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Research Paper

Factors affecting the performance of household rainwater harvesting systems in the south-western coastal region of Bangladesh

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ABSTRACT

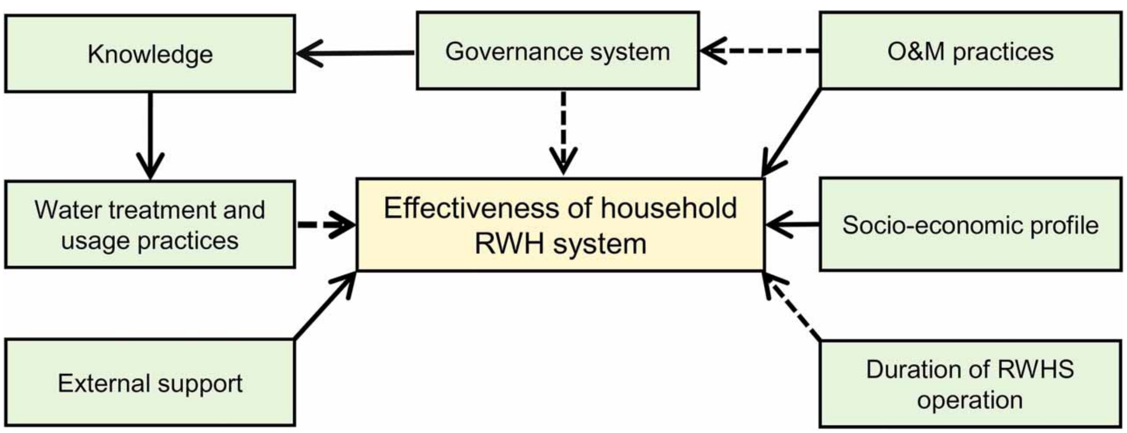
This study aims to evaluate the post-installation performance of household (HH) rainwater harvesting (RWH) systems in the southwestern coastal region of Bangladesh. A conceptual framework for evaluating the effectiveness of RWH systems was developed based on seven determinants. An application of multivariable logistic regression showed that family size, monthly income, the practice of tank and downpipe cleaning, and the organizations supporting the installation were the most significant parameters ($p < 0.05$) affecting the effectiveness of the RWH systems. A family size of 1–4 has higher odds of having a properly functioning system (adjusted odds ratio (AOR) = 28.3; 95% confidence interval (CI) = 4.8–167.7) than a family of 9 or more. The practice of tank cleaning once per year (AOR = 3.3; 95% CI = 1.2–9.1) and downpipe cleaning more than 3 times/year (AOR = 9.7; 95% CI = 1.5–62.5) had higher odds than HHs practicing no cleaning at all. RWH systems installed by institutions other than the Department of Public Health Engineering, and NGOs had higher odds (AOR = 22.0; 95% CI = 2.3–213.0) compared to systems installed on their own. This study provides clues to strengthening the existing RWHS intervention programs in the water-challenged regions of Bangladesh.

Key words: adjusted odds ratio, logistic regression, operation and maintenance, rainwater harvesting system

HIGHLIGHTS

- A conceptual framework for evaluating the effectiveness of household rainwater harvesting systems was developed.
- The post-installation performance of RWH systems was evaluated.
- Parameters that significantly affected effectiveness were identified using statistical methods.
- This study provides clues to strengthening the existing RWH intervention programs in the water-challenged regions of Bangladesh.

GRAPHICAL ABSTRACT



1. INTRODUCTION

The struggle for drinking water in coastal areas of Bangladesh is well documented, with the most acute crisis occurring in the southwestern coastal regions, particularly the Khulna and Satkhira districts (Haq & Alum 2017). People in these regions experience an extreme shortage of drinking water because suitable freshwater aquifers at reasonable depths are not available, and the surface water is highly saline and turbid (Islam *et al.* 2011a, 2015). Rainwater harvesting (RWH) is considered one of the alternate options for drinking water in coastal and arsenic-affected areas where existing ground and surface water sources are contaminated or the water supply system is inadequate to meet demand (Igbinosa & Aighewi 2017; Ahmed *et al.* 2018). Rooftop RWH at the household (HH) level is increasingly promoted worldwide to reduce the number of people lacking improved water supply (UNEP 2009). As Bangladesh is a tropical country, it receives high seasonal rainfall, with an average annual rainfall of around 2,400 mm in most parts of the country (Ahmed 1999). Rainfall in the coastal areas is much higher than the country's average rainfall, with the availability of suitable roof catchments and construction materials making RWH more reliable in these regions (GOB 2002; Karim 2010a).

