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Original Research Paper

Potential of Household Rainwater Harvesting for Drinking Water Supply in Hazard Prone Coastal area of Bangladesh

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ABSTRACT

The coastal region of Bangladesh has been identified as the most climate induced, hazard-prone, hard-to-reach area in Bangladesh. The conventional drinking water sources (rivers, ponds, groundwater) in the coastal area have become contaminated recently due to saltwater intrusion from the rising sea levels and frequent natural disaster. Household rainwater harvesting could be an alternative measure for reducing impact of climate change on water supplies because of the availability of rainwater. This study is to explore the potential of household rainwater harvesting for drinking purposes in the coastal area of Bangladesh. Rainwater harvesting is found technically feasible on the basis of rainfall pattern, household roof constructing material, and roof size. The annual rainfall of over 1900mm with inter annual variability of 0.18, makes the rainwater harvesting ideal in the coastal areas. Harvested rainwater can satisfy household monthly drinking water demand from March to October. The excess rainwater stored in September and October is sufficient to meet the demand in the dry months (November to February) provided there is adequate storage facility. The quality of stored rainwater was satisfactory from chemical parameters perspective and additional treatment is recommended for the harvested rainwater due to frequent detection of microbial contamination.

INTRODUCTION

Access to safe and affordable drinking water is one of the fundamental human rights and a foundation for the socio-economic development of any country. In the recent times, increase in human population, environmental degradation and climate induced natural disaster in many countries, are reducing human access to safe drinking water. Despite being a tremendous development potential area, the people of coastal area in Bangladesh, usually lead their life fighting against cyclone, tidal surge, flood, salinity, drinking water scarcity and so on. Climate change has further worsened the situation. The presence of high level of salt in drinking water sources in coastal Bangladesh is a cause of public health concern and a challenge for the Government of Bangladesh, donor communities, and non-governmental organizations. Approximately 20 million people living along the coast are affected by varying degrees of salinity in drinking water obtained from various natural sources (MOEF 2006). Higher rates of (pre)eclampsia and gestational hypertension in pregnant women in coastal Bangladesh, compared with non-coastal pregnant women, were hypothesized to be caused by saline contamination of drinking water (Khan et al. 2008). Historically, the coastal population of Bangladesh relies heavily on rivers, tube wells (groundwater) and ponds for washing, bathing, and obtaining drinking water. However, the sources have become contaminated recently by saline water due to saltwater intrusion from rising sea levels, frequent natural disaster (such as cyclone), shrimp farming and upstream withdrawal of freshwater. Due to non-availability of suitable surface and groundwater sources (high salinity and nonexistence of shallow aquifer); Household Rainwater Harvesting (HRWH) is considered as a sustainable option for drinking water supply in the coastal areas of Bangladesh. It has been a common practice in many nations all over the world for thousands of years (Pinfold et al. 1993, Simmons et al. 2001), especially in arid or remote areas, where the provision of water through piped networks is uneconomic or not technically feasible. Bangladesh is a tropical country, receives high seasonal rainfall all over the country. The average annual rainfall is about 2400 mm and in most parts of the country, people normally can have the access to rainwater for 8 months on an average. Even though such a solution seems to be so attractive from an ecological point of view, potential health risks from ingestion of harvested rainwater related to microbiological and chemical contaminants should be taken into account. Either a chemical or microbiological contaminants have been found in the harvested rainwater, often at levels exceeding the international or national guidelines set for safe drinking water (Simmons et al. 2001, Chang et al. 2004, Zhu et al. 2004). Household rainwater harvesting has been practiced in

