Household Water Security through Stored Rainwater and Consumer Acceptability: A Case Study of the Anuradhapura District

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Abstract

Rainwater harvesting has increased in popularity in Sri Lanka over the past two decades due to the number of water supply projects funded by the government and non-governmental organizations (NGOs). The stored rainwater can provide accessible, reliable, timely and adequate supplies of water to households but there are uncertainties as to safety, in terms of water quality, and consumer acceptability. A study was, therefore, conducted in the Anuradhapura District, in the dry zone, to assess consumer acceptability of stored rainwater for household purposes and to conduct rainwater quality tests in a laboratory.

The majority of households in Anuradhapura meet their drinking water requirements from protected wells (59.6 %). Prior to the project, people greatly preferred open wells as a source of domestic water, followed by tubewells, because they believed that water in open wells is of good quality and drinkable. However, stored rainwater has become the priority source now, especially through roof rainwater harvesting (RRWH), which is used during the dry periods. The study revealed that more than 85 % of households use stored rainwater for drinking although some have concerns over the quality and only drink it after boiling. The easy accessibility of water and the assurance by the project team that it is of good quality are the main reasons that people are willing to drink it. The acceptability of stored rainwater for consumption was very high in water-scarce areas and with the increasing distance to the nearest and alternative sources of good-quality water. Of those who felt that they had adequate water, 84 % of the sample households found it adequate in the wet season but only 21 % in the dry season.

Water quality analysis revealed that the chemical and physical quality of stored rainwater is within the acceptable range with respect to Sri Lankan Standards, SLS: 614, for potable water quality (SLIS 1983). Other domestic water sources exceeded standards for electrical conductivity, total alkalinity, hardness, ammonium nitrogen, fluorides and total iron. However, stored rainwater was of lower biological quality than other domestic water sources.

Introduction

Rainwater harvesting has increased in popularity in Sri Lanka over the past two decades as a result of various projects. In most cases, roof rainwater harvesting (RRWH) has been undertaken, mainly for reasons of convenience for the households, in areas where the planned supply is unreliable or where local water sources dry up for a part of the year. However, it has also been introduced in places as part of an integrated water supply system, where it may be used as the sole water source for a community or household.

A feasibility study of RRWH revealed that it could be successfully practiced in all parts of Sri Lanka (Hapugoda 1995; Chandrapala 1996; Rajkuma 1998). It is a technology that is flexible and adaptable to a very wide variety of conditions, being used in the richest and the poorest societies, and in the wettest and the driest areas of the country. As a result, various different types of rainwater harvesting systems have been adopted by rural people for domestic use in almost all parts of Sri Lanka (Ariyabandu 1998). The attractive benefits of rainwater harvesting are the low cost, simple design and construction technology, its independence from a central system, accessibility and easy maintenance.

In typical RRWH, rainwater from the house roof is collected in a storage vessel or tank for use during periods of scarcity. Usually these systems are designed to support the drinking and cooking needs of the family, and also in rare situations for home gardening. Such a system usually comprises of the roof, a storage tank and guttering to transport the water from the roof to the storage tank. A first flush system to divert the dirty water that contains roof debris collected during non-rainy periods and a filter unit to remove debris and contaminants before water enters the storage tank are also required.

Although rainwater harvesting has been accepted as an alternative rural water supply source in Sri Lanka, and can provide accessible, reliable, timely and adequate water, fewer than 10 % of households that have acquired RRWH systems consume the water (Ariyabandu and Aheeyar 2000). Consumers have concerns about safety (rainwater quality) and hence, there are issues over consumer acceptability in RRWH systems. One reason for this is the users' perceptions of quality during the storage period. As a result, the prospect of rainwater harvesting in Sri Lanka would primarily depend on consumer attitudes and user perceptions of roof water as a drinkable domestic source. In addition, Heijen and Mansur (1998) investigated the improvement in water security of the RRWH beneficiary community and showed that it remains low due to a lack of awareness and poor recognition of the technology by policymakers. Several initiatives have been made by NGOs to change these misconceptions and the situation is changing rapidly.