During the last few years, the Department of Public Health Engineering (DPHE) has undertaken several interventions through various projects to promote RWH systems, community-based RWH systems, and pond sand filter (PSF) both in the coastal and arsenic-affected areas in the country to augment the drinking water supply. Besides these, NGOs and other donor agencies have been actively promoting RWH through several programs.

The capacity of RWH tanks provided by the Government or donor agencies was 500–5,000 L (Karim 2010b; Karim *et al.* 2015a). However, family size and water demand, catchment types, and rainfall quantity were not accounted for in prescribing these tanks, so HHs probably cannot meet their yearlong demand. Most HHs could avail water from rainwater tanks for about 8 months, and for the rest of the year, people generally use other unreliable and often unsafe (due to microbial and chemical contamination) distant sources like pond water, tube wells, and PSF during the dry season (Karim *et al.* 2015a). Women are affected most during those dry periods since they are traditionally responsible for collecting water from such sources. Carrying water over large distances and in-house storage can also introduce pathogens if proper precautions are not taken. HH treatment can improve the quality of water, especially for drinking purposes. HHs often do not have proper knowledge about in-house water treatment methods. Planning for the effectiveness of water supply in rural coastal Bangladesh requires a proper in-depth understanding of the existing HH rainwater consumption patterns and treatment practices (Islam *et al.* 2013; Karim *et al.* 2015b).

RWH can be an attractive drinking water supply system, but potential health risk factors, such as microbial and chemical contamination, cannot be ignored (Simmons *et al.* 2001; Chang *et al.* 2004; Zhu *et al.* 2004). The performance of the RWH system depends on numerous factors. The effectiveness of RWH systems hinges on factors such as supplying water free from microbial contamination, having good taste, and being adequate in quantity all year round (Ravenscroft *et al.* 2014). The lack of knowledge about proper materials, rainwater collection, conveyance systems, and storage reservoirs can potentially decelerate the adoption of RWH in water-challenged areas (Lye 2009; Ward *et al.* 2010; Islam *et al.* 2013).

While RWH remains a popular option for potable use in HHs in southwestern coastal regions in Bangladesh, sustainable operation and maintenance of the infrastructure is a great challenge. A study found that around 24% of RWH systems remained non-functional due to a lack of proper maintenance (Ravenscroft *et al.* 2014). Regular cleaning of the tank, gutters, downpipes, and rooftop is not done properly by the HH often due to the absence of well-defined protocols or lack of awareness (Haq & Alum 2017). Since RWH is a decentralized water supply option, it is difficult for the DPHE to set up an institutional operation and maintenance (O&M) and surveillance service, and the successful operation depends practically on the HH.

Previous studies regarding harvested rainwater in the southwestern coastal region of Bangladesh have focused on the drinking water quality at primary schools (Islam *et al.* 2019), potable water scarcity issues (Islam *et al.* 2013), drinking water quality at the HH level (Karim 2010a; Islam *et al.* 2011b), people's perception and acceptance of RWH (Karim *et al.* 2005), and estimating the water collection potential (Yusuf 1999). But very few of them have considered the performance of existing RWH systems and explored its linkages with operation and maintenance, financing and governance, and social acceptance. The objectives of this study are (i) to explore the performance of existing HH RWH systems in relation to HH water consumption behavior, socio-economic factors, and operation and maintenance practices and (ii) to understand the various linkages of RWH performance with such factors in the southwestern coastal region.

2. METHODS

2.1. Study area

A survey was conducted in randomly selected HHs using an RWH system in the southwestern coastal areas of Bangladesh. The study area included Dacope, Paikgachha, Batiaghata, Dumuria Upazilas (sub-district) of Khulna district, and Kaliganj, Shyamnagar, Assasuni, Upazilas (sub-district) of Satkhira district (Figure 1). Geographically, this area extends from 21°0′N to 22°20′N latitude and 88°59′E to 89°32′E longitude, and the average elevation is less than 10 m above mean sea level. The area has a humid climate with three distinct seasons: pre-monsoon (March to June), monsoon (July to October), and post-monsoon (November to February). This region's mean annual rainfall varies between 1,500 and 2,000 mm, with about 70% of the rainfall occurring in the monsoon season (Kabir *et al.* 2016).