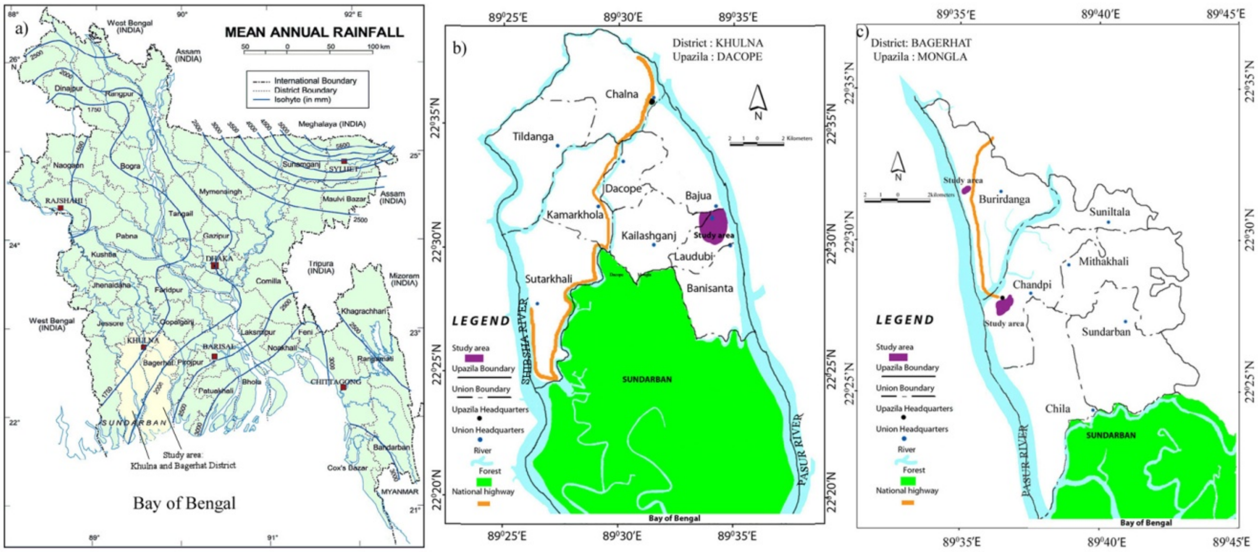

Fig. 1: Map of the study area.

coastal area of Bangladesh for a long time on a limited scale. Moreover, harvested rainwater is mainly used for only drinking purpose without any in-house treatment and quality of the harvested rainwater in Bangladesh is hindered by lack of information. The aim of this study is to analyse the potential of household rainwater harvesting for drinking purpose using rainfall data, household roof material and size, water demand, harvestable rainwater quantity and stored rainwater quality.

MATERIALS AND METHODS

Study area: This study was carried out in the south-west coastal region of Bangladesh. The Khulna and Bagerhat districts (the districts are the first tier of administrative units of local government in Bangladesh) were selected for this study (Fig. 1a). Because of the geographical location, prone to various natural calamities and sensitive to climate change issues, Dacope upazila (the upazilas are the second lowest tier of administrative units of local government in Bangladesh) (Fig. 1b) of Khulna district and Mongla upazila (Fig. 1c) of Bagerhat district were selected for this study. Dacope upazila has 25377 units of house hold with an area of 991.58 km² and is surrounded by the Pasur River and the Shibsa River system. The southern part of this upazila is surrounded by the Sundarban-the world's largest mangrove forest. On the other hand, Mongla upazila has 27192 units of houses with an area of 1461.22 km². The western part of the Mongla Upazila is surrounded by the Pasur River and the southern part is surrounded by the Sundarbans.

Data collection: The study team collected data, conducting a cross sectional survey at household level during December 2012 to February 2013. Data were collected from 80 households (30 households from Dacope and 50 households from Mongla upazilla) using a purpose designed questionnaire. We invited household members to participate in the study following explanation of the nature of the research and obtaining informed consent. One adult (>18 years old) from each household was asked to report on demographic and socio-economic information, details on house and key possessions and water usage. Total roof top area of each household was calculated on the spot during the questionnaire survey. To analyse the rainfall, a total of 21 years (from 1991 to 2011) of rainfall data collected by Mongla station of Bangladesh Meteorological Department was considered. The intra annual variability was determined by finding the coefficient of variation of the monthly rainfall. Similarly, inter annual and inter monthly variability of the annual cumulative rainfall was determined by finding the coefficient of variation of the cumulative rainfall for the years under investigation from 1991 to 2011.

The volume of rainwater that could be harvested per household per month was determined by the equation (1).

$$Y = f \times R \times A \quad ...(1)$$

Where Y is the amount of water yielded per month (m^3); f is the catchment's efficiency or coefficient of available runoff (0.7); R is the monthly rainfall (m); and A is the catchment area (m^2).

