# SOCIO-TECHNICAL PERFORMANCE EVALUATION OF RAINWATER HARVESTING OPTIONS AS AN ALTERNATIVE WATER SOURCE IN SOUTHWESTERN COASTAL REGION OF BANGLADESH

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## ABSTRACT

Access to safe drinking water is a basic well-being issue at national, regional, and local levels. However, in the coastal areas of Bangladesh, drinking water scarcity has become intense as the freshwater aquifers are not available at reasonable depths and the surface water is profoundly saline and turbid. Arsenic contamination and low dry season rainfall are also behind this deplorable condition. Such is the case in a southwestern district Satkhira, where the inhabitants are suffering from a shortage of drinking water, long after the cyclone Aila in 2009. In 2020, cyclone Ampaan has devastated this district again. During the disaster, high tidal surges contaminated all freshwater sources with saline water devastated the major drinking water sources. As rainwater is available in adequate quantity during the monsoon period, conserving and harvesting this gift of nature could be an environmentally sound solution among the various technologies to augment freshwater resources. Rainwater harvesting (RWH) in a proper way can minimize water scarcity issues without creating any environmental hazards. For this reason, it is increasingly becoming an integral part of the sustainable water management toolkit. However, some issues are obstructing the successful implementation of RWH options. The absence of technical knowledge, lack of training program on the usage and maintenance of the technology, unawareness of the hygiene, economic constraints, etc. are the major reason for reducing the acceptability of RWH technology. The study investigates the suitability of rainwater harvesting for safe drinking water solutions for coastal habitats, which is currently a crisis in such disaster-prone and saline-affected areas. It assessed existing RWHs from Shyamnagar Upazila of Shatkhira district, incorporating social and technical aspects. A mixed-method approach was adopted for the assessment, which included 10 site inspections. For the technical evaluation, a suitable behavioral model has been implemented according to a daily mass balance equation which determined the water-saving efficiency, overflow ratio, and reliability of the system. Questionnaire surveys and focus group discussions with the consumers have been done to assess the social perspectives. From the analysis, we identified RWH to be the most appropriate alternative water source in this region. There was enough quantity of water to support the total water need in household activities. The significant features which enhanced the suitability of RWH in the study area were the availability of water in comparison to alternative water sources, the potential for improved livelihoods, protection against climate unpredictability, and support from local government and non-government organizations. However, a lack of awareness and financing mechanisms were identified as significant social barriers to RWH use. This assessment evaluates the socio-technical outcomes of a supplementary water source in the coastal region, emphasizing the prominence of the human-water relationship to sustainable development.

***Keywords:*** *Water Scarcity; Rainwater Harvesting; Water management; Human-Water Relationship; Sustainable Development*

## 1. INTRODUCTION

Rapid population growth along with industrialization, urbanization, and infrastructure leading to global water scarcity. Like many other developing countries public water supply in Bangladesh eventually short falling (M. R. Ahmed, M. A. Ahmed, M. S. Islam, 2018). Especially the coastal regions of Bangladesh have been experiencing an acute shortage of safe drinking water over the past few decades. Due to geographical location, this south-western region is commonly subjected to floods, river erosion, and tidal surge but most importantly cyclones and storm surges. The situation is particularly distressing for this area due to salinity intrusion in surface and groundwater. There is also a principal concern of arsenic in some parts of coastal regions. Consequently, the coastal inhabitants are victims of an enduring crisis of water for drinking and other domestic uses both in terms of quality and quantity (Abedin et al., 2014). Considering the cumulative salinity intrusion, pollution of surface water bodies, groundwater contamination by arsenic, and groundwater depletion due to excessive withdrawal, rainwater harvesting (RWH) has become a potential source of water supply in the coastal area in Bangladesh. (Khan et al., 2017). The system includes collecting water from catchments on which rain falls and saving it for future uses. Usually, water is collected from the roofs of buildings and stored in a rainwater tank or cisterns. In addition, water can also be collected in ponds from runoff produced from rain (Ratu & Attoza, 2021). A greater intensity of normal yearly rainfall in the coastal areas is favorable for rainwater harvesting (RWH)(Nasir et al., 2013). For this reason, RWH has become a vital part of the sustainable water management toolkit (Ward et al., 2012). However, the lack of maintenance practice and knowledge often turns this water into contaminated water and causes health concerns (Sharma & Bhattacharya, 2017). This study is an attempt to access the technical and social issues and aspects of existing rainwater harvestings of the southwestern coastal area and check the feasibility for adaptation as an alternative freshwater source.