In general, the safety of rainwater can be measured at a household level by people's perception and in the laboratory by absolute measurements. It is particularly important to study changes in rainwater quality during the storage period inside a tank under dry zone conditions. In the past few years, many studies have been conducted to improve techniques of RRWH but less emphasis has been given to consumer attitudes and the perceptions regarding domestic consumption and quality of harvested rainwater. This study attempts to assess the quality of stored rainwater through laboratory analysis and by evaluating consumer preference through a questionnaire circulated in the Anuradhapura District, in order to determine the suitability of stored rainwater for domestic use.

Materials and Methods

The Study Area

The study was conducted in Anuradhapura District, which occupies a significant portion of the dry zone and where the dry period is experienced from May to September. It has a population of 746,756 in 22 District Secretariat (DS) Divisions. The majority of households (59.6 %) obtain drinking water from protected wells, 13.7 % from tubewells and the rest use water from unprotected wells, pipe-borne water, tanks and reservoirs (Census of Population and Housing, Anuradhapura, 2001). Agriculture is the main income generating activity for 75 % of the total district population (Census of Population and Housing, Anuradhapura, 2001). By the end of 2005, more than 2,800 rainwater tanks had been constructed by the National Water Supply and Drainage Board (NWSDB), Anuradhapura, under an Asian Development Bank (ABD) project. In addition, several other organizations, including CARE, Rajarata and Navodaya had also contributed to the use of rainwater in Anuradhapura.

Sampling and Questionnaire Survey

The 2,800 rainwater harvesting systems constructed by the NWSDB in 10 DS divisions in were selected as the study population, within which 60 households (10 from each DS division) were randomly selected for a questionnaire survey. All the survey data were analyzed using SPSS statistical package.

Water Sample Analysis

For water quality testing, 10 stored rainwater samples were collected on a weekly basis for a period of 2 months from November to December 2005, using a stratified sampling technique. Simultaneously, water samples from the other main water sources of the selected households were also collected once for water quality analysis. All water samples were analyzed for important physical, chemical and biological parameters for drinking water at the regional laboratory of NWSDB in Anuradhapura. The results were also analyzed using SPSS.

Results

Use of Multiple Water Sources

The rainwater user communities do not depend totally on stored rainwater for domestic purposes. In the dry zone, communities use multiple sources to achieve water security (Ariyabandu 2001). Table 1 indicates six priority water sources available in the area. Most of the people preferred to use (priority 1) open wells because they believe that water in open wells is better in quality and potable.

Table 1. Water availability on priority basis in the study area.

Source	Percentage of households*		
	Priority 1	Priority 2	Priority 3
Open wells	63	3	05
Tubewells	33	2	02
Pipe-borne water	2	0	0
Lake	0	50	08
River	2	0	05
Rainwater harvesting	0	45	80

Note: * Multiple answers

Table 2 shows that more than 50 % of households fetch water for drinking purposes from sources that are close to the home, but according to the findings of the survey, the quality and availability of water changes with the season. Based on the perception of high water quality in those sources, respondents were not entirely in favor of rainwater, but the introduction of RRWH has significantly reduced travel time for fetching water and increased the availability of good quality water at the doorstep of households, thus improving the quality of rural life.

Table 2. Travel distance to water sources before introduction of RRWH.

Purpose	Percentage of households (%)			
	<100 m	100-500 m	500-1,000 m	>1,000 m
Drinking	50	39	6	5
Cooking	52	39	6	3
Bathing	27	29	26	18

Water Quality Perceptions and Drinking Water Priorities

According to the survey data, before RRWH units were introduced, most of the households fulfilled their domestic water requirements from open wells (priority 1) throughout the year (Table 1). However, after introducing the RRWH units, their priority for available water sources changed, particularly in the dry periods, with many now preferring rainwater, as shown in Table 3. In almost all the households with RRWH units, rainwater was used in combination with other sources during certain periods of the year. However, during the dry periods the most crucial water source for 71 % of the households has become stored rainwater (Table 3).