2.2. Sampling and data collection

A female from each HH (responsible for collecting HH drinking water) was the primary participant in the survey. Sometimes female participants were unwilling to participate in the interview due to shyness or fear of providing wrong information. In such a situation, data were collected from a male family member in the presence of the female participant. The HHs were randomly sampled from approximately 200 villages in the study area. When any HH member refused to participate, the nearest house having an RWH system was considered. The total sample size was 300. A list of HHs using RWH in the study area, obtained from the DPHE, was used to guide the surveyor. Data were collected using a questionnaire survey and an on-spot

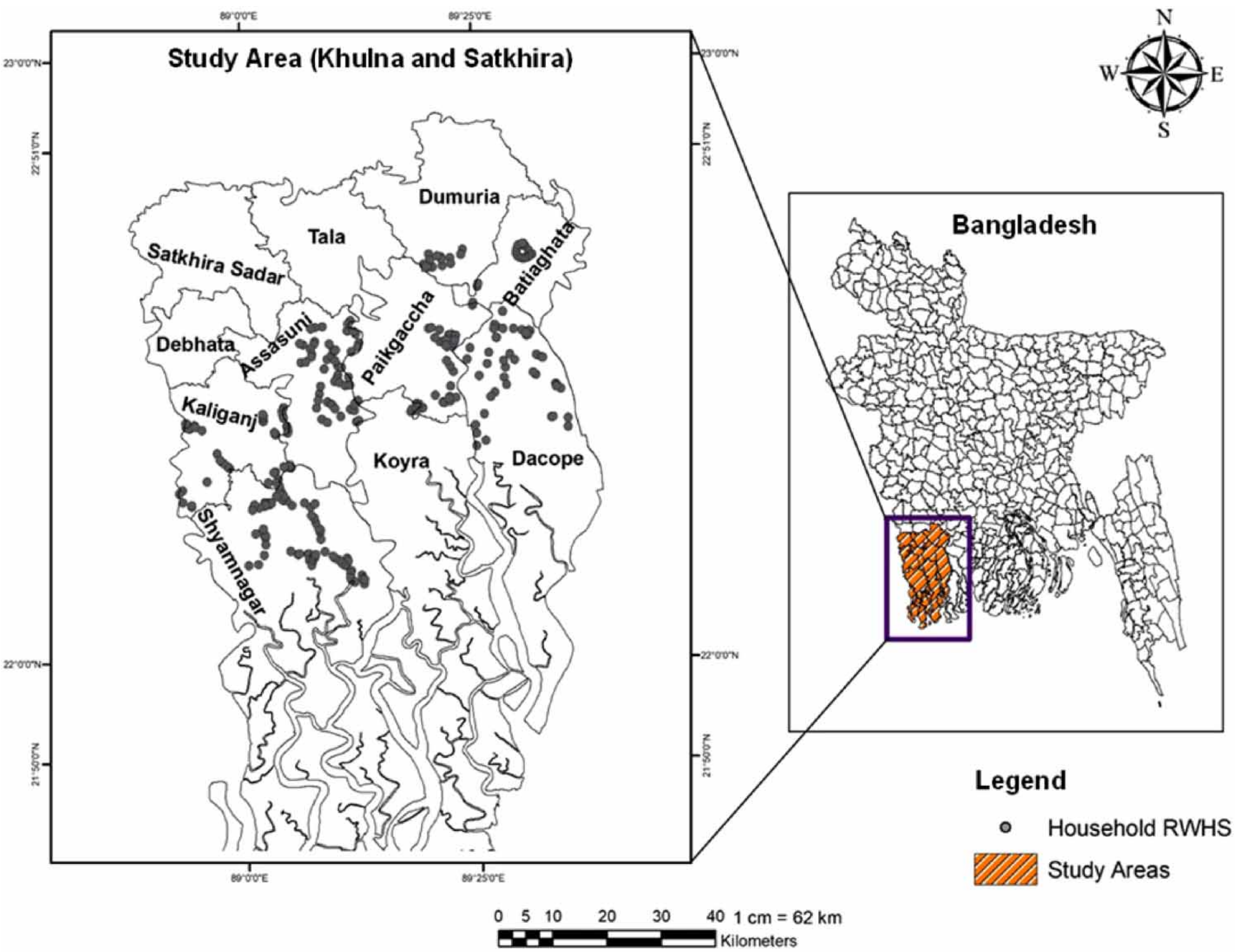


Figure 1 | Locations of sampled HH RWH systems in Khulna and Satkhira districts.

assessment of RWH. Questions were set regarding socio-demographic characteristics, HH water collection and consumption behavior, O&M practice (cleaning of the tank, gutters, mesh, catchment, etc.), HH perception of water quality, water treatment practice, involvement of NGOs and other institutions in surveillance of the RWH system, and monitoring and capacity building for the RWH system (see Supplementary Material). Data were entered into SPSS v26.0 and exported to Stata/SE v17.0 for analysis.