## 2. METHODOLOGY

### 2.1 Study Area

The study was conducted in Shyamnagar Upazila of Satkhira, which is is located at 22.3306°N 89.1028°E which is an offshore area close to the world's largest mangrove Sundarban in the southwest part of the country (Figure 1).

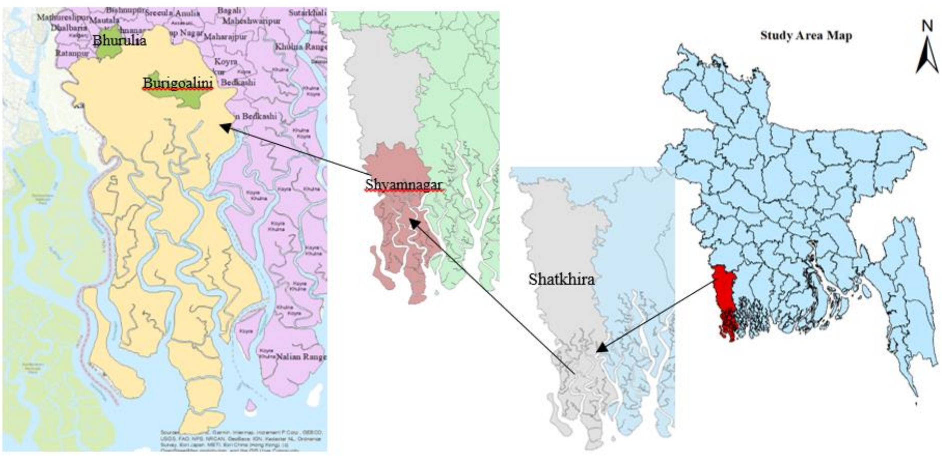



Figure 1: Study area map

It has 46,592 households and a total area of 1968.24 km. Shyamnagar has a population of 318,254 which constitutes 48.21% male and 51.79% female (Population & Housing Census 2011). The main economic activities of the people are shrimp culture, agriculture, and fishing. Due to geographical location, this south-western region is commonly subjected to floods, river erosion, and tidal surge but most importantly cyclones and storm surges (M. M. Rahman et al., 2019). The people in this area are suffering from a shortage of drinking water long after the cyclone Aila in 2009 (M. Rahman et al., 2021). During the cyclone high storm surge inundated almost all the areas and left almost all contaminated freshwater sources with saline.(Suriya Tajrin & Hossain, 2017) Again in the 2020 cyclone, Amphan devastated the area by flooding 21 villages from Shyamnagar and Asasuni Upazila. 57 kilometers of the embankments have been damaged following the cyclone which again leads to salinity intrusion into freshwater bodies. People have been suffering an enduring crisis of drinking water as they rely heavily on surface and groundwater for drinking and other purposes. The freshwater aquifer is rarely available, and the geological condition is not suitable for groundwater development, and shallow tube wells are not operative to supply domestic water in this region. The monsoon rainfall starts earlier in this region by the end of April and continues up to September, and the rainfall is much higher than the average rainfall in the Khulna region. That's why rainwater harvesting is one of the most appropriate supplementary water sources in this region. The study attempts to evaluate the socio-technical performance of existing RWHs in Bhurulia and Burigoalini Unions of Shyamnagar Upazila of Shatkhira district and find out the opportunities and challenges. The unions were selected after observing the existing water scarcity condition through a reconnaissance survey.

## 2.2 Methods

An extensive program for the inspection of existing RWH systems and analysis was undertaken from September 2020 to October 2020 in several locations from Bhurulia and Burigoalini unions in Shyamnagar Upazila. A mixed-method approach was adopted for the assessment, including;

- Reconnaissance Survey
- Development of structured questionnaires
- Translation of questionnaires into Bengali
- Focus group discussion with the users and stakeholders
- Model development
- Data processing and analysis

First of all reconnaissance survey was done to understand the condition of the study area. The objective of the survey was to quickly obtain basic information for developing an understanding of existing rainwater harvestings in the area. It was also conducted to set an outline of the overall study.