Table 3. Prioritization of water source by users during dry periods.

Source	Percentage of households*		
	Priority 1	Priority 2	Priority 3
Open wells	24	40	10
Tubewells	3	32	5
Pipe-borne water	2	0	0
Lake	0	8	62
River	0	0	10
Rainwater harvesting	71	20	13

Note: * Multiple answers

According to the survey results shown in Table 4, more than 85 % of households use stored rainwater for drinking. Easy accessibility of water, cleanliness and quality assurance by project staff are the main reasons for this. They also mentioned depletion of water levels in drinking wells and high concentrations of fluoride in groundwater. The reasons for not drinking it were mainly focused on quality and palatability.

Table 4. Reasons for drinking or not drinking stored rainwater.

Reason	Households* (%)
Drinking	
Long distance to the nearest water source	6
Easy access of water	40
Cleanliness	39
Quality assurance by project partners	11
Hygienic and healthy	4
Not drinking	
Cement taste in water	13
Easy accessibility of good-quality water	20
Lack of tank cover or filter	40
Unclean roof surface	14
Hygienically unhealthy	13

Note: *Multiple answers

One of the primary objectives of RRWH systems is to provide an assured supply of quality water at the homestead. Perceptions about the quality of rainwater are summarized in Table 5, which shows that more than 62 % of the respondents stated that the quality of rainwater was good and suitable for drinking without boiling.

Table 5. Quality perception of harvested rainwater.

Perception	Households* (%)
Quality of water is poor and not good for drinking	10
Quality of water is poor but can be used for drinking after boiling	3
Quality of water is good but cannot be used for drinking without boiling	20
Quality of water is good and can be used for drinking without boiling	62
No answer	5

Note: *Multiple answers

Status of Rainwater Harvesting Units

There are a number of houses that use RRWH units without proper gutters, down pipes, filters and tank lids. All these deviations from the standard method for a RRWH system affect the quality of stored water. Collection of water depends on two main factors: intensity of rainfall and roof coverage (the area installed with a gutter to collect the runoff). In most houses the roof coverage for harvesting is only between 25-50 %, which may affect water collection in dry periods because occasional rains during inter-monsoonal periods do not fill the tank to its capacity.

Although the project partners recognized concrete lids as standard, several other types of tank lids such as wood, aluminum and plastic have also been used. A large number of households do not seal the tank opening securely, which leads to mosquito breeding. In addition, about 30 % of households practiced rainwater harvesting without a filter. This can support mosquito breeding and contamination of the water with external materials such as leaf litter, animal and birds excreta, and can even lead to the growth of small fauna and flora given the increased nutrient content of the water. More than 50 % of beneficiaries of the RRWH system responded that roof litter was the main problem for water quality deterioration during the storage period.

Use of Rainwater for Animal Husbandry and Home Gardening

The total water requirement for animals and home gardening is met with other sources of water and harvested rainwater is rarely used unless the household rears one or two animals. Stored water is never used for home gardening mainly because the tank capacity is insufficient to meet the water requirement for such a purpose.

Adequacy of Stored Rainwater

Storage tanks of 5 m^3 are usually recommended to meet the water demand for a 50-day dry period, based on a designed parameter of 20 liters per person per day for a family of five members (Hapugoda 1995). Water demand can vary between 25 and 30 liters per person per day for all domestic purposes depending on the season and availability of water (Ariyabandu and Aheeyar 2000). However, households have often complained about the inadequacy of stored rainwater capacity for dry periods (Table 6).

Table 6. Adequacy of rainwater storage tank as a supplementary water source.