The minimum roof area A, required for the collection of rainwater for N number of people supplied with q litres per capita per day of water and rainfall intensity of I in m/year was determined by adapting equation expressed by Ahmed

& Rahman (2000). The equation is modified as:

$$A = (0.365 \times q \times N \div (f \times I) \quad ...(2)$$

The basic monthly drinking water balance was estimated by subtracting monthly water demand from collected monthly rainwater.

Rain water sampling: Sampling of stored rainwater was performed three times since October 2012 till February 2013. Total nine samples were collected from three rainwater harvesting systems: a) corrugated iron (CI) sheet based roof with cement storage tank (RWH-1); b) CI sheet based roof with clay pot storage tank (RWH-2); and c) thatched based roof with clay pot storage tank (RWH-3). The samples were collected at point of use and placed in polyethylene bottles for physicochemical analysis; and in sterilized glass bottles for microbiological analysis, put into icebox containers and transported to the laboratory.

Chemical and microbial analysis: Chemical analyses were conducted according to the standard methods (APHA 1995) and included for the ammonia, nitrate, phosphate and sulphate. pH, TDS and conductivity were measured on site. All the samples were examined for total coliforms by the membrane filter technique (APHA 1995).

RESULTS AND DISCUSSION

Water use, satisfaction and health: The data collection phase of the study took place during December and January of 2012 and 2013 respectively, months which are usually marked as dry season in Bangladesh. A total of 80 households participated in the study. In these 80 households there lived 359 people, an average of 4.5 people per house and water demand of 3 litres per capita per day for only drinking. Around 28% of the participants were male and 72% were female. Most families had lived in the same community for more than 10 years. The main earning sources of the people are agriculture, fishing, daily labour and others. The sample households had a total family income, over the past 12 months, of US$ 1580. The families generally used pond-sand-filter, shallow tube-well, pond and rain water for drinking purposes. Just over a quarter (26%) of the household depend solely on the roof top rainwater harvesting during rainy season (April to October). Households using roof rainwater, change to alternative sources predominantly, to pond and shallow tube-well water, during the dry season (November to March). The walking distance between houses and water collection points were within 0.5 km and average water consumption was 3 litres per capita per day for only drinking. Women and girls are generally responsible for household water collection. Those who consumed rainwater were generally more satisfied with the quality of their water than those who consumed pond or tube-well water.

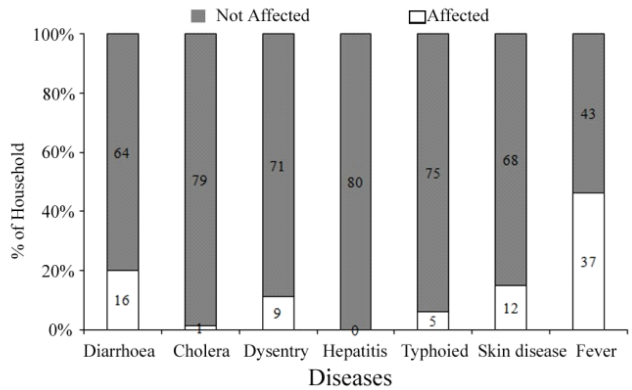

Fig. 2: Status of household affected by water-borne diseases.

The study found that 70% of the people were satisfied with their current source of drinking water, 21% were quite satisfied and 9% were not satisfied at all. The taste and availability of water appeared to be important factors for satisfaction, and salinity was the only cause of bad taste. When questioned about potential health risks and water supply, most of the people are totally unaware of the parameters to declare the water as safe. The people think that safe water is nothing but salt free water. The study also found that at least one person of the 20%, 11%, 6% and 2% households had diarrhoea, dysentery, typhoid and cholera, respectively, within the past six months (Fig. 2). Interestingly, around 46% households suffered from skin diseases, and believed that water salinity is the main cause of skin diseases.

