Acceptability of the rainwater harvesting system to the slum dwellers of Dhaka City

M. M. Islam, F. N.-F. Chou and M. R. Kabir

ABSTRACT

Urban area like Dhaka City, in Bangladesh, has scarcity of safe drinking water which is one of the prominent basic needs for human kind. This study explored the acceptability of harvested rainwater in a densely populated city like Dhaka, using a simple and low cost technology. A total of 200 random people from four slums of water-scarce Dhaka City were surveyed to determine the dwellers’ perception on rainwater and its acceptability as a source of drinking water. The questionnaire was aimed at finding the socio-economic condition and the information on family housing, sanitation, health, existing water supply condition, knowledge about rainwater, willingness to accept rainwater as a drinking source etc. A Yield before Spillage (YBS) model was developed to know the actual rainwater availability and storage conditions which were used to justify the effective tank size. Cost-benefit analysis and feasibility analysis were performed using the survey results and the research findings. The survey result and overall study found that the low cost rainwater harvesting technique was acceptable to the slum dwellers as only the potential alternative source of safe drinking water.

Key words | cost-benefit analysis, feasibility analysis, low cost technology, YBS model

INTRODUCTION

Bangladesh is a tropical country and it is situated between latitude 20°34’ to 26°38’N and longitude 88°01’ to 92°41’E. The country experiences heavy rainfall during the monsoon, generally varying between 150 cm and 350 cm annually. But Dhaka City (capital of Bangladesh) averages nearly 220 cm rainfall per year. Monsoon usually lasts from May to October and there is occasional rainfall also in November. Thus, during this period it gets ample rainwater, which could reduce the dependency on groundwater at least for six months during monsoon. It is revealed from the literature that about 15% of the total supply can be met by harvested rainwater. For the densely populated area like Dhaka, where the population density is increasing day by day, it is not feasible to use the groundwater for long term because the groundwater table is depleting every year. The present rate of depletion is alarming because it can potentially cause environmental hazards such as land subsidence, prolonged waterlogging, alteration in vegetation etc (Kabbour & Zouhri 2005; Karami & Hayati 2005). Hence, it is necessary to alleviate the demand on the upper aquifers and explore more sustainable sources to augment the present water supply. So, there is an urgent need to supplement the ground water source.

The Dhaka Water Supply and Sewerage Authority (DWASA)—a government entity entrusted with supply of piped water in the Dhaka Metropolitan and its peripheral areas has water supply coverage of 75%, out of which 83% is derived from groundwater sources. The remaining 17% of the water is supplied from the surface water bodies comprising the peripheral rivers around Dhaka City which is treated by water treatment plants before entering the distribution system (Rahman & Hossain 2008). It now supplies 1.51 billion litres of water to 12.5 million residents. But average demand of water in the city is 2.1 billion litres...
a day, forecast to climb to 2.7 billion litres a day by 2010 (Asia Water Wire 2005). Dhaka is facing a water shortage of about 500 million litres per day (mld) and needs over 25% of the existing demand. This shortage will hit 1.500 mld in 2015, if no action is taken now (Asia Water Wire 2005). One potential solution is the use of rainwater to reduce the shortage of safe drinking, cooking and dishwashing purposes (Islam 2001). Theoretically, 20% of the total rainfall might satisfy almost the whole of the Dhaka City's demand, collected during the monsoon (Kabir & Faisal 1999). The main objective of the study is to develop low cost rainwater harvesting in Dhaka City and to assess its acceptability to the slum dwellers.

MATERIALS AND METHODS

Description of the study area

A slum is a densely populated area of substandard housing, usually in a city, characterized by unsanitary conditions and social disorganization. Four slums of Dhaka City were selected to conduct a questionnaire survey to get the dwellers' willingness towards the rainwater harvesting system (RWHS). For comparative study, Kathalbagan and Nakhalpara from new part of Dhaka, Rahmatganj and Namapara from the old part of Dhaka City were selected. These wards were situated within ward nos. 8, 48, 16 and 30 respectively. Short descriptions of those areas are given below.