2.3. Conceptual framework development and statistical analysis

A conceptual framework was developed to identify the factors associated with the effectiveness of the HH RWH system (Figure 2). The outcome variable 'effectiveness of the HH RWH system' was formed considering the three indicators: getting enough drinking/cooking water throughout the year, being satisfied with the rainwater quality (physical parameters), and being satisfied with the odor/taste of the rainwater. When the respondents replied positively to all the above indicators, RWH systems were categorized as 'effective,' while the rest were regarded as 'not effective.' Although measured water quality could have been a robust indicator of effectiveness, the study was confined to using 'perceived water quality' as an indicator. Water quality data are scarce in such water-challenged areas, and the user experience is generally governed by factors affecting the availability of water in adequate quantities.

A bivariate logistic regression (LR) was performed to identify the predictor variables (socio-economic profile, O&M practices, water treatment practice, financial support, surveillance system, and knowledge) associated with the outcome variable (with a $p < 0.25$) for the final model. The LR gives each predictor a crude odds ratio (OR) and 95% confidence interval that measures its independent contribution to variation in the dependent or outcome variable. Afterward, a final model (using multivariate LR analysis) was developed by adjusting all the significant predictor variables in predicting the outcome variable. Variables with a p-value of <0.05 were considered statistically significant associations, and the test was assured using an adjusted odds ratio (AOR) at a 95% confidence interval (CI) cut-off value. Multicollinearity was checked using the variance inflation factor cut-off of 10. A higher primary screening threshold ($p<0.25$) is initially chosen to identify the maximum number of predictor variables, which suggested elsewhere in similar studies (Austin & Tu 2004; Eticha *et al.* 2022).

LR calculates the probability of success over the probability of failure. The dependent variable Y takes the value of 1 if the response is 'Yes' and takes a value of 0 if the response is 'No.' The model form for predicted probabilities is expressed as a natural logarithm (ln) of the OR:

$$\ln\left[\frac{P(Y)}{1-P(Y)}\right] = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k \quad (1)$$

where $\ln\left[\frac{P(Y)}{1-P(Y)}\right]$ is the log (odds) of the outcomes, Y is the dichotomous outcome, $P(Y)$ is the probability of the event, $X_1, X_2, \ldots, X_k$ are the predictor variables, $\beta_0, \beta_1, \beta_2, \ldots, \beta_k$, are the regression (model) coefficients, and β_0 is the intercept (Boateng & Abaye 2019).

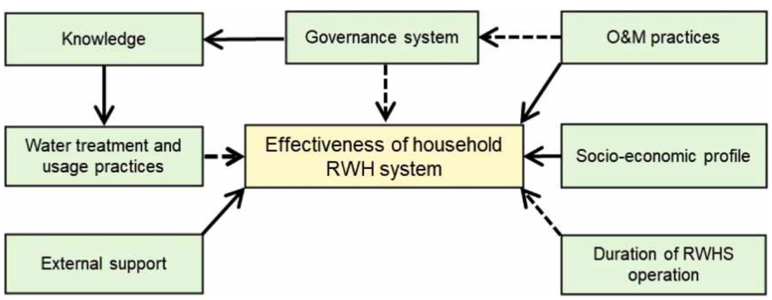


Figure 2 | Conceptual framework on the effectiveness of the HH RWH system (The dash and solid lines means the indirect and direct association with the variables, respectively).

3. RESULTS AND DISCUSSION

3.1. Socio-demographic characteristics

The socio-demographic characteristics of the respondents are shown in Table 1. Most of the respondents (82.7%) were more than 25 years old, indicating that they were well acquainted with their RWH system and could provide reliable and accurate information. The mean age of the respondents was about 37 years. In the study area, HH size widely varies between 2 and 16, with an average HH size of 5.5. The majority of surveyed respondents (39.3%) only completed secondary education, and a few were found to be university graduates (8.7%). Most respondents (37%) reported their average monthly family income to be between BDT 5,000 and 10,000.