The questionnaire survey was conducted among 30 people from 10 different locations of the Bhurulia and Burigoalini union. The selection of respondents was by random cluster method, and different groups of people like fishermen, farmers, van pullers, businessmen, and housewives were interrogated during the questionnaire survey. Focus group discussion was done with 04 different groups from these two unions: small businessmen, housewives, van pullers, and farmers. In some cases, multiple responses were considered during the field interview.

For technical evaluation, a water balance model has been implemented to perform continuous simulation of a rainwater harvesting system. The tank storage capacity is compared with the daily rainfall. In the case when rainfall quantity exceeds the storage tank volume, the extra amount has been subtracted from the stored rainfall volume. For the calculation of catchment area, georeferencing and digitization features of ArcGIS are used. The google co-ordinate system was previously recorded while interviewing people. Roofs are calculated on google earth pro and saved as kml/kmz files. These files are converted as shapefiles while exporting to ArcGIS. 70% of the roof area has been considered as the catchment area. For the development of the model following mass balance equation has been set up:

$$V_t = Q_t + V_{t-1} - Yt - O_t \quad (1)$$

Where $Q_t$ is the inflow, $V_t$ is the harvested rainwater volume, $Y_t$ is the rainwater supply, $D_t$ is the water demand, and $O_t$ is the overflow.

Water storage equation,

$$S_t = V_t + S_{t-1} - D \quad (2)$$

$$If\ S_t < 0,\ S_t = 0 \quad (3)$$

$$If\ S_t > C,\ S_t = C \quad (4)$$

where $S_t$ is the stored rainwater in the tank (L) after the end of $t^{th}$ day, $V_t$ is the volume of rainwater harvested (L) on the $t^{th}$ day, $S_{t-1}$ is the storage volume in the tank (L) at the beginning of the $t^{th}$ day, D is the daily rainwater demand of a family (L), and, C is the capacity of rainwater tank (L).
The water demand has been calculated by the following equation,

$$Dt = Resident\ in\ the\ household * per\ capita\ water\ consumption \quad (5)$$

For simplifying the model, when storage volume is less than zero then it is assumed to be zero. On the other hand, when it exceeds the capacity and eventually overflow occurs, the model assumed that the storage is equal to the capacity.

Overflow Equation:

$$If\ S_t > C;\ OF = S_t - C_t \quad (6)$$

The final performance assessment has been done by three indices; time-based reliability, water-saving efficiency, and overflow ratio.

Reliability is calculated with the equation,

$$Re = N\text{-}U/N \times 100\% \quad (7)$$

Here, Re is the reliability of the tank (%) to be able to supply to meet the demand, U is the number of days when the tank failed to meet the demand, and N is the number of days in a year. Water-Saving Efficiency $E_t$ is defined as the ratio between the volume of rainwater supplied and the water demand during the selected time interval (Dixon et al. 1999).

$$E_t = \frac{\sum_{t=1}^{T} Yt}{\sum_{t=1}^{T} Dt} \quad (8)$$

Where $Y_t$ represents the rainwater quantity (yield) at each time step t, $D_t$ is the water demand, and T is the total time. The rainwater overflow ratio, $O_T$, is the ratio between the volume of rainwater exceeding the tank capacity and the inflow of the rainwater during the selected time interval and is obtained as:

$$O_t = \frac{\sum_{t=1}^{T} Ot}{\sum_{t=1}^{T} Qt} \quad (9)$$

An excel database based on a daily water balance model was developed considering daily rainfall, contributing catchment (roof) area, and storage (tank) volume (Imteaz et al., 2012). Finally, the model calculates daily rainwater use, daily rainwater storage in the tank, daily overflow along with annual reliability, water-saving efficiency, and reliability.