Rain-water harvesting potential: Roof rainwater harvesting can help to reduce the vulnerability of water supply in the coastal area of Bangladesh considering the fact that centralized water reservoirs are more sensitive and vulnerable to natural disaster and climate change. The variation of annual rainfall between 1991 and 2011 is shown in Fig. 3. The highest annual rainfall depth of 2786 mm was observed in 2002 while the lowest annual rainfall of 1232 mm was in 1992. The average annual rainfall was 1932 mm and there was a trend of increasing rainfall (Fig. 3). The intra annual variability ranges between 0.82 and 1.27 while inter annual variability was 0.18 (Fig. 3). These show that there was high seasonal variability in the rainfall distribution, but the variability over the years was low in the study area.

The inter month rainfall variability from 1991 to 2011 for a specific month between November and March was higher than 1.0 (range 1.4 to 2.6), however, it was less than 1.0 (range 0.3 to 0.8) between April and October. This shows that there was high variability in the rainfall within months between November and March over the years.

In the study area, almost 80% of the houses were judged to be of very good quality for rainwater harvesting (CI sheet

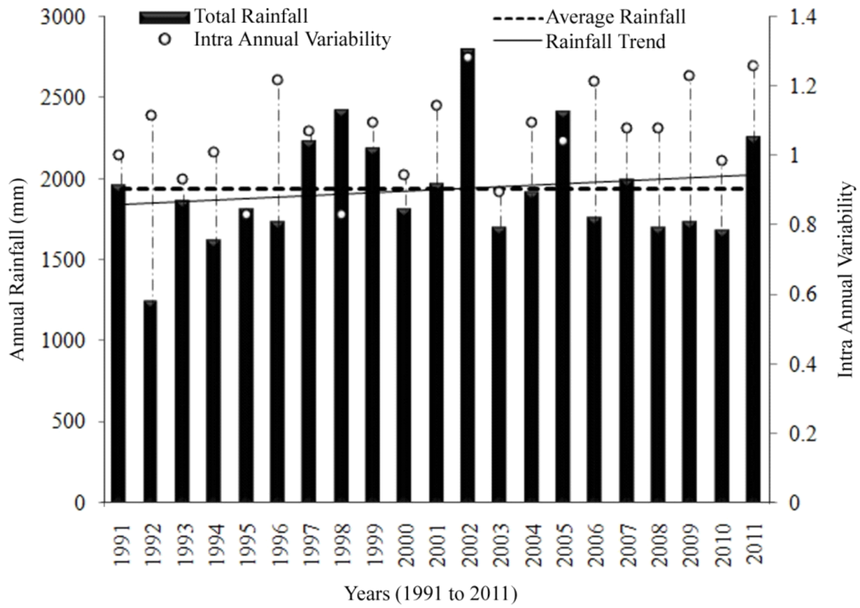

Fig. 3: Variation of annual rainfall and intra annual variability.

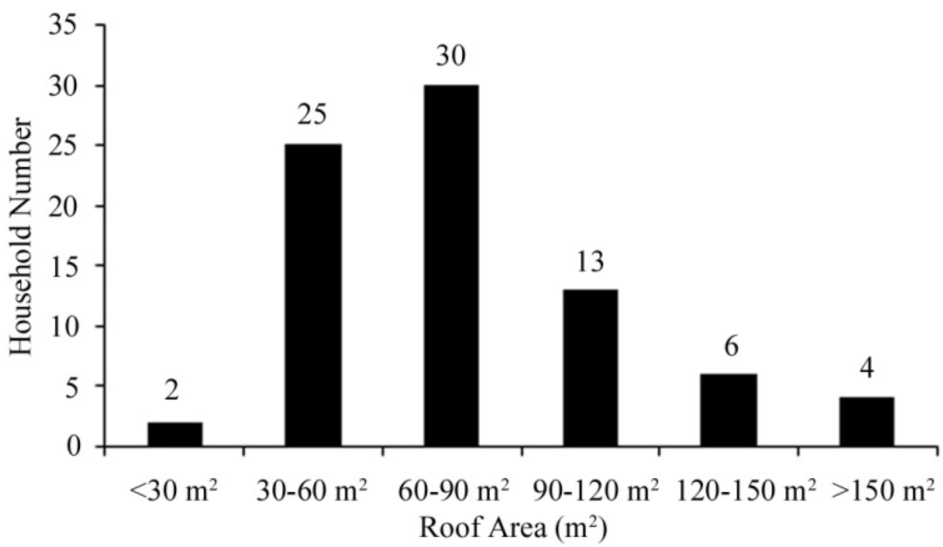

Fig. 4: Roofing size.