3.2. Rainwater management practices of the HH

Table 2 shows the existing practices for rainwater management, including O&M, by the HHs. Almost all of the surveyed HHs (98%) cleaned tanks every year, while HHs not cleaning tanks at all were marginal (2%). More than 85% of the participants cleaned the gutter and downpipes at least once a year. Around 13.3% of the HHs reported that they did not clean the downpipe. The lack of knowledge on how to fix the downpipe after the cleaning might be a reason for not cleaning the downpipe frequently. Most (35%) respondents having mesh/filter in their RWH system practiced cleaning. Around 21.1% of HHs cleaned the mesh several times a year, while the rest (43%) preferred to replace their mesh. Approximately three-fourths (78.7%) of the surveyed HHs relied on the first rain of the season to wash the roofs for them instead of cleaning the roof purposefully. Overhanging vegetation (OHV) is another important factor that could significantly influence rainwater quality. On-spot assessment showed no OHV on the roof in 79% of the surveyed houses, indicating that users were aware of the importance of cutting or trimming trees. Around 51% of the surveyed HHs waited more than or equal to 25 min, while 22% waited 16–24 min before collecting water. A few HHs (5%) were not discarding the first-flush. Water collection using a tap and transportation using a jar or pitcher were common among the surveyed HHs (97%); only about 3% withdrew the water directly from the tank without a tap. Most HH RWH system users (48.3%) spent less than 50 BDT for O&M purposes.

3.3. Factors affecting the effectiveness of RWH systems

The bivariate analysis showed that the respondent's family size, monthly average income, duration of RWH system operation, tank, filter/mesh, presence of OHV, downpipe cleaning practice, the portion of a catchment area, financial support, duration of first flushing, and yearly O&M annual cost affected the effectiveness of RWH systems. An application of multivariable LR

Table 1 | Socio-demographic characteristics of the surveyed HH s

Characteristics	Category	No. of HHs (%)
Age (years)	18–25	52 (17.3)
	26–35	97 (32.3)
	>35	151 (50.4)
Family size	1–4	111 (37.0)
	5–8	160 (53.3)
	≥9	29 (9.7)
Education level	Primary	46 (15.3)
	Secondary	118 (39.3)
	College	54 (18.0)
	University	26 (8.7)
	No education	56 (18.7)
Main occupation	Day labor	3 (1.0)
	Employee/teacher	19 (6.3)
	Housewife	250 (83.3)
	Farmer	23 (7.7)
	Business	5 (1.7)
Average monthly income (BDT)	<5,000	43 (14.3)
	5,000–10,000	111 (37.0)
	10,001–20,000	107 (35.7)
	>20,001	39 (13.0)

Table 2 | Rainwater management practices of the households

Characteristics	Category	No. of HHs (%)
Roof cleaning ($n = 300$)	Yes	64 (21.3)
	No	236 (78.7)
Storage tank cleaning ($n = 300$)	1 time/year	211 (70.3)
	2 times/year	77 (25.7)
	3 times/year	6 (2.0)
	Do not clean	6 (2.0)
Gutter cleaning ($n = 239$)	1 time/year	97 (40.6)
	2 times/year	62 (25.9)
	3 times/year	33 (13.8)
	>3 times/year	23 (9.6)
	Do not clean	24 (10.1)
Downpipe cleaning ($n = 256$)	1 time/year	117 (45.7)
	2 times/year	65 (25.4)
	3 times/year	23 (9.0)
	>3 times/year	17 (6.6)
	Do not clean	34 (13.3)
Filter media/mesh cleaning ($n = 270$)	Replace the mesh	116 (43.0)
	1 time/year	20 (7.4)
	2 times/year	39 (14.4)
	3 times/year	35 (13.0)
	>3 times/year	57 (21.1)
	Do not clean	3 (1.1)
OHV cleaning ($n = 62$)	Yes	5 (8.1)
	No	57 (91.9)
Duration of first-flush ($n = 300$)	5–15 min	66 (22.0)
	16–24 min	66 (22.0)
	≥25 min	153 (51.0)
	No first-flush	15 (5.0)
Water collection from the tank ($n = 300$)	Manual abstraction	10 (3.0)
	Using tap	290 (97.0)
Annual O&M expenditure ($n = 300$)	<50 BDT	145 (48.3)
	50–100 BDT	107 (35.7)
	101–300 BDT	35 (11.7)
	>300 BDT	13 (4.3)

showed that HH family size, monthly income, the practice of tank and downpipe cleaning, and the organizations supporting the installation were the most significant parameters ($p < 0.05$) affecting the effectiveness of the RWH systems. Table 3 shows the association of these variables under the conceptual model framework presented in Figure 2.