## 2.3 Data

### 2.3.1 Demographic Data

Household size is a function of many variables related to culture, social and economic development, and it is an important criterion for measuring the household condition. In the study area, household size widely varies between 2 to 11 members, with an average household size of 5.68 persons that were comparatively higher than the national average household size. The national average household size in Bangladesh is 5.8 and the urban household size is 4.2 (BSVS, 2018). Among the respondent, 60% were male and 40% were female. 70% of the respondents were poor, 22% were lower-middle class and only 8% were middle class which indicates the economic level of the area. For the well-being of society, education is an important factor. Figure 3 shows that the literacy rate of the study area is quite well. Among the respondents, about 2% of people have never been to school. In the study area, 40% of households are semi Paka (CI sheet roof and brick wall), 38% are of CI sheet roof and wall, and 14% are Paka (Brickwall and concrete roof). Motorcycles, auto-rickshaws, and vans are very familiar types of vehicles used for public transport, and boats are mainly used during the monsoon period.

### 2.3.2 Rainfall Data

The rainfall data used in this study is the normal rainfall data from Bangladesh Meteorological Department (BMD) (Figure 2).

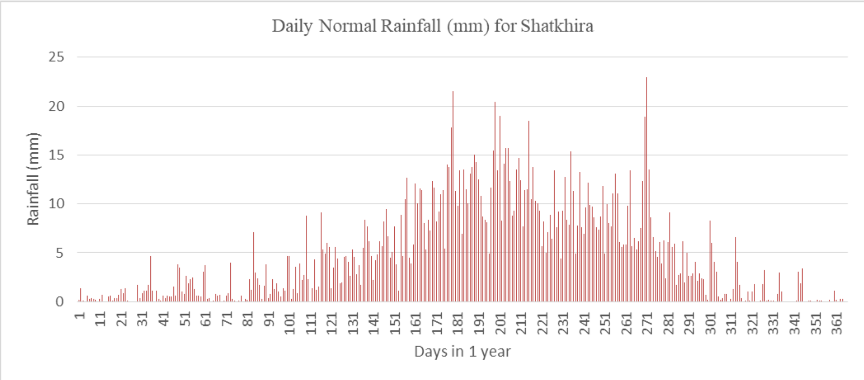



Figure 2: Daily normal rainfall (mm) for Shatkhira

### 2.3.3 Data for Model

From the peoples' reaction, it has been found that people generally use water only for drinking and some people for both drinking and cooking. So the model has been implemented for both cases. For dinking purposes per capita water need has been assumed as 3.53 liter and for drinking and cooking it has been assumed to be 10.24 liter per household (Milton et al., 2006). From the survey average household is nearly 6. The catchment has been calculated by considering the 70% of the existing roof area. From the data 25th and 75th percentile of the catchments have been taken for the calculation which is 331.625 sqft and 456.75 sqft respectively. As maximum roof area was found to be built with CI sheets the runoff coefficient was considered as 0.9 to account for leakage, spilling, and evaporation losses.

## 3. RESULT AND DISCUSSION

### 3.1 Social Assessment

From the social perspective, there is a lot of issues and opportunities regarding rainwater harvesting. The main issue is lack of knowledge which is inadequate and outdated. There is also a lack of acceptance, motivation, and involvement among users. Often the technology used is inadequate to meet the requirements of the region, or else it is too expensive. Moreover, hydrological, topographic, and land use data for the planning, design, and implementation of RWH systems are missing most of the time. Another important social issue is found as the ownership issue. Lack of training and maintenance hindering the acceptance of the rainwater harvestings. From the analysis of exiting RWHs from different perspectives, the strength, weaknesses, opportunities, and threats can be summarized as follows:

| Strength | Weakness |
|---|---|
| ▪ Provide a sustainable source of drinking water<br>▪ Provide water with a relatively better quality<br>▪ Supply water at low cost with minimal investment for the household use<br>▪ Reduce centralization of water distribution<br>▪ Reduce dependence on surface and groundwater<br>▪ Improve water security<br>▪ Allow water for storage | ▪ Absence of proper laws and regulations regarding the implementation<br>▪ High initial cost<br>▪ Highly dependable on rainfall amount<br>▪ The amount and quality of water is dependent on catchment size and material<br>▪ The quality of water may have deteriorated upon storage<br>▪ Treatment and disinfection of water may add extra expenses<br>▪ Ownership problem<br>▪ Lack of training on operation and management |

| Opportunity | Threat |
|---|---|
| ▪ Provides an opportunity to invest at a large scale to supply drinking water at the remote areas of the coastal region<br>▪ Captured water can be used for drinking and domestic purposes<br>▪ Can decrease water scarcity<br>▪ Reduce runoff and non-point source pollution<br>▪ Can reduce flooding | ▪ Expected climate change impact on precipitation<br>▪ Prolong dry periods<br>▪ Inadequate monitoring and management<br>▪ Absence of treatment of captured water<br>▪ Water quality is threatened by the surrounding environment |

## 3.2 Technical Assessment

The technical analysis is based on a daily water balanced equation using daily rainfall and water use data. From the analysis, time-based reliability, water-saving efficiency, and overflow have been calculated for two demand cases and two catchment sizes.

