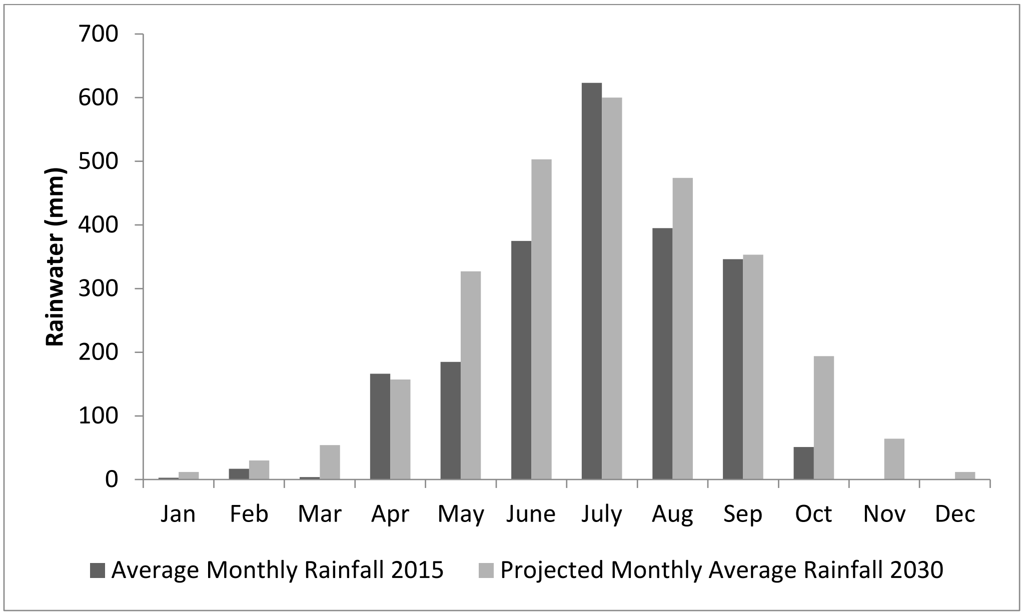

Figure 4: Average monthly rainfall of 2015 and projections for 2030
Source: BMD (2020) & Author's calculations (the lighter blocks)

To accurately measure the potential volume of available rainwater for non-potable uses for the total population of Dhaka, we need to calculate the consumption demand.

Table 1: Breakdown of DWASA Survey of Water Consumption Patterns – 2016

Feature	Demand (lpcd)	Percentage
Personal Washing	73	25%
Toilet Requirement	28	19%
Washing Apparatuses	24	13%
Clothes Washing	20	12%
Drinking	2	1%
Cooking	4	18%
Floor Washing	3	12%
Other Uses	1	0%
Total	155	100%

Source: Haque (2019)

From Table 1, we note that excluding personal washing, cooking and drinking, the other uses together will require 76 lpcd or 56% of the total domestic water use. We use this as a reference value to make the calculations (see Appendix F).

Result and Discussion

Analysis of Water Availability of RWH

From our own calculations (see Appendix F), we estimate the seasonally adjusted percentages of non-potable water demand that can be fulfilled by RWH for both 2015 and 2030 for Dhaka city. These are displayed in Figure 5 below.

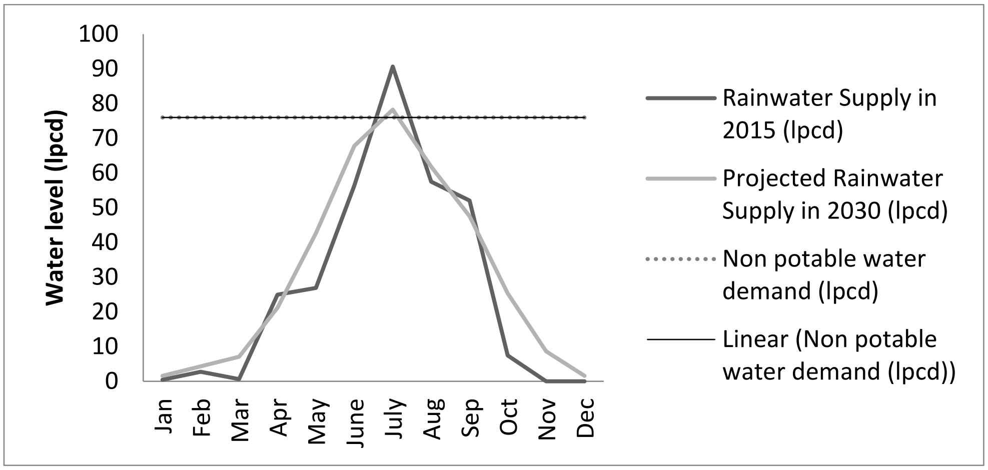

Figure 5: Harvested Rainwater Supply Potential and Domestic Non-potable Demand
Source: Author's calculations