Inadequate storage and large family sizes are the root causes of insufficient year-round drinking and cooking water in the southwestern coastal region. It was found that the odds of HHs that had 1–4 family members were 28.3 times more likely to have an effective RWH system compared to those having greater or equal to 9 members (AOR = 28.3, 95% CI = 4.8–167.7), indicating that the effectiveness of HH RWH systems was significantly associated with the family size of the HHs ($p < 0.025$) (Table 3). HHs with a monthly average income greater than 25,000 BDT were 9.1 times more likely to have an 'effective' RWH system than those with a monthly family income of less than 5,000 BDT (AOR = 9.1, 95% CI = 1.6–50.7, $p < 0.025$). HHs who have installed RWH more than 4 years ago are less likely to have an effective RWH system, indicating that years of operation could be a contributing factor. HHs understand the importance of rainwater during the dry season when drinking water is scarce. Most of the surveyed HHs said that they did not use stored rainwater for anything other than drinking and cooking. The fact that the RWH system has become more popular in the last few years as a primary drinking and cooking water source is an indication of high acceptability.

Table 3 | Factors affecting the performance of the RWH system

Variables	Category	Number of HHs having RWH systems		COR (95% CI)	AOR (95% CI)
		Effective (%)	Not effective (%)		
Family size	≥9	2 (2.0)	27 (13.6)	Ref.	Ref.
	1–4	52 (51.0)	59 (29.8)	12 (2.7–52.5)**	28.3 (4.8–167.7)**
	5–8	48 (47.0)	112 (56.6)	5.8 (1.3–25.3)**	7.3 (1.3–41.3)*
Monthly income	<BDT 5,000	8 (7.8)	35 (17.7)	Ref.	Ref.
	BDT 5,000–10,000	40 (39.2)	71 (35.9)	2.5 (1.1–5.8)*	2.8 (0.9–8.9)
	BDT 10,001–15,000	22 (21.6)	44 (22.2)	2.2 (0.9–5.5)	2.3 (0.6–7.9)
	BDT 15,001–20,000	16 (15.7)	25 (12.6)	2.8 (1.0–7.5)*	2.6 (0.7–10.2)
	BDT 20,001–25,000	7 (6.9)	13 (6.6)	2.4 (0.7–7.8)	4.5 (0.7–26.5)
	>BDT 25,000	9 (8.8)	10 (5.0)	3.9 (1.2–12.9)**	9.1 (1.6–50.7)**
Duration of operation	1–4 years	96 (94.1)	160 (80.8)	Ref.	Ref.
	5–8 years	6 (5.9)	33 (16.7)	0.3 (0.1– 0.7)**	0.4 (0.7–9.8)
	≥9 years	0 (0.0)	5 (2.5)	1.0	1.0
Tank cleaning	Do not clean	6 (6.0)	0 (0.0)	Ref.	Ref.
	1 time/year	88 (86.2)	123 (62.1)	6.2 (2.8–13.5)**	3.3 (1.2–9.1)**
	2 times/year	8 (7.8)	69 (34.9)	1.0	1.0
	3 times/ year	0 (0.0)	6 (3.0)	1.0	1.0
Downpipes cleaning	Do not clean	8 (7.8)	26 (13.1)	Ref.	Ref.
	Do not have a downpipe	13 (12.8)	31 (15.6)	1.4 (0.5–3.8)	5.3 (1.1–25.7)*
	1 time/year	54 (52.9)	63 (31.8)	2.8 (1.2–6.7)**	5.2 (1.5–17.8)**
	2 times/year	17 (16.7)	48 (24.2)	1.2 (0.4–3.0)	2.7 (0.7–10.5)
	3 times/year	5 (4.9)	18 (9.1)	0.9 (0.3–3.2)	7.9 (1.3–48.3)**
	>3 times/year	5 (4.9)	12 (6.2)	1.4 (0.4–5.0)	9.7 (1.5–62.5)**
Mesh cleaning	Replace the mesh	40 (39.2)	79 (39.9)	Ref.	Ref.
	Do not have a mesh	15 (14.7)	15 (7.6)	1.9 (0.9–4.4)	1.2 (0.4–3.6)
	1 time/year	11 (10.8)	9 (4.6)	2.4 (0.9–6.3)	2.0 (0.6–7.0)
	2 times/year	12 (11.8)	27 (13.6)	0.9 (0.4–1.9)	1.2 (0.4–3.3)
	3 times/year	10 (9.8)	25 (12.6)	0.8 (0.3–1.8)	2.3 (0.7–7.1)
	>3 times/year	14 (13.7)	43 (21.7)	0.6 (0.3–1.3)	0.9 (0.3–2.7)
OHV cleaning	Do not clean	25 (24.5)	32 (16.2)	Ref.	Ref.
	Do not have OHV	76 (74.5)	162 (81.8)	0.6 (0.3–1.1)	0.7 (0.3–1.5)
	Trimming OHV	1 (1.0)	4 (2.0)	0.3 (0.0–3.0)	0.1 (0.0–1.7)
Duration of the first-flush	No first-flush	5 (4.9)	11 (5.6)	Ref.	Ref.
	5–15 min	21 (20.6)	46 (23.2)	1.0 (0.3–3.3)	2.2 (0.4–13.2)
	16–24 min	25 (24.5)	42 (21.2)	1.3 (0.4–4.2)	2.8 (0.5–17.5)
	≥25 min	51 (50.0)	99 (50.0)	1.1 (0.4–3.4)	4.5 (0.8–25.9)
The portion of roof catchment	Half roof	44 (43.1)	100 (50.5)	Ref.	Ref.
	Whole roof	34 (33.3)	40 (20.2)	1.9 (1.1–3.4)*	2.7 (1.1–6.8)*
	Quarter roof	21 (20.6)	44 (22.2)	1.1 (0.6–2.0)	0.8 (0.3–1.8)
	Others	3 (3.0)	14 (7.1)	0.5 (0.1–1.8)	0.6 (0.1–3.7)
Financial support	Self	7 (6.9)	34 (17.2)	Ref.	Ref.
	DPHE	78 (76.5)	89 (45.0)	4.3 (1.8–10.1)**	4.6 (1.5–14.6)**
	NGOs	10 (9.8)	53 (26.8)	0.9 (0.3–2.6)	1.4 (0.4–5.4)
	Sharing	2 (1.9)	20 (10.0)	0.5 (0.1–2.6)	0.4 (0.1–3.0)
	Other donors	5 (4.9)	2 (1.0)	12 (1.9–75.7)**	22.0 (2.3–213.0)**
O&M cost	<BDT 50	62 (60.8)	83 (41.9)	Ref.	Ref.
	BDT 50–100	31 (30.4)	76 (38.4)	0.5 (0.3–0.9)*	0.8 (0.4–1.7)
	BDT 101–300	3 (2.9)	32 (16.2)	0.1 (0.1–0.4)**	0.1 (0.1–0.6)**
	>BDT 300	6 (5.9)	7 (3.5)	1.1 (0.4–3.6)	2.9 (0.5–16.8)