### 3.2.1 Volume Based Assessment

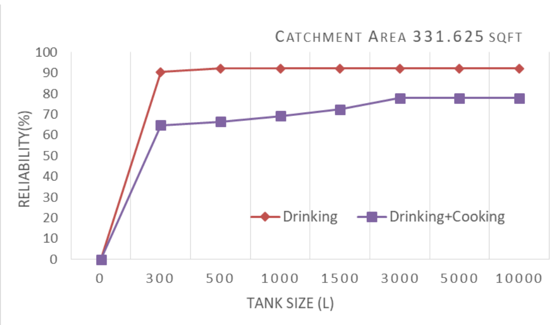



Figure 3: Reliability curves for catchment size of 331.625 ft$^2$ with varying tank size

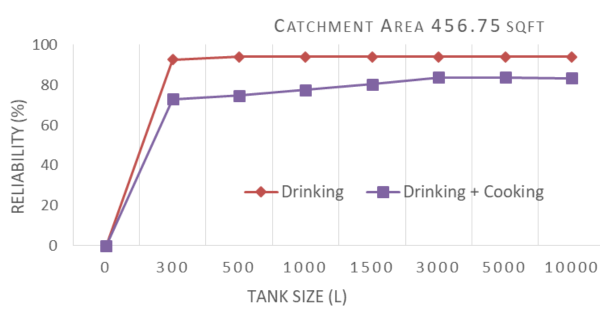



Figure 4: Reliability curves for catchment size of 456.75 ft$^2$ with varying tank size

Figures 3 and 4 show the reliability relationships with the tank sizes and water demand. For both cases, we have found suitable reliability which indicates that rainwater harvesting is a reliable water source in the study area. For drinking purposes, tank size has no significant effect on reliability. Whereas for drinking and cooking purposes reliability increases with the increase of tank size.

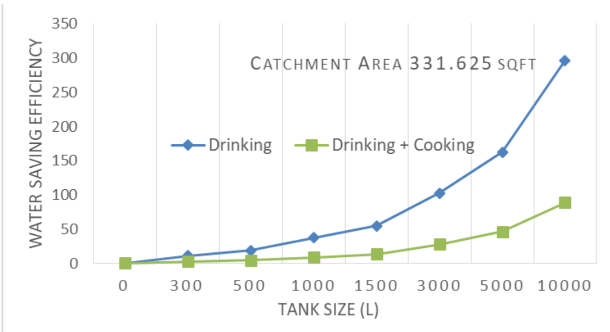



Figure 5: Efficiency curves for catchment size of 331.625 ft$^2$ with varying tank size

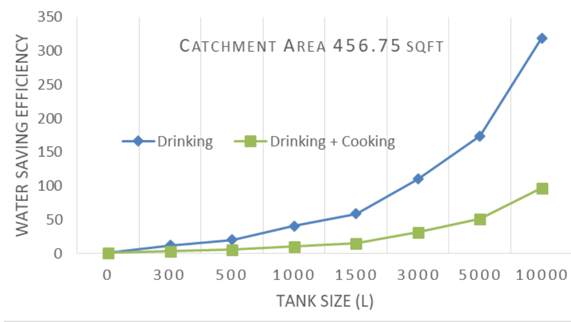



Figure 6: Efficiency curves for catchment size of 456.75 ft$^2$ with varying tank size

Efficiency indicates the supply of rainwater with respect to demand. Figures 5 and 6 show that for both demand cases and both catchments water-saving efficiency increases with the increase of tank size. For only drinking purposes rainwater is found to be more efficient than drinking and cooking purposes.