From Figure 5 we note that, from April to October, the supply of rainwater expressed as the percentage of demand varies from 33% to 76% for 2015, and in 2030 from 28% to 81%. In both cases, a surplus was seen in July, 119% in 2015 and 103% projected for 2030. This paper calculates these ratios based on the entire built-up area of Dhaka city, deeming 80% as catchment areas. These catchment areas include residential and commercial buildings. Rahman et al. (2011) did a similar gross water availability analysis using a different method, and found similar results, which validates our study. Zaman et al. (2011) determined the yearly supply of rainwater for a single residential building and found that it would fulfill 293% of non-potable demand. Ara (2017) and Rahman et al. (2011) found that September and October, respectively, would have the highest surplus water against the demand for residential buildings of Dhaka in future projections. Our study shows that the amount of rainwater that can be harvested will be sufficient enough to supplement the domestic non-potable water demand of Dhaka city in the year 2030.

Economic Cost-Benefit Analysis

Consultation with architects and experts from several NGOs dealing with the urban RWH designing and sanitation sector of Dhaka revealed that the average cost of including an RWH system by using OTS (see Appendix D) is BDT 95,000. This average cost estimate includes the construction of the storage tank (Masudul Islam, Personal Communication, May 9th, 2020). For the traditional design RWH system with an underground storage tank, Ashraful and Islam (2015) found the installation cost to be around BDT 65,000 and the monthly operational cost to be BDT 3,000.

We calculate the net present value (NPV) for the next 10 years for this current study for these two scenarios, 1) OTS construction design and 2) use of the existing tank and plumbing system design. An average catchment area of 600 m^3 has been considered an average roof size for buildings in Dhaka (Karim et al., 2015), and monthly rainfall variations have been taken into account. The average unit water cost considered for residential and commercial use was 27tk/1,000 L (DWASA, 2015). Yearly monetary savings were calculated by multiplying total harvested water volume by the unit price. The discount rate is fixed at 5.4% by the Bangladesh Bank (2020). From the calculations (see Appendix G) we find the following results.

Table 2: Economic Analysis Results

	Scenario 1	Scenario 2
NPV (BDT)	132,014.5	162,014.5
Payback period (years)	3.6	2.5

Source: Author's Calculations

NPV is positive for both scenarios, implying that investment in this project will provide monetary benefits after 2.5-3.6 years. After that, the owner of a building with a 600 m^3 catchment area can save up to BDT 36,028 per year. Water price in Dhaka city appears to have increased almost every year in the past (DWASA, 2015). Therefore, the gradual increase in the price of water will shorten the payback period and increase monetary savings in the future.

Conclusion

Access to clean and safe water is critical to economies, ecosystems, and the general survival of humankind. A scarcity of water can directly affect the long-term prospects of sustainable development as it has great socio-economic effects. It is found from this study that 28% to 81% of non-potable water demand can be supplemented by RWH from April to October and a surplus of 103% is available in July of 2030 for Dhaka city. The NPV for 2 types of designs considered is positive and the payback period is between 2.5-3.6 years. Therefore, if we start harvesting now, even more water can be saved. This will be a huge step in mitigating the water supply crisis, as Dhaka faces the pressure of ever-increasing population and adverse effects of climate change. Most other cities and urban areas in Bangladesh face limitations and challenges that are similar to the ones encountered by Dhaka. The design considerations applied here for Dhaka can be replicated all over Bangladesh.