*$p < 0.05$, **$p < 0.025$.

About 52.9 and 86.3% of the surveyed HH RWH systems were 'effective' when the users cleaned their downpipes and storage tanks, respectively, at least once a year. The users who cleaned downpipes (AOR = 5.2, 95% CI = 1.5–17.8) and storage tanks (AOR = 3.3, 95% CI = 1.2–9.1) once a year had nearly 5.2 and 3.3 times higher odds, respectively, of their RWH system being 'effective' compared to those users who did not clean their downpipes and storage tank at all. Moreover, the surveyed HHs who cleaned downpipes three times in a year had nearly 7.9 times higher (AOR = 7.9, 95% CI = 1.3–48.3) and >3 times/year had 9.7 times more (AOR = 9.7, 95% CI = 1.5–62.5) odds of having an effective RWH system than those who did not clean their downpipes. The frequency of cleaning downpipes appeared to have a good association with water quality from the RWH system, underlining the importance of having a good O&M protocol.

The portion of the roof used as a catchment showed good association with the effectiveness of the RWH system. Around 33% of the RWH systems were 'effective' when the users collected rainwater using the whole of the roof. The odds of HHs who collected rainwater using the whole roof were 2.7 times more likely to have an effective RWH system than those who used half of the roof for rainwater collection (AOR = 2.7, 95% CI = 1.1–6.8).