based roof) and 20% houses had thatched roofs. A thatched roof can also be used as catchment area by covering it with polyethylene, but it required good skills to guide water to the storage tank. The roof area of the household was 20 to 180 m^2 range with an average roof area per household as 80.0 m^2 (Fig. 4). The amount of water yielded per month calculated according equation (1) shows that the average annual yield of rainfall (108.18 m^3) by the household roof area has been seemed to be sufficient to fulfil the required annual demand (4.93m^3) of water (Fig. 5). The largest volume (21.35 m^3) and the lowest volume (0.15 m^3) collected in July and December, respectively. The shortfall of 0.27 m^3 was observed only for December and this can be met with excess from previous months. However, water yield per month was found to vary significantly based on rainfall pattern. Rainfall is very rare between November and February, months which usually mark as dry season in Bangladesh. As a result of low average monthly rainfall with high

Table 1: Physicochemical and microbiological analysis of stored rainwater at point of use.

Parameters	Rainwater Harvesting System		
	RWH-1	RWH-2	RWH-3
pH	9.07 ± 0.37	7.9 ± 0.8	8.3 ± 0.3
TDS (mg/L)	84 ± 9	130 ± 10	370 ± 25
EC (μS/cm)	172 ± 17	265 ± 20	755 ± 51
NH_4-N (mg/L)	0.03 ± 0.01	0.09 ± 0.17	0.27 ± 0.11
NO_3-N (mg/L)	2.9 ± 0.5	4.5 ± 2.0	4.2 ± 0.4
PO_4 (mg/L)	0.02 ± 0.01	0.09 ± 0.17	0.16 ± 0.04
SO_4 (mg/L)	2.3 ± 1.5	5.3 ± 2.5	27±3.5
Total coliforms (CFU/100mL)	2 - 20	10 - 30	90 - 170

RWH-1: Corrugated iron (CI) sheet based roof with cement tank storage tank; RWH-2: CI sheet based roof with clay pot storage tank; and RWH-3: thatched based roof with clay pot storage tank

rainfall variability from November through February, shortfall can be expected in any month between November and February in a specific year. According to the rainfall pattern from 1991 to 2011, monthly harvestable rainwater in the study area is shown using box-and-whisker plots in Fig. 6. Each box in the figure represents the bounds of the first and third quartile, the medial is marked by the horizontal line inside the box, and the ends of the 'whiskers' represent the minimum and maximum.

The minimum catchment area required for the collection of rainwater by using equation 2 was found 3.64 m^2 which was much smaller than the average roof area (80.0 m2) of the household. For full utilization of rainwater potential, a storage tank with adequate capacity (1.63 m^3 to fulfil four months water demand) is required for uninterrupted water supply at a constant rate throughout the year.

Stored rainwater quality: The physicochemical and microbiological rainwater quality data reported in Table 1. The physicochemical quality of harvested and stored rainwater depends on the characteristics of the individual area, such as topography, weather conditions and proximity to pollution sources (Evans et al. 2006). The examined stored rainwater samples met the requirements for safe drinking water in terms of physicochemical composition. The pH values, ranging from 7.5 to 9.5 with a mean value of 8.3, indicate that in the studied area stored rainwater is not acidic. Rainwater had moderate values for conductivity (median conductivity 265 μS/cm). The variation of conductivity (156 to 795 μS/cm) demonstrates the influence of the sea environment or due to storage tank itself. Rest of the studied chemical parameters: ammonia (0.01 to 0.4 mg/L), nitrate (2.4 to 6.8 mg/L), phosphate (0.01 to 0.2 mg/L) and sulphate (1 to 27 mg/L) were also within Bangladesh drinking water standards. The coastal area of Bangladesh is relatively pure from traffic emissions, industrial and agricultural wastes. Total coliforms were detected in the majority of the samples. The microbiological quality of harvested and stored rainwater depends on the type of the catchment area (Chang et al. 2004, Zhu et al. 2004), the type of water tank (Dillaha & Zolan 1985, Evison & Sunna 2001) and the handling and management of the water (Pinfold et al. 1993, Evison & Sunna 2001). The total coliform in thatched roof system (RWH-3) was much higher than CI sheet based system (RWH-1&2). Possible explanations for the lower values of