The limitations of the study include lack of specific data about the number of buildings and their roof structure for the study area. All roofs have been assumed to be made of concrete, and therefore runoff coefficient was held constant for calculation. In addition, lack of data for the unit price of energy used for water pumping resulted in energy savings to be omitted from the benefit calculations. Further, primary and secondary research should be done for specific areas concerning specific needs of the communities, feasibility analysis of new technologies of RWH systems, cost-benefit analysis of the implementation of different methods for all cities, and designing small-scale and large-scale systems, given available data. Perception surveys can be done as to why people are not adapting this technology faster and more exploratory research using advanced forecasting tools can be used to accurately measure the water crisis and analyze numerous other opportunities to explore the topic further.

Overall, it may be concluded that rainwater harvesting is a convenient option for water supply and demand deficit management in urban Bangladesh. We find that proper water management, with rainwater harvesting systems as the source of supplementary water supply for non-potable use, can conserve valuable groundwater. This will allow

DWASA to pump less groundwater. Thus, more people will have access to safe drinking water. The implementation of the technique would be economically beneficial for the owners as well. The government has taken the first step in establishing a rule to make the installation of RWH systems mandatory for all new residential buildings of Dhaka city; this should be done all across the country. Further policy suggestions will be to set up a regulatory and monitoring board to ensure implementation of this rule, and add further amendments, including the proper design of the systems for both potable and non-potable use as well as for groundwater recharge. The regulatory board should also take up the responsibility to check the quality of rainwater for specific areas and instruct the homeowners accordingly. All in all, the simultaneous effort of homeowners and the concerned authority is essential to make RWH possible at a mass level. By incorporating RWH systems to the urban water supply of Bangladesh, we can work towards building more sustainable and greener cities and communities.

List of Abbreviations

ADB	Asian Development Bank
AUST	Ahsanullah University of Science and Technology
BB	Bangladesh Bank
BIP	Bangladesh Institute of Planners
BMD	Bangladesh Meteorological Department
BNBC	Bangladesh National Building Code
BUET	Bangladesh University of Engineering and Technology
BWP	Bangladesh Water Partnership
DWASA	Dhaka Water Supply and Sewerage Authority
INGO	International Non-Government Organization
IWM	Institute of Water Modeling
Lpcd	Liters per capita per day
MIST	Military Institute of Science and Technology
MLD	Millions of liter per day
NGO	Non- Government Organization
NPV	Net Present Value
OTS	Over the Toilet Storage
PB	Pay Back Ratio
PVC	Polyvinyl Chloride
PWD	Public Works Department
RWH	Rainwater Harvesting
SDG	Sustainable Development Goals
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UN-HABITAT	United Nations Human Settlements Program
WHO	World Health Organization
WPR	World Population Review
YAS	Yield After Spillage
YBS	Yield Before Spillage

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Appendix A

Table 3: Rainwater Quality Result of Collected Samples by DWASA and IWM

SL. No.	Parameters	Unit	Allowable Limit (ECR'97)	Location Name					
				Uttara	Mirpur	Segunbagicha	Lalmatia	Hazaribag	Tejgaon
1	pH		6.5-8.5	7.17	6.83	6.85	5.13	5.12	6.1
2	Silica (SiO_2)	mg/l		2.2	2.2	2.4	1.1	0.8	1.5
3	Sulphate (SO_4)	mg/l	400	<1.0	<1.0	<7.0	<7.0	<7.0	<7.0
4	Iron (Fe)	mg/l	0.3-1.0	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
5	Total Hardness (as $CaCO_3$)	mg/l	200-500	11	5	17	5.3	4.7	7.4
6	Magnesium (mg)	mg/l	30-35	0.584	0.4	0.447	0.22	0.15	0.26
7	Calcium (Ca)	mg/l	75	4.6	1.7	5.96	0.86	0.65	1.66
8	Potassium (K)	mg/l	12	0.06	0.21	0.4	0.48	0.62	0.36
9	Chloride (Cl-)	mg/l	150-600	4	4	2	3	3	4
10	Arsenic (As)	mg/l	0.05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
11	Electrical Conductivity (EC) at 25^o	µS/cm		32	20	43	18	17	20
12	Nitrate (NO_3-N)	mg/l	10	1.7	0.5	0.4	0.3	0.4	0.3
13	Fluoride (F)	mg/l	1	0.08	<0.05	0.31	<0.05	<0.05	<0.05
14	Ammonia (NH_3-N)	mg/l	0.5	0.063	0.03	0.105	0.469	0.419	0.396
15	Phosphate (PO_4)	mg/l	6	0.167	0.128	<0.04	<0.04	<0.04	0.043
16	Sodium (Na)	mg/l	200	0.15	0.98	0.85	3.22	3.15	3.8
17	Boron (B)	mg/l	1	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
18	Iodine (I_2)	mg/l		0.05	<0.04	0.05	0.04	0.04	0.06
19	Lead (Pb)	mg/l	0.05	0.015	0.02	0.014	<0.01	<0.01	0.014
20	Cadmium (Cd)	mg/l	0.005	0.001	0.001	0.001	<0.001	0.001	0.001
21	Zinc (Zn)	mg/l	5	0.037	0.104	0.046	0.131	0.137	0.175
22	Chromium (Cr)	mg/l	0.05	0.007	0.008	0.009	0.005	0.01	0.006
23	Manganese (Mn)	mg/l	0.1	<0.005	<0.005	0.007	0.021	0.017	0.008
24	Total Alkalinity (as $CaCO_3$)	mg/l		13	10	16	<0.1	<0.1	<0.1