Due to prevailing hardship in the southwestern coastal areas, most people rely on assistance from external organizations (DPHE, NGOs, and other donor institutions) to install their RWH system. Around 76.5% of RWH systems were installed by the DPHE, which were found to be 'effective.' The users who got financial support from the DPHE and other donors had 4.6 times (AOR = 4.6, 95% CI = 1.5–14.6) and 22 times (AOR = 22.0, 95% CI = 2.3–213.0) higher odds, respectively, of their RWH system being 'effective' than those installed by the HHs using self-financing. On-spot assessments showed that when the HHs installed RWH systems using their own funds, they used small storage tanks to economize. RWH systems installed by other institutions not only used larger tanks with properly designed components but also came with user instructions and training on maintenance. This could be the reason for the higher odds of effectiveness with these RWH systems.

Around 60.8% of surveyed RWH systems were found to be 'effective' when users spent less than BDT 50 as an O&M expenditure. However, about 16.2% of HH RWH systems were 'not effective' even after spending BDT 101–300 for O&M purposes. The odds of having 'effective' RWH systems were 10 times higher for HHs who spent greater than BDT 50 than those who spent BDT 101–300 (AOR = 0.1, 95% CI = 0.1–0.6) for O&M purposes (Table 3). Those who spent >300 BDT had a higher OR but with a low significance level. There was no significant association found with the amount being spent, indicating that there could be other factors governing the effectiveness of RWH systems.

4. DISCUSSION AND CONCLUSION

This study has aimed to evaluate the post-installation performance of HH RWH systems in the southwestern coastal region of Bangladesh with respect to socio-economic parameters, quality of components of the RWH systems, operational features, maintenance practice, and type of installations involved in the installation. Family size, monthly average income, tank and downpipe cleaning frequency, financial support, and the portion of roof available as catchment were the factors that had a statistically significant association with the effectiveness. Some of these parameters have been highlighted in previous studies. For example, a roof catchment area of about 15 sq. m (160 sq. ft) was calculated to be sufficient for a family of 6–7 members for domestic water demand during the dry period (Karim 2010b). Cleaning various components of the RWH system has been emphasized in many guidelines and manuals on RWH design and operation (Dao *et al.* 2021). There was evidence that the lack of awareness about the proper operation and maintenance (O&M) of the RWH system adversely affected its performance (Rahman & Jahra 2006; Abdullah & Rahman 2015).

The findings emphasize the need for having a storage tank commensurate with the size of the family and its water demand to ensure yearlong water availability. Properly functioning RWH components, especially having the whole of the roof as a catchment, is also important to collect water in adequate quantity. This also includes having gutters and connections capable of collecting water from the entire catchment. HHs who are affected by insufficient water due to unutilized roof catchment or the low capacity of the storage tank can upgrade their setup with some support from the Government or NGOs. This is also true for self-supply HHs who might be able to add another tank in 2- or 3-years' time and then use both sides of the roof, achieving a service level similar to a DPHE system. Again, it is difficult to meet yearlong water demand with a large family with the same storage tank. We see that the effectiveness of the system reduces significantly for HHs having higher family members. On the other hand, the practice of first-flush diversion has been found to be positively linked with effectiveness of the system. However, the absence of a first-flush diversion device may result in arbitrary discarding of first-flush and potentially affect the quantity of water available.

Design aspects of RWH and its operation and maintenance are technical issues, which the HHs need to be sensitized if they are to run the system properly. Increasing public awareness regarding the beneficial effects of good O&M practice through various capacity-building programs is essential. This is where the Government institutions (DPHE), NGOs, and donor agencies can play a crucial role in providing post-installation support and building capacity at the HH level. An institutional O&M strategy for small-scale water supplies (including RWH systems) with the allocation of resources for O&M should help in running RWH systems fruitfully. Also important is the adoption of water safety plans for RWH systems to reduce the risk of water quality from microbial and chemical contaminations.

In this study, we aimed to compile the parameters that had a statistical significance on affecting the performance. Other socio-economic and behavioral aspects associated with rainwater management, knowledge, and practice gaps at the HH level can also contribute to the effectiveness of the RWH system. A deeper understanding of the behavioral aspects of the HH could have shed more light into this. However, the parameters that we have defined here as predictors have a reasonable influence for modulating the effectiveness of the RWH system, which is evident from the statistical analysis. The southwestern coastal region of Bangladesh is one of the most water-challenged areas in the country, and RWH is an important source of water supply in the area. There is a strong need for monitoring the performance of RWH systems and this study provides clues to strengthening the current RWH programs in the region.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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