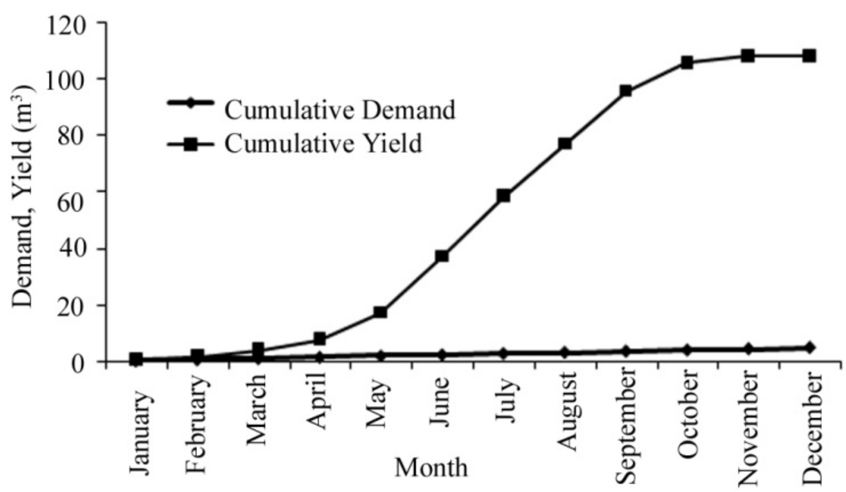

Fig. 5: Cumulative rainwater availability and demand per household.

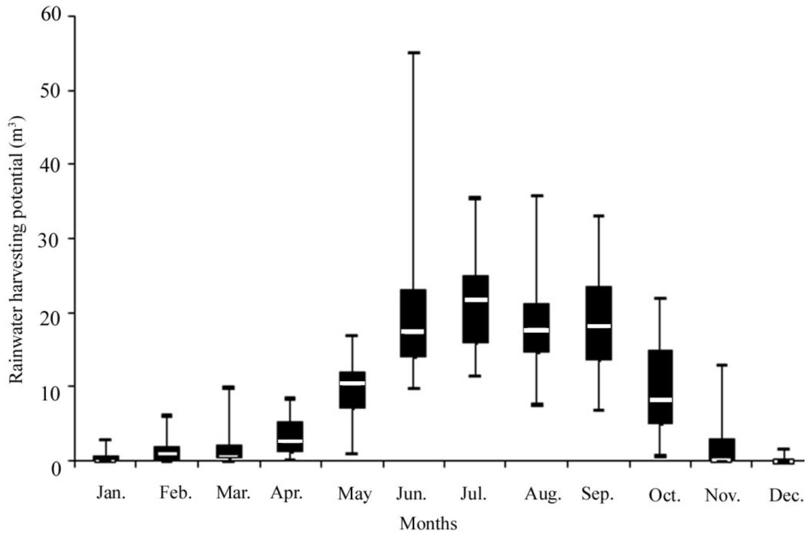

Fig. 6: Box-and-whiskers plot illustrate the range of harvestable rainwater per household

total coliform in the CI sheet roof system could be due to roof top high temperature, which do not favour the growth of microorganisms, and smooth surface which facilitated self cleaning. Despite the acceptable chemical quality of the rainwater, the presence of microbial indicator makes it unsuitable for drinking, at least without any treatment. Unfortunately, people drink harvested rainwater without any treatment in the study area.

CONCLUSION

Rainwater harvesting appears to be one of the most promising alternatives for supplying drinking water in the face of increasing water scarcity, due to climate change in coastal areas of Bangladesh. Rainwater harvesting is found technically feasible on the basis of rainfall, roof size and roofing material. The integrated management must consist of regular cleaning of the catchment areas and the storage tanks to reduce microbial contamination. With adequate storage, household rainwater harvesting will sufficiently satisfy not only the drinking water demand but also other household demand.

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