Level of adequacy	Season	
	Wet (%)	Dry (%)
More than adequate	10	0
Adequate	84	21
Satisfactory	6	19
Not adequate	0	60

Those who responded positively to the adequacy of the stored rainwater had sufficient water due to judicious water management and control. Those households that used water during the wet season for domestic activities understood the water availability in the tank. In the dry season, water was mainly used for drinking and also for cooking particular foods, for example, such households believe that the lentil curry can be cooked well with rainwater.

Maintenance of Rainwater Harvesting Units

Regular maintenance of RRWH units is important to obtain good quality water as well as to ensure the sustainability of the tank. More than 60 % of respondents clean the system at least once a year but 6 % do not clean the system at all. Most of the respondents have doubts about the consistency of rainfall. Moreover, people hesitate to clean the system in view of household water security and in case the rains are delayed. The respondents were asked about the problems encountered in RRWH and raised several issues that are summarized in Table 7.

Table 7. The problems encountered with the practice of RRWH.

Problems	Households (%)
Maintenance difficulties	37
Technological problems	30
Insects vector problems	30
No problems	3

Most of the households stated that the maintenance of the system was difficult. Another major reason was technical problems during construction, partly because not all the components were provided with the unit under the subsidy (for instance, gutters, down pipes, first flush device). Later, filters and tank lids were incorporated into the subsidy under the Asian Development Bank (ADB) project. In the case of the components that were not covered by the subsidy, the beneficiaries were requested to install such parts using their resources. The ability to purchase these materials depends on the financial capability of households. The absence of lids and filters has allowed harmful matter to enter into the tank creating health problems for poor people and opportunities for insect vectors to breed.

Water Quality Analysis

According to the results of stored rainwater sample analysis, most of the water quality parameters are within the acceptable range with respect to potable water quality standards for Sri Lanka (Sri Lankan Standards; 614, 1983). These include color, turbidity, electrical conductivity (EC), total alkalinity, nitrate, nitrite, chlorides, sulphate, phosphate, total iron, biochemical oxygen demand (BOD), fluoride and Escherichia Coli (E. Coli).

Ammonium nitrogen, pH and total coliform were above acceptable limits in a number of samples. The pH levels range from 8.25-10.71 (Figure 1), which may be caused by rehydration of cement mortar in the tank. Normally, rainwater becomes acidic when it mixes with atmospheric carbon dioxide, producing carbonic acid, which could increase corrosion in the tank. In addition, during thunderstorms, large amounts of nitrogen are oxidized to N_2O_5 and its union with rainwater produces nitric acid. Ammonium nitrogen concentration values vary from 0-0.59 mg/l and are higher than the Sri Lankan Standards 614 of 0.15 mg/l (Figure 2). It can be found in storage tanks because of the biological decomposition of protein substances such as bird droppings and dead insects from roofs and gutters, and the RRWH system needs to have measures to prevent such contamination.

Figure 1. Variation of pH values of stored RRWH units during sample periods.