Kathalbagan slum

Kathalbagan is located adjacent to an upper-class residential area of New Dhaka. Free School Street (south) and Crescent road enclose this area. The houses are built on high land that is surrounded by low land in the North-East. The other two sides are attached with high and middle class residential areas and commercial shopping establishments.

Nakhalpara slum

It is located at the northern side and 1.5 km away from the light industrial area of new part of the city. A railway lines pass through Nakhalpara. It is mainly a mixed area.

Rahmatganj slum

Rahmatganj is situated in a most important part of old Dhaka that is the most congested with the complex range of settlement patterns. It is located near a depressed land filled with vast collection area. Water works road, Rahmatganj road and playground enclose this area.

Namapara slum

Namapara is one of the two sample areas located in old part of the city. The location is about 4 km from Sutrapur thana and opposite to Dupkhola maidan. The slum is located on slope land surface with frequent undulation which causes water pressure to be lowered in places reducing the supply of water.

Questionnaire formulation

To fulfill the objectives of the study, a questionnaire was formulated which was divided into two major parts. The first part was designed to identify the household information, housing, sanitation, health facilities, ownership of slums etc. and the second part was to identify the existing water supply, bottleneck of the existing system, water demand, present water tariff rate, knowledge on rainwater harvesting system and acceptability of rainwater harvesting technique etc. The questionnaire was structured and recorded as multiple choice answers.

Sampling procedure of the questionnaire survey

After selecting the survey areas, a household survey was conducted as a case study. The number of households in the survey areas Kathalbagan, Nakhalpara, Rahmatganj and Namapara were 85, 120, 200 and 100 respectively. Around 40% of the households from the survey areas were selected for field survey. Based on the household survey, sample households accounted for Kathalbagan 35, Nakhalpara 55, Rahmatganj 70 and Namapara (Sharafatganj) 40. All together 200 households were randomly selected to get the answer of the questionnaire carefully and efficiently. The overall acceptability was analyzed from this survey.
Tank size design according to the actual water demand

From the survey, the actual water demand for drinking, cooking and dishwashing was revealed for the slum dwellers. To provide the economic and effective size of the rainwater harvesting tank for the slum dwellers, YBS model (water release rule) using spreadsheet was developed. The YBS rule assumes that the demand should be used before the spillage is occurred. The operation principles of YBS can be illustrated mathematically as,

\[
Y_t = \min\left\{ \frac{D_t}{S_{t-1} + Q_t} \right\}
\]

(1)

\[
S_t = \min\left\{ \frac{S_{t-1} + Q_t - Y_t}{C_a} \right\}
\]

(2)

where, \(D_t\) is water demand at time \(t\); \(S_{t-1}\) is storage at the beginning of the \(t-1\)th time period; \(S_t\) is storage at the beginning of the \(t\)th time period; \(Q_t\) is inflow during the \(t\)th time period; \(Y_t\) is release during the \(t\)th time period; and \(C_a\) is storage capacity. Mitchell (2007) has provided the detailed explanation of the YBS model. Liaw & Tsi (2004) invented that for a small size storage tank, the YBS model is more effective. This model was used to determine the required capacity of the tank which can satisfy a given demand. The catchment area 20 sq m, everyday demand 0.026 m³, the runoff coefficient 0.85, initial losses 0.002 m³ were used in the simulation. The rainfall data of year 2004 were used in the simulation because the rainfall of this year was equivalent to the average rainfall of Dhaka City. A lot of simulations were performed using different sizes of tanks and finally revealed a size which can provide rainwater throughout a year (365 days) to a family having 5 members.

Cost analysis

Cost effectiveness analysis was performed using different water demands and corresponding sizes of the storage tanks for different purposes such as (i) drinking, (ii) drinking and cooking, (iii) drinking, cooking and dishwashing. Based on the market price, the cost effectiveness of optimum size of the constructed (ferro-cement) tank was also analyzed in comparison to plastic and GI tanks. Materials and costing of gutters and flushing device, materials and costing of storage tanks were analyzed considering market price and determined the low cost storage tank for the study. Cost effectiveness analysis on the existing water supply system (DWASA) and the rainwater harvesting system was analyzed to compare the unit production cost between the two systems.