Source: IWM & DWASA (2016)

Appendix B

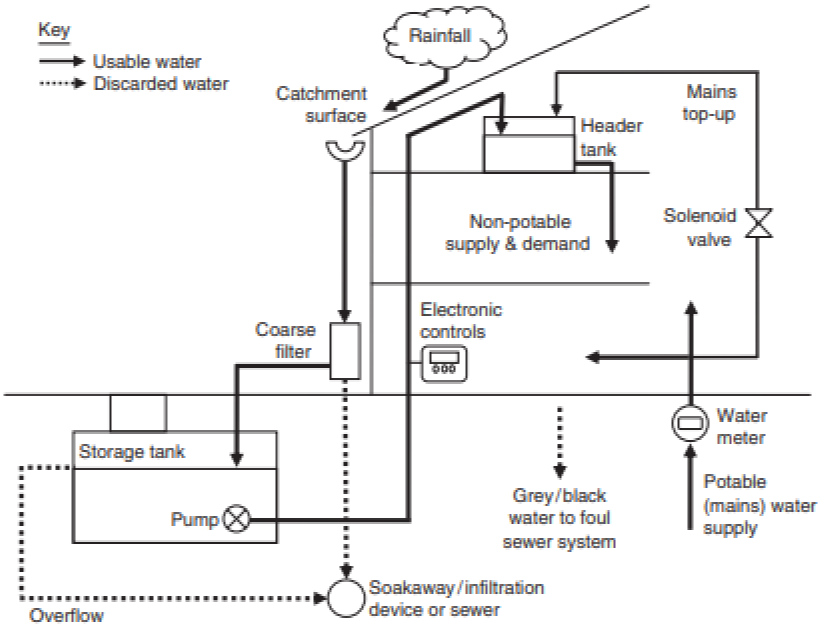

Figure 6: RWH system design for household non-potable use.
Source: Roebuck et al. (2011)

Appendix C

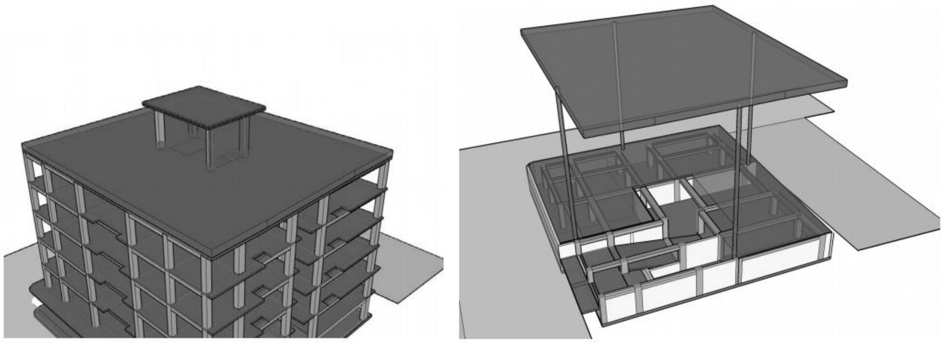

Figure 7: Rooftop catchment of a concrete structure (left) and catchment and underground storage tank system illustration (right).
Source: Sultana (2007)