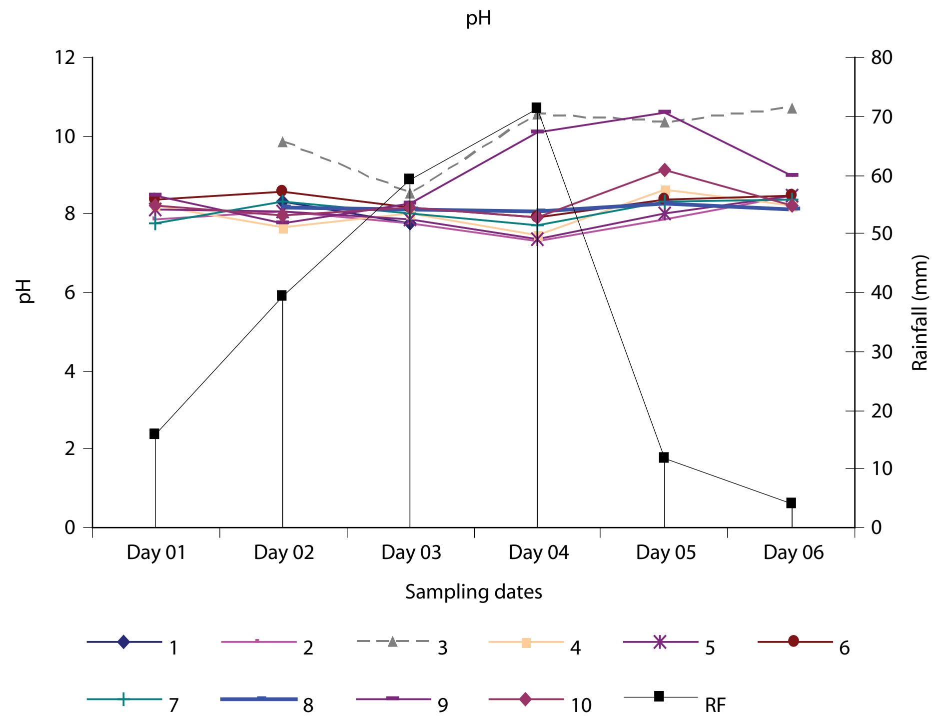
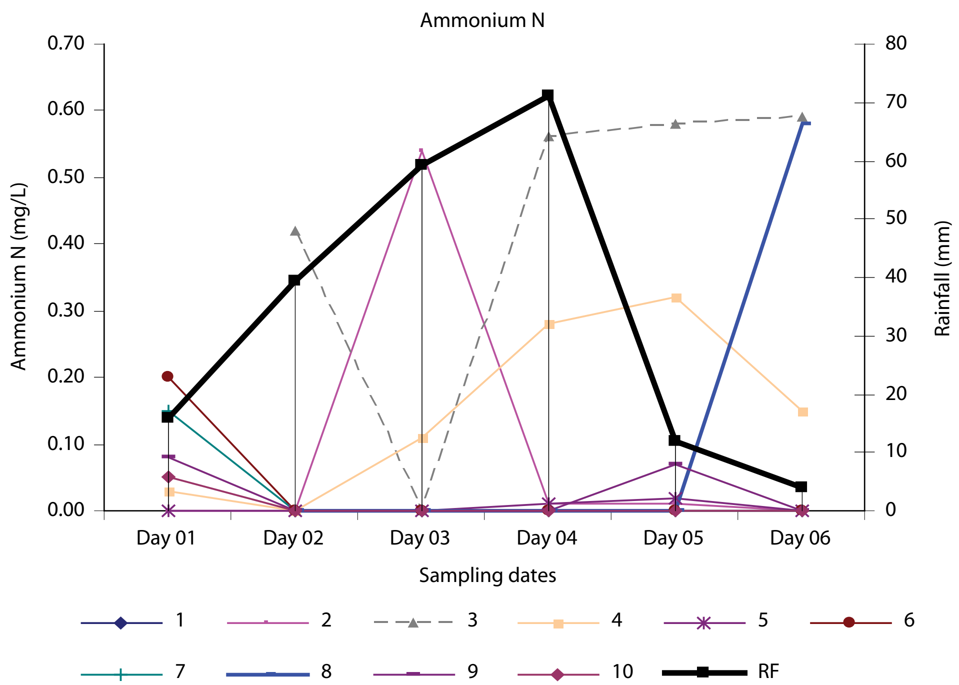
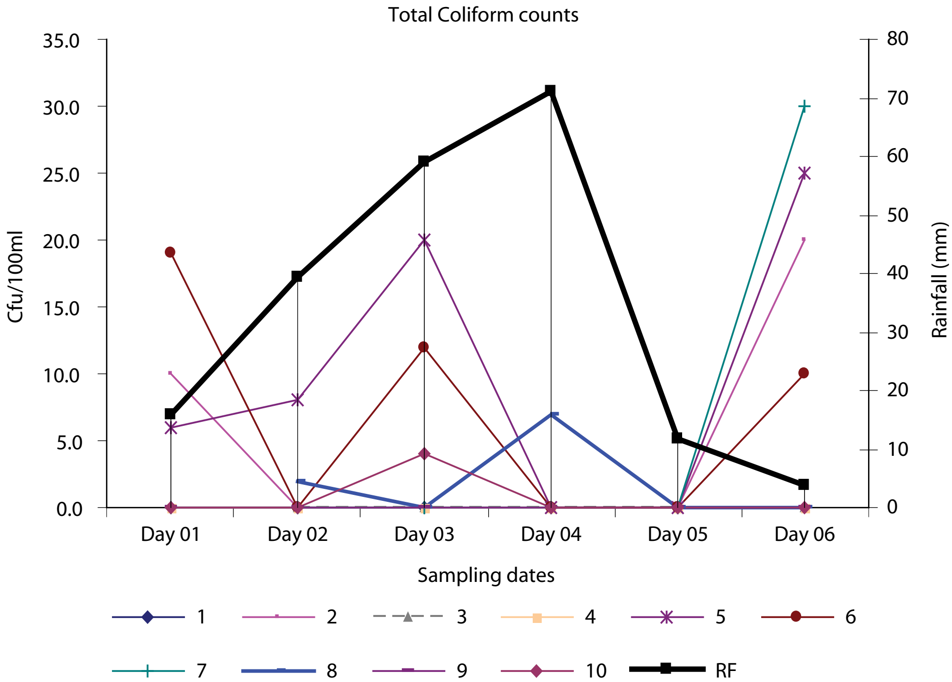