Feasibility analysis

The feasibility analysis of the study was also performed using environmental, technical, economic and social considerations.

RESULTS AND DISCUSSION

Questionnaire survey findings for acceptability of the system

A questionnaire survey was conducted to get people’s perception about the DWASA, the rainwater harvesting system and the willingness towards the rainwater harvesting system. The survey had found some difficulties on the DWASA such as inadequate supply, uncertainty due to the electricity failure, inferior quality water (color and smell) and long queue (wastage of time). So, they were not satisfied with the DWASA. The study also had revealed that 46.5% of dwellers were moderately satisfied and 42.5% of people were not satisfied with the DWASA. A few important survey findings are described below step by step.

A question was furnished to know the average family size of the selected slums. The survey results were analyzed and found that the families having five members are higher than others which is shown in Figure 1 and it was about...
41%. Only at Kathalbagan area found that four member families has the higher percentage and it was about 43%. The four member family was the average second highest (24%) and more than five member families were third highest. So, the calculated volume of water demand considering a family having 5 members was justified.

A question was set to know about the roof structures which could be used as catchment. The survey study found that four slums have the mostly corrugated iron (tin) roofing as is shown in Figure 2. A total of 81.05% roof material was tin which was suitable to use as a catchment to collect rainwater. But the condition of the tin was very poor, there was lots of rust on the tin and some places used color to prevent rust which was not suitable to collect the rainwater. Because this poor condition of the color and rust on the tin the quality of the collected rainwater would be impaired. On the basis of the roofing condition, a non-toxic waterproof cloth was suggested to use as catchment to collect the rainwater in these areas. The survey studies also found that majority of the families did not have enough blank space to install the rainwater harvesting tank.

The minimum water requirements for different water usage components like drinking, cooking and dishwashing were collected from the survey. The water requirements are shown in Figure 3. From the figure it is apparent that all of the requirements are higher in the Kathalbagan area than the others. From the results it was found that the total water requirement for drinking, cooking and dishwashing was 9.89 m³/year/family for Kathalbagan area which was the highest water demand. On the other hand, the Rahmatganj slum was found to be the least water 8.76 m³/year/family consumed area. From the figure, it is also evident that water requirement increased linearly with different water use components.

A lot of simulations were performed using different sizes of tanks and finally revealed that 4.8 m³ tank can provide rainwater throughout a year to a family having 5 members. The final simulation results are shown in Figure 4. The upper part of the figure indicates the effective rainfall volume of the simulation and it was 39.75 m³ where as the total demand for a year was 9.52 m³. The middle part of the figure shows the overflow condition of the simulation. A total of 29–75 m³ rainwater was overflowed which was about three times higher than that of the total demand. From the effective rain volume and overflow volume it was found that the total rainwater available was 10.00 m³ which was more than that of the total demand for a year. The lower part of the figure shows the final rainwater storage condition in the storage tank. The dotted line shows the maximum tank capacity and the stepped solid line is the water storage condition. From the storage condition part, it is found that after about 97 days the rainwater started to store in the tank. But at the end of the year, it is found that 2.77 m³ of rainwater remained in the tank. This volume of water can satisfy the demand up to 106 days. Therefore, it is revealed that this tank can satisfy one year demand effectively.

Another question was placed in the questionnaire to get the dwellers’ perception about the DWASA’s water tariff rate (cost/unit volume) and the analyzed results are shown in Figure 5. The options to get the dwellers’ opinion about the tariff rates were: very high (if the rate > 0.25 BDT/l), high (if the rate 0.15–0.25 BDT/l), normal (if the rate 0.05–0.15 BDT/l) and no response. While 54% of dwellers from the Kathalbagan slum opined...
that the DWASA’s water tariff rate was normal, the majority dwellers from the remaining areas adjudged this to be high. The overall result revealed that 45% of the dwellers were not satisfied by the DWASA because the water tariff rate was too high.