Appendix D

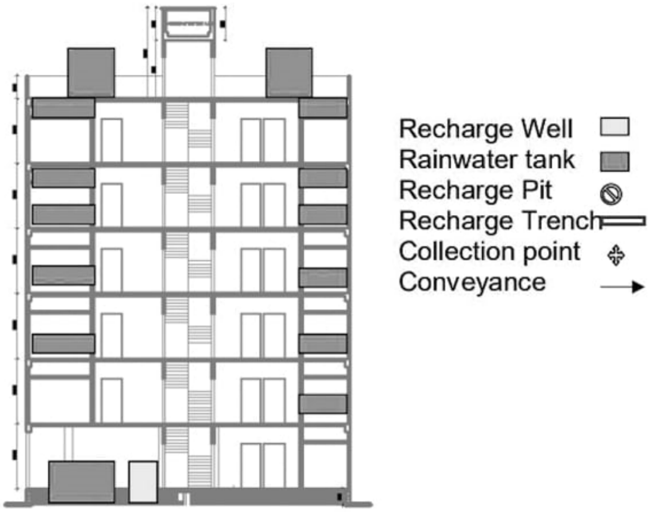

Figure 8: Design of RWH for non-potable use using Over Toilet Storage (OTS) space as rainwater storage
Source: Ara (2017)

Appendix E

1) Demand-side approach
This methodology presumes sufficient rainfall and catchment area. Formula to calculate the required tank capacity is as follows:

Water consumption per capita per day = C
Number of members per household = n
Longest average dry days = t
Then, the daily demand = Cn and the storage tank volume will be = Cnt (i)

2) Supply-side approach
This methodology uses available catchment area with appropriate capture efficiency to determine optimal tank capacity.

Supply S (m^3) = Catchment Area (m^2) x Rainfall (mm) x Run-off coefficient (Cf) (ii)

Source: Sendanayke (2016)

Appendix F

Table 4: Rooftop Catchment Area Estimations

Year	Total Built-up Area of Dhaka Rooftop Area (m^2)	Rainfall Catchment Area (m^2) considering 80% as available
2015	124,055,100	99,244,080
2030	177,376,500	141,901,200

Source: Pramanik & Stathakis (2016) and Author's Calculations

Table 5: Available rainwater calculation and percentage expressed as demand calculations for 2015

Month	Year 2015	Total built up rooftop area of Dhaka available for RWH (m^2)	Run-off coefficient	Harvested Total Rainwater Supply (HRWS)	Liters Per Day	Million Liters Per Day	Population	Liter Per Capita Per Day (lpcd)	Demand (lpcd)	Percentage of demand fulfilled by supply
Jan	3	99,244,080	0.8	238,185,792	7,683,412.645	7.68	17,597,177	0.436628	76	1%
Feb	17	99,244,080	0.8	1,349,719,488	48,204,267.43	48.2	17,597,177	2.739318	76	4%
Mar	4	99,244,080	0.8	317,581,056	10,244,550.19	10.24	17,597,177	0.58217	76	1%
Apr	166	99,244,080	0.8	13,179,613,824	439,320,460.8	439.32	17,597,177	24.96539	76	33%
May	185	99,244,080	0.8	14,688,123,840	473,810,446.5	473.81	17,597,177	26.92537	76	35%
June	375	99,244,080	0.8	29,773,224,000	992,440,800	992.44	17,597,177	56.39773	76	74%
July	623	99,244,080	0.8	49,463,249,472	1,595,588,693	1595.59	17,597,177	90.67299	76	119%
Aug	395	99,244,080	0.8	31,361,129,280	1,011,649,332	1011.65	17,597,177	57.4893	76	76%
Sep	346	99,244,080	0.8	27,470,761,344	915,692,044.8	915.69	17,597,177	52.0363	76	68%
Oct	51	99,244,080	0.8	4,049,158,464	130,618,015	130.62	17,597,177	7.422669	76	10%
Nov	0	99,244,080	0.8	0	0	0	17,597,177	0	76	0%
Dec	0	99,244,080	0.8	0	0	0	17,597,177	0	76	0%

