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Reliability and economic analysis of urban rainwater harvesting: A comparative study within six major cities of Bangladesh

Mohammad Zobair Ibne Bashar[a], Md. Rezaul Karim[b], Monzur Alam Imteaz[c,*]

[a] Department of Civil and Environmental Engineering, Louisiana State University (LSU), Baton Rouge, LA, United States
[b] Department of Civil and Environmental Engineering, Islamic University of Technology (IUT), Board Bazar, Gazipur, 1704, Bangladesh
[c] Department of Civil & Construction Engineering, Swinburne University of Technology, Melbourne, VIC, Australia

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ABSTRACT

Rainwater harvesting (RWH) has been a popular practice in coastal and arsenic affected rural areas of Bangladesh. However, the urban communities still showing reluctance in adopting a RWH system. The main reason for such reluctance is lack of confidence in potential water savings and payback period on initial investment. To tackle with severe water scarcity in major cities of Bangladesh, the government has made it mandatory to install a RWH system in all the proposed new buildings. This paper presents reliabilities and economic benefits of RWH systems for six major cities (Dhaka, Chittagong, Rajshahi, Khulna, Sylhet, and Barishal) of the Bangladesh using a daily water balance model. Reliability parameters were calculated based on a scenario of six storied residential building with 50 inhabitants and with a roof area of 200 m^2. The results indicate that Sylhet and Chittagong regions have the high potentials of rainwater harvesting, where a maximum reliability of 30–40% can be achieved. The results also reveal that approximately 500–800 m^3 of water can be saved each year if a rainwater harvesting system is used in combination with the town water supply. This study also proves that the current underground tank sizes in these cities are sufficient to prevent any spillage of water, which may significantly alleviate urban flooding/water logging. Payback period analysis indicate that the costs associated with the installation and maintenance of RWH system could be equalized within 2–6 years depending on the topographic and climatic conditions.

1. Introduction

In the recent years, rainwater harvesting (RWH) has received an increased attention as one of the most promising alternative source of water, which can be used to partially offset the increasing demand of clean water globally. Bangladesh is one of the most densely populated countries in conjunction with being one of the largest climate ravaged countries all over the world. Due to climate variability, excessive groundwater extraction and increasing water stress with the rapid growth of urban population, water supply has become a major issue in Bangladesh (Dakua et al., 2013; Mukherjee and Hyde, 2013). Like many other cities in the developing countries, most of the cities in Bangladesh are also facing shortages of potable water due to decline in groundwater as well as inefficient water management (Akter and Ahmed, 2015). To partially offset the increasing water demand some alternative water sources have received a great attention lately in Bangladesh. Some developed nations adopting grey water reuse and waste water recycling, both of which require higher level treatments and consequently become expensive while having safety concerns. In comparison to these expensive and safety-concerned approaches, rainwater harvesting was found to be the most sustainable in the context of Bangladesh.

As a part of addressing the issue of increasing potable water demand, Bangladesh government has already amended the Building Construction Rules (2008) by making the installation of rainwater harvesting facilities mandatory for all new residential buildings in Dhaka city (capital of Bangladesh) corporation area. It has also been incorporated in the Bangladesh National Building Code (BNBC), 2014 that every proposed residential building to be built on plots having area above 300 m^2 must have the arrangements for harvesting rainwater. Although these rules are being included in the codes, no in-depth study has been carried out yet to evaluate the rainwater harvesting potential in terms of reliability and efficiency in Dhaka as well as in the other major cities of Bangladesh. There are numerous studies on rainwater harvesting potentials in various regions of the world; however very few in-depth studies have been conducted on rainwater harvesting potentials in Bangladesh. Karim et al. (2015) evaluated the reliability and economic benefits of urban RWH in Dhaka city. As the water demand and supply pattern in other cities in Bangladesh varies greatly from one

* Corresponding author.
E-mail addresses: mbasha4@lsu.edu (M.Z.I. Bashar), rezaulmd@iut-dhaka.edu (Md. R. Karim), mimteaz@swin.edu.au (M.A. Imteaz).

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Table 1
Existing RWH analysis models.

Model	Description	Reference
1 RWH Evaluation Tool	Model based on rainwater harvesting in UK. Offers performance evaluation, tank design, and behavioural simulation with historical rainfall.	Melville-Shreeve et al. (2016)
1 RWH simulator	Model based on Italian settings. Offers household demand forecasting, water saving assessment, and behavioural simulation with historixal data.	Campisano and Modica (2016)
1 SARET (Storage and Reliability Estimation Tool)	Offers reliability and tank size estimation based on historical precipitation data.	Basinger et al. (2010)
1 AquaCycle	Model based on Australian conditions. Offers behavioural simulation with historical data.	Zhang et al. (2010)
1 Rainwater Harvester	Model based on USA studies. Offers behavioral simulation only.	Jones and Hunt (2010)
1 eTank	Model developed in Australia. Offers reliability calculation based on a daily water balance model.	Imteaz et al. (2011)

another, there is a need for a comparative study regarding the reliability and economic parameters to help the authorities to set a more accurate guideline for different cities. Moreover, the city dwellers are reluctant in adopting RWH system due to lack of information of potential water saving and economic benefits of rainwater harvesting through scientific studies. This paper presents the variability of reliability and potential economic benefits of rainwater harvesting systems for residential buildings among the six major cities of Bangladesh.