A supplementary descriptive question was used to know their opinion about the incentives from the government and mode of repayment for the rainwater harvesting system. They mentioned that they were willing to pay extra money for a safe drinking water system. They explained that sometimes they suffered from water-borne diseases when drinking the existing supply water, if they don’t boil it which also costs extra money. So, the dwellers would accept the rainwater system easily if the government would provide them the installation cost amounting to BDT 12,000 for each unit without any interest. The dwellers would repay the money to the government within 5 years on a monthly basis. Some of the dwellers opined that it would be easier for them to set up the system if they got 50% of installation cost as incentive from the government.

Table 1 describes about the amount of money, the dwellers were willing to pay to use the rainwater harvesting system. It was found that the highest number, i.e. 42.5% of dwellers, from Namapara were willing to pay BDT 300/month, where as the second highest number (42.14%) from Kathalbagan were agreed for the same amount. From the table, it was revealed that total 38.61% people from the four selected slums were interested to pay BDT 300/month, if they could get the rainwater harvesting system to use it as a safe drinking water.

The overall acceptability of the rainwater harvesting system to the dwellers were reviewed and presented in
The options to get dwellers’ opinions were: don’t accept, small acceptance, moderate acceptance, high acceptance, complete acceptance and no response. It is seen from the table, most dwellers from all slums opined that the rainwater harvesting system was acceptable to them and the acceptance level was moderate. The highest about 58% of dwellers from the Nakhalpara slum mentioned that the system was moderately acceptable to them and they were interested to use the rainwater harvesting system. The overall acceptable level was within moderate (52.5%) range over the study areas. Only a 7.5% of the slum dwellers opined that the system was completely acceptable to them.

**Cost effectiveness analysis**

The main objective of this study was to provide a low cost rainwater harvesting system which would be easily acceptable to the Dhaka City slum dwellers. Costing of the materials of gutters and first flush and the costing of the materials of the storage tank were analyzed to determine the low cost technology. The cost of rainwater harvesting system and the DWASA were compared as well to identify the economic system. The analyzed results are described below.

Gutters and first flush system made from four materials - bamboo, wood, PVC and GI pipe - were available in the market. The prices of the first flush systems for different materials were: BDT 420 for bamboo, BDT 1,050 for wood, BDT 1,240 for PVC and BDT 5,300 for G.I. pipe. Considering the durability, availability and economic life, the PVC made first flush was regarded as effective for the slum dwellers.

**Materials and costing of storage tanks**

Considering the literature review, Table 3 was furnished on the basis of the present market prices for different materials for storage tank which were readily available in the market. From the table it is revealed that the unit cost of the plastic tank is the highest BDT 6,000 among the four materials. On the other hand, the unit cost of the cement jar tank is BDT 1,950 which is the lowest one, provided that the tank size should be constructed at least 5 m$^3$. Considering the unit cost of production, economic life of the tank, simplicity in construction, and space availability in the selected slums, the ferro-cement molded tank was found to be a low cost technology for the slum dwellers of Dhaka City.

**Table 1 | Willing to pay for rainwater**

<table>
<thead>
<tr>
<th>Study area</th>
<th>BDT per month/family</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Kathalbagan (%)</td>
</tr>
<tr>
<td>0–100</td>
<td>9.29</td>
</tr>
<tr>
<td>101–200</td>
<td>20</td>
</tr>
<tr>
<td>201–300</td>
<td>42.14</td>
</tr>
<tr>
<td>301–400</td>
<td>11.43</td>
</tr>
<tr>
<td>401–500</td>
<td>2.86</td>
</tr>
<tr>
<td>&gt;500</td>
<td>–</td>
</tr>
<tr>
<td>N/A</td>
<td>14.29</td>
</tr>
<tr>
<td>NR</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
</tr>
</tbody>
</table>
To get the clear picture about the cost analysis, a cost comparison had been performed between rainwater harvesting system and the DWASA. The costing included the total construction and the repair & maintenance cost for 20 years of the rainwater harvesting system. In case of the DWASA, only the monthly water consumption cost was used for 20 years and no any construction or repair & maintenance cost was added.