Source: BMD (2020) & Author's Calculations

Table 6: Available rainwater calculation and percentage expressed as demand calculations for 2030

Month	Year 2030	Total built up rooftop area of Dhaka available for RWH (m^2)	Run-off Coefficient	Harvested Total Rainwater Supply	Liters Per Day	Million Liters Per Day	Population	Liter Per Capita Per Day (lpcd)	Demand (lpcd)	Percentage of demand met by HRWS
Jan	12	141,901,200	0.8	1,362,251,520	43,943,597.42	43.94	28,075,660	1.565185	76	2%
Feb	30	141,901,200	0.8	3,405,628,800	121,629,600	121.63	28,075,660	4.332208	76	6%
Mar	54	141,901,200	0.8	6,130,131,840	197,746,188.4	197.75	28,075,660	7.043332	76	9%
Apr	157	141,901,200	0.8	17,822,790,720	594,093,024	594.09	28,075,660	21.16043	76	28%
May	327	141,901,200	0.8	37,121,353,920	1,197,463,030	1,197.46	28,075,660	42.65129	76	56%
June	503	141,901,200	0.8	57,101,042,880	1,903,368,096	1,903.37	28,075,660	67.79424	76	89%
July	600	141,901,200	0.8	68,112,576,000	2,197,179,871	2,197.18	28,075,660	78.25924	76	103%
Aug	474	141,901,200	0.8	53,808,935,040	1,735,772,098	1,735.77	28,075,660	61.8248	76	81%
Sep	353	141,901,200	0.8	40,072,898,880	1,335,763,296	1,335.76	28,075,660	47.57727	76	63%
Oct	194	141,901,200	0.8	22,023,066,240	710,421,491.6	710.42	28,075,660	25.30382	76	33%
Nov	64	141,901,200	0.8	7,265,341,440	242,178,048	242.18	28,075,660	8.625908	76	11%
Dec	12	141,901,200	0.8	1,362,251,520	43,943,597.42	43.94	28,075,660	1.565185	76	2%

Source: BMD (2020) & Author's Calculations

Appendix G

Table 7: Economic Analysis Calculations for Scenario 1

Year	Installation Cost	Operations and Maintenance Cost (BDT)	Yearly Monetary Savings	Accumulated Cash Flow, CF	Inflation Rate	Present Value of Cash Flow
2020	95,000	3,000	25,980	-72,020	5.54	-72,020
2021	0	3,030	26,759.4	23,729.4		22,483.8
2022	0	3,060.3	27,562.18	24,501.88		21,997.09
2023	0	3,090.9	28,389.05	25,298.15		21,519.76
2024	0	3,121.81	29,240.72	26,118.91		21,051.67
2025	0	3,153.03	30,117.94	26,964.91		20,592.71
2026	0	3,184.56	31,021.48	27,836.92		20,142.74
2027	0	3,216.41	31,952.12	28,735.71		19,701.64
2028	0	3,248.57	32,910.69	29,662.12		19,269.28
2029	0	3,281.06	33,898.01	30,616.95		18,845.52
2030	0	3,313.87	34,914.95	31,601.08		18,430.24
						NPV= 132,014.5

Source: Author's Calculations

Table 8: Economic Calculations for Scenario 2

Year	Installation Cost	Operations and Maintenance Cost (BDT)	Yearly Monetary Savings	Accumulated Cash Flow, CF	Inflation Rate	Present Value of Cash Flow
2020	65,000	3,000	25,980	-42,020	5.54	-42,020
2021	0	3,030	26,759.4	23,729.4		22,483.8
2022	0	3,060.3	27,562.18	24,501.88		21,997.09
2023	0	3,090.9	28,389.05	25,298.15		21,519.76
2024	0	3,121.81	29,240.72	26,118.91		21,051.67
2025	0	3,153.03	30,117.94	26,964.91		20,592.71
2026	0	3,184.56	31,021.48	27,836.92		20,142.74
2027	0	3,216.41	31,952.12	28,735.71		19,701.64
2028	0	3,248.57	32,910.69	29,662.12		19,269.28
2029	0	3,281.06	33,898.01	30,616.95		18,845.52
2030	0	3,313.87	34,914.95	31,601.08		18,430.24
						NPV= 162,014.5

Source: Author's Calculations