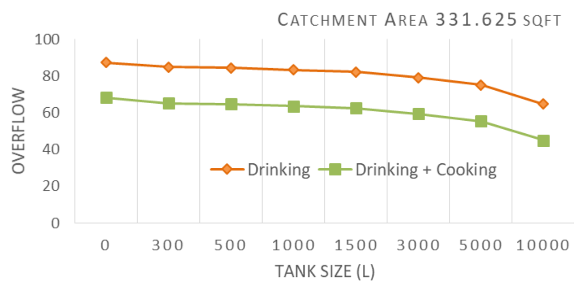



Figure 7: Overflow curves for catchment size of 331.625 ft$^2$ with varying tank size

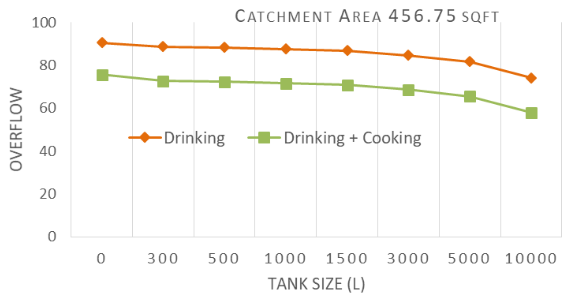
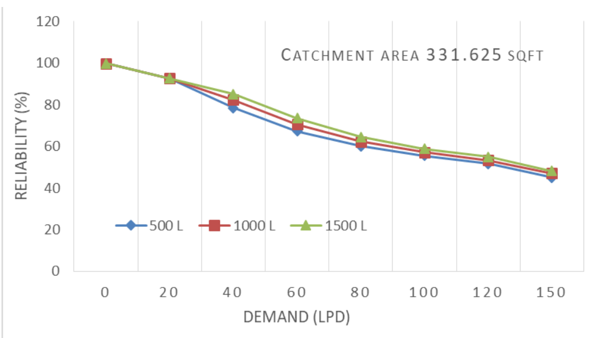



Figure 8: Overflow curves for catchment size of 456.75 ft$^2$ with varying tank size

Figures 7 and 8 shows that overflow depends on tank size. A higher tank size can retain more water which lowers the tendency of overflow.

### 3.2.2 Demand-based Analysis

Another analysis has been done based on the relationship between varying water demand with time-based reliability, water-saving efficiency. It has been done for two catchment areas and three tank sizes. These sizes of tanks are mostly used in the study area.



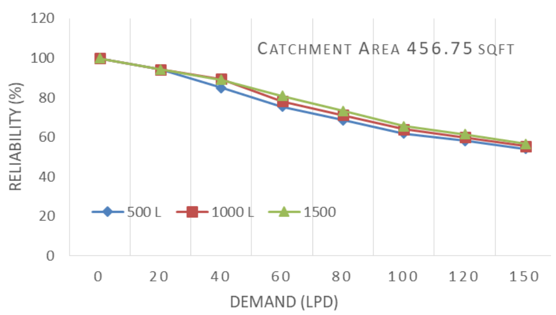



Figure 9: Reliability curves for catchment size of 331.625 ft2 with varying water demand

Figure 10: Reliability curves for catchment size of 456.75 ft2 with varying water demand

From Figures 9 and 10 it has been found that for both cases reliability decreases with increasing water demand. The lower value of reliability is found near 50% and above 50% for 331.625 $ft^2$ and 456.75 $ft^2$ areas respectively. This indicates the water is still sufficient for this area after a remarkable increase in demand.

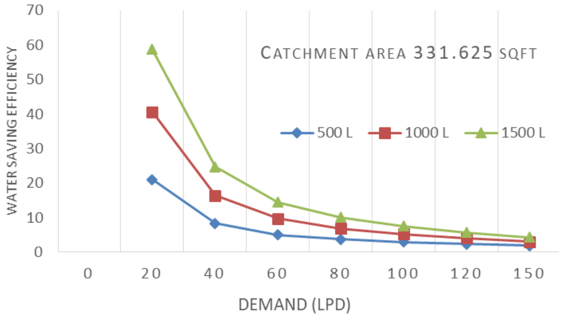



Figure 11: Efficiency curves for catchment size of 331.625 $ft^2$ with varying water demand