Table 3 indicates that the construction cost for the rainwater harvesting system was BDT 12,000 which was found for ferro-cement tanks having capacity of 4.8 m³ for a family consisting of five members. The economic life was considered to be 20 years for the tank and the annual repair & maintenance cost was BDT 200. The cost of first flush and gutter system (for PVC) was BDT 1,240. The total cost for the rainwater system was BDT 17,040, annual payment was BDT 852 and the water cost was BDT 0.089/litre. On the other hand, DWASA water tariff rate was BDT 0.15–0.25/litre. Considering the same 20 years, the annual payment was calculated as BDT 1,424. The annual payment for the DWASA was 1.6 times higher than that of the rainwater harvesting system.

Figure 6 indicates that the first year’s cost involvement is much higher for the rainwater harvesting system than that of the DWASA. But the annual payment is higher for the DWASA than that of the rainwater system. It needs only a small amount of money each year for chlorination and repair & maintenance purposes after construction of the storage tank which the dwellers could be done by themselves. The figure also illustrates that the cumulative cost increase rate is higher for the DWASA than that of the rainwater harvesting system.

It is clear from the above illustration that the cost-benefit analysis based on construction cost, repair & maintenance cost, water use rate, etc. was financially feasible for rainwater harvesting system. Therefore, rainwater harvesting system would definitely be more economically feasible when health, safety and life benefits would be included. However, these factors were not quantified in terms of money in present study.

### Table 2: Overall acceptability of rainwater harvesting system

<table>
<thead>
<tr>
<th>Location</th>
<th>No (%)</th>
<th>Small (%)</th>
<th>Moderate (%)</th>
<th>High (%)</th>
<th>Complete (%)</th>
<th>No res (%)</th>
<th>Total (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kathalbagan</td>
<td>2.86</td>
<td>20</td>
<td>42.86</td>
<td>14.29</td>
<td>5.71</td>
<td>14.29</td>
<td>100</td>
</tr>
<tr>
<td>Nahkhalpara</td>
<td>–</td>
<td>25.45</td>
<td>58.18</td>
<td>7.27</td>
<td>5.45</td>
<td>3.64</td>
<td>100</td>
</tr>
<tr>
<td>Rahmatganj</td>
<td>5.71</td>
<td>15.71</td>
<td>55.71</td>
<td>8.57</td>
<td>8.57</td>
<td>5.71</td>
<td>100</td>
</tr>
<tr>
<td>Namapara</td>
<td>7.5</td>
<td>17.5</td>
<td>42.5</td>
<td>12.5</td>
<td>10</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>4</td>
<td>19.5</td>
<td>52.5</td>
<td>10</td>
<td>7.5</td>
<td>7.5</td>
<td>100</td>
</tr>
</tbody>
</table>

### Table 3: Costing of storage tank considering present market price and construction cost

<table>
<thead>
<tr>
<th>Materials</th>
<th>Capacity (m³)</th>
<th>Total cost (BDT)</th>
<th>Unit cost (BDT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrocement molded tank</td>
<td>4.8</td>
<td>12,000</td>
<td>2,500</td>
</tr>
<tr>
<td>Ferrocement wire framed tank</td>
<td>10</td>
<td>20,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Ferrocement bamboo reinforced tank</td>
<td>4.5</td>
<td>10,350</td>
<td>2,300</td>
</tr>
<tr>
<td>Cement jars</td>
<td>2.0</td>
<td>4,200</td>
<td>2,100</td>
</tr>
<tr>
<td>Cement ring tank</td>
<td>5.0</td>
<td>9,750</td>
<td>1,950</td>
</tr>
<tr>
<td>Brick reinforced tank</td>
<td>5.0</td>
<td>19,500</td>
<td>3,900</td>
</tr>
<tr>
<td>Steel sheet tank</td>
<td>3.2</td>
<td>11,000</td>
<td>3,438</td>
</tr>
<tr>
<td>Steel sheet tank</td>
<td>5.0</td>
<td>15,000</td>
<td>3,000</td>
</tr>
<tr>
<td>Plastic tank</td>
<td>1.0</td>
<td>6,000</td>
<td>6,000</td>
</tr>
</tbody>
</table>