Figure 2. Variation of ammonium nitrogen values of stored RRWH units during sample periods.



Total coliform counts ranged from 0 to 30 (Figure 3) but the permissible level, according to the Sri Lankan Standard 614, is 10. The bacteriological quality of the stored rainwater, based on the faecal coliform count, does not meet the SLS or the WHO standards either (SLIS, 1983; WHO, 2008). A similar result was obtained in a study carried out by Ariyananda (2001). Coliform bacteria can attach to some of the tiny clay particles dispersed in the atmosphere, which mix with raindrops and enter the tank during rainy periods (UNEP 2000). Bird and animal excreta on the roof will add to the total coliform count as they will be washed into the tank. These hypotheses are supported by the fact that those households with the highest coliform and faecal coliform counts did not have filters or lids.

Figure 3. Variation of total coliform counts of stored RRWH units during sample periods.



For the other main water sources sampled, colour, turbidity, EC, nitrogen, nitrite, chloride, sulfate, phosphate, BOD and E. Coli were within an acceptable range. Observed pH, total alkalinity, fluoride, total Coliform and hardness values were higher than the desirable level of Sri Lankan standards but were within the acceptance level. The ammonium nitrogen concentration obtained was higher than the permissible level in potable water.

Conclusions

In most cases where RRWH is practiced, only 50 % of the roof area is utilized for the collection of rainwater due to the poor arrangement of gutters for water collection. This indicates that there is potential to improve the total water quantity harvested at each household.

Although the priority water source before the introduction of RRWH was open wells, harvested rainwater has become the priority source now, especially during dry periods. The perceptions and attitudes of people towards the use of stored rainwater for drinking have also changed. From the total sampled population, 85 % use rainwater for drinking although some have concerns about the quality and use it only after boiling. The acceptability of rainwater for consumption was very high in water-scarce areas and such acceptability improves with increasing distance to the nearest and alternative source of good quality water.

The stored water meets the Sri Lankan potable water quality standard in terms of chemical and physical parameters but not biological parameters since the total coliform count exceeded the permissible standards. Therefore, the boiling of this water should be recommended before drinking.

The quality of the main water sources are within the Sri Lankan potable water quality standards except for EC, total alkalinity, hardness, ammonium nitrogen, fluorides and total iron, which are higher than the stored rainwater.

The biological quality of stored rainwater is below that of the main water sources. The use of proper structural devices, first flushing and periodic treatment (e.g., chlorination) of stored rainwater may improve its quality and could increase user-confidence in this alternative water source.

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