2. State-of-the-art

Bangladesh has a tropical monsoon climate characterized by heavy seasonal rainfall. According to the survey of Bangladesh Bureau of Statistics (BBS), Bangladesh receives almost about 2600 mm of rainfall each year, which makes rainwater harvesting a potential alternative source of water (Karim et al., 2015). Nevertheless, there are regions like the western part of Rajshahi division which receives less than 1400 mm of rainfall each year. The coastal areas of the country receive relatively greater amount of rainfall and rainwater harvesting has already become a popular practice there. Although rainwater harvesting systems are common in coastal and arsenic affected rural areas of the country, it is not a common practice in the urban communities of Bangladesh (Akter and Ahmed, 2015). This scenario is quite common in different urban communities all over the world. Statistics from the Australian Bureau of Statistics (ABS) show that about 47% of the population of Melbourne show reluctance in adopting a rainwater harvesting system (Rahman et al., 2012).

Akter and Ahmed (2015) studied the potentiality of rainwater harvesting in an urban community living in South Agrabad of Chittagong in Bangladesh. An Analytic Hierarchy Process (AHP) based multi-criteria decision analysis technique was adopted, which revealed that if the storage system permits the rainwater could be used to supplement up to 20 liters/person/day throughout the year and at the same time rooftop rainwater harvesting could reduce the water clogging problem by about 26%. Dakua et al. (2013) found that about 70–80% of the water demand can be met during the months of June-September. Rahman et al. (2014) investigated the sustainability of rainwater harvesting systems in the Dhaka city in terms of water quantity and quality. In addition to monitoring several water quality parameters, they have found a RWH system in Dhaka city will be effective and economical for an apartment building with a catchment area of 170 square meters and a daily water demand of 135 liters/capita/day. They have tested several water quality parameters from a rainwater tank in Dhaka city for a period of one year and concluded that all the water quality parameters (pH, BOD_5, TDS, Turbidity, NH_3-N and Lead) were below the Bangladesh Standard for Drinking Water (ECR, 1997), except for Fecal Coliform. In regards to Fecal Coliform, it was much higher than the allowable limit in summer and autumn months, whereas lower in winter months. Several studies from Bangladesh and other countries also reported the presence of various pathogens in the harvested rainwater and often did not comply the national drinking water quality standards (Simmons et al., 2001; Lye, 2002; Meera and Ahammed, 2006; Howard et al., 2006; Sazakli et al., 2007; Karim, 2010; Schets et al., 2010).

The selection of optimum rainwater tank size is a major factor to increase the efficiency of a rainwater harvesting system and to shorten the payback period (Mun and Han, 2012). A study by Mehrabadi et al. (2013) showed that at least 75% of the non-potable water demand could be satisfied for typical buildings for almost about 70% of the time by storing the rainwater. Ward et al. (2012) also investigated the performance of a rainwater harvesting system for a large building. The results indicated that about 87% water saving efficiency could be achieved for an office-based RWH system over an 8-month period. Some of the other studies on rainwater harvesting potential around the world are Ghisi et al. (2007) for Southeastern Brazil; Imteaz et al. (2013) for Adelaide, Australia; Matos et al. (2015) for Portugal; Imteaz et al. (2012) for Nigeria; Souza and Ghisi (2012) for 12 countries; Rahman et al. (2012) for Sydney; Imteaz et al. (2011) for Melbourne; Farreny et al. (2011) for Spain; Cheng and Liao (2009) for Taiwan and Hanson et al. (2009) for USA. Other notable works on efficiency of RWH systems are Domènech and Saurí (2011) in Barcelona, Spain; Ghisi and Schondermark (2013) in Santa Catarina State of Southern Brazil; Roebuck et al. (2011) in UK. A comparison among the existing RWH analysis models has been shown in Table 1.

Economic analysis of RWH systems plays a key role to convince the end users to adopt a rainwater harvesting system. A recent study by Karim et al. (2015) conducted for Dhaka city indicated that RWH systems become economically beneficial if the service life exceeds 15 years under wet and average climatic conditions. Similar studies by Coombes and Kuczera (2003) indicated that for an individual building in Sydney with a roof area of 150 m^2 and a tank size of 1–5 m^3 can facilitate in 10–58% water savings, which depends upon the number of inhabitants of the building. Khastagir and Jayasuriya (2011) evaluated the investments on rainwater tanks and concluded that the maximization of the return on the initial investment depends on the efficient use of the tank and which is very much dependent on the selection of the optimum tank size. For economic assessment, the scale of analysis plays a significant role (Morales-Pinzón et al., 2015). It reveals that rainwater harvesting tends to become more economically efficient as more parameters are included in the analysis. Rahman et al. (2010) showed that payback in Sydney can be achieved for multi-storey buildings under the conditions of a low discount rate and a large number of users. Imteaz et al. (2011) showed that the capital cost can be recovered within 15–21 years for large rainwater tanks connected to commercial roofs in Melbourne under future water price increase rate. Various results have been found on the different level of viability of RWH systems with regard to the system size. In reality, significant spatial variations are likely to exist within a country, even within a large city. Imteaz et al. (2013) has presented significant spatial and climatic variations of rainwater tank outcomes within a large city. Based on the mentioned shortcomings of the earlier studies, this study attempted to investigate spatial and climatic variabilities of rainwater tank outcomes within six