*68.5 Tk = 1 US $.
Feasibility analysis

Technical

The initial consideration of the feasibility of rainwater harvesting system concerned water availability as compared to its use or demand. The supply of the system depends on how much rainfall occurs during the year and the variability of rainfall. The demand imposed on the system depends on water use. If the supply exceeds the demand, then the rainwater harvesting system is feasible from a technical point of view (UNDP-World Bank 1990). From Figure 4, it was clear that on an average supply (10.00 m$^3$/year) exceeded the demand (9.52 m$^3$/year) for all slums. Besides, a large volume of water (29.75 m$^3$/year) overflowed from the system, a small part of which could be used by taking special measure. Hence, the rainwater harvesting system was found technically feasible.

Economical

From Table 3, it was revealed that the construction cost of ferro-cement tank having capacity of 4.8 m$^3$ was BDT 12,000, whereas the per capita annual income in Bangladesh is BDT 47,375 or US$ 690 (BBS, as of May 2009). Clearly, up front payment in cash for a tank would be a major problem for lower income groups but still they are interested to use rainwater. The economic life of a ferro-cement tank is 20 years (UNDP-World Bank 1990). From the cost effective analysis, it was found that the cost of rainwater was BDT 0.089/litre whereas DWASA’s water tariff rate was BDT 0.15–0.25/litre. As a result, the rainwater was found more economic.

Social

Bangladesh Rural Advancement Committee (BRAC) constructed two types of rainwater harvester in Sonargaon and Jhikargachha areas of Bangladesh. It was observed that although people were happy with the quality of rainwater but the cost was prohibitive. Also in every case, the rainwater harvester was used by more than one family, so, the stored rainwater only lasted for a limited period (maximum one month), not long enough to cover the full dry period (BRAC 2000). Study made it clear that even with the problem of managing the utilization of rainwater effectively; people of those areas accepted the system which reflected the social feasibility of the system.

Considering the above mentioned three constraints, it was clear that rainwater harvesting system was feasible in the context of slum dwellers of Dhaka City.

CONCLUSIONS AND RECOMMENDATIONS

From this study, it was apparent that the rainwater harvesting would be a very useful, cost effective, safe and acceptable, and might be very potential alternative water source for water-scarce Dhaka City. The slum dwellers were very much interested to get the system if they get some government incentives because the initial installment cost was high compared to their income. They were not satisfied on the DWASA because the quality of water was not always good and they were facing a lot of problems to collect the water. Almost every time they need to boil the DWASA’s water which costs extra money. Otherwise they have to suffer from different water-borne diseases. The dwellers were willing to accept the rainwater as an alternative source of safe drinking water because the quality of this water was acceptable in Dhaka City areas. The dwellers had some previous knowledge about the quality and safety of rainwater for drinking purpose and they were interested to pay extra money for it. The dwellers opined that they would be able to repay the construction cost of rainwater storage tank.

Figure 6  Cost comparison between rainwater system and DWASA.
within 4–5 years as monthly installments, if they get the money from the Government.

The groundwater table of Dhaka City is depleting at an alarming rate. So, rainwater is only the alternate potential source of safe drinking water for the dwellers of Dhaka City. To make this source available to the dwellers, Government needs to impose some rules, create awareness about the safety of RWHS through mass media campaign. A lot of NGO's are now working throughout Bangladesh and Government should introduce a website collecting all the related updated sporadic information from different working groups and make readily available to the inhabitants. A different and independent department could be set up using different ministries and divisions. The department would include research and innovation division to find out the proper implementation mechanism of the rainwater harvesting system.

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