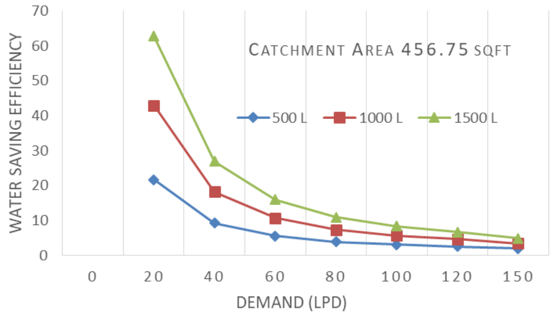



Figure 12: Efficiency curves for catchment size of 456.75 $ft^2$ with varying water demand

Figures 11and 12 shows that for both the catchments for all the tanks water-saving efficiency decreases with increasing demand. In this case, comparatively water saving is more efficient in larger tanks.

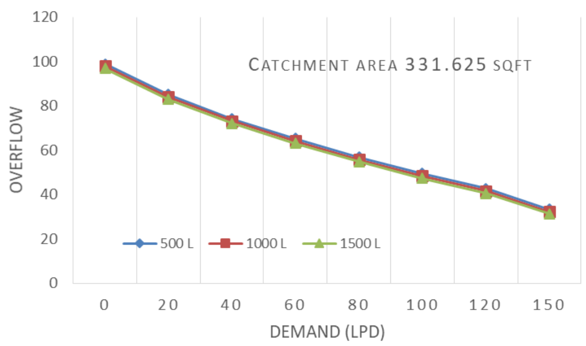



Figure 13: Overflow curves for catchment size of 331.625 $ft^2$ with varying water demand

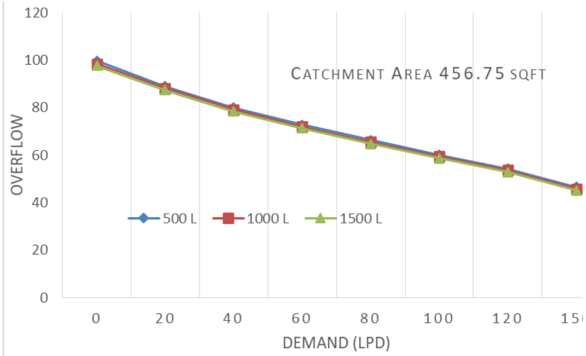



Figure 14: Overflow curves for catchment size of 456.75 $ft^2$ with varying water demand

Figure 13 and 14 shows the relation between overflow and demand. As demand increases water use increases. As a result, overflow decreases.

## 4. CONCLUSION

Rainwater harvesting (RWH) is considered a potential alternative water supply source in the coastal area of Bangladesh. From the technical assessment, it was found to be the most reliable and efficient freshwater source all over the year. It has been capable of meeting demands for drinking and cooking in most cases. For the evaluation of rainwater harvesting a daily water balance model has been implemented which is innovative in calculating daily water inflow, storage, spillage along with annual reliability and water-saving efficiency. The model can be used for different types of catchments for any study area. The present analysis indicates that a maximum of 93.99% reliability for drinking can be achieved if sufficient rainfall is available throughout the year. But there is a significant gap in-tank sizing at the field level. There is no correlation between the demand and tank size which sometimes hinders the success of rainwater harvesting. There were some limitations in our study. That we only considered the 25th and 75th percentile values of the catchments found. We did not show the scenarios when the catchment will exceed this limit. Water demand varies depending upon the type of the building, as this research is mainly concerned with the residential buildings it did not discuss the reliability of rainwater harvesting systems in the buildings which are used for different purposes like school, college, mosques, etc. For the successful implementation of rainwater harvesting tank size as well as the catchment area should be designed considering the total water demand of the consumers. From the social perspective, there are many issues against the successive implementation of rainwater harvestings. Among various issues, ignorance, lack of training, indifference, and ownership are the main. In the emerging water crisis in areas where considerable rain is available, rainwater harvesting is the next option as a source of water, especially in coastal areas. Promoting rainwater harvesting in water-scarce areas needs both policy and technological support. Local government and concerning stakeholders need to be more concerned to provide necessary supports to ensure the sustainability of rainwater harvestings.

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