Analysis of Quality and Consumer Preference for Harvested Rainwater in Anuradhapura District

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ABSTRACT. *This study includes development of an interactive simulation model to determine the dynamics of rainwater collecting tanks based on rainfall distribution in different Agro Ecological Regions. Further, the study also makes an attempt to assess water quality in stored rainwater through laboratory analysis and evaluate consumer preference for domestic rainwater by a questionnaire survey in Anuradhapura district.*

The developed model for rainwater tank dynamics can be used to find out suitable tank capacities for a given Agro Ecological Region with respect to catchment area and household water demand. It also provides information on the available daily consumption of rainwater for a given family size in a given Agro Ecological Region. The Rainwater Harvesting (RWH) model can be used in determining capacity of tanks, roof size, and utilization pattern in Domestic Rainwater Harvesting (DRWH). The ability to simulate different components in the rainwater tank water balance would also be helpful in understanding the dynamics of rainwater and tank hydrology in DRWH.

The utilization of roof area has been less than 50% in most of the cases and this is due to the poor arrangements of water collection mechanism from roofs through gutters. It indicates that there is a potential for improving the total water quantity harvested at each household.

Although the previous priority water was open wells, harvested rainwater has become the priority source now, especially of DRWH during dry periods. The perception and attitudes of people have changed for the use of stored rainwater for drinking. From the total sampled population, 85% use rainwater for drinking although some have concerns on the quality and use only after boiling. The acceptability of rainwater for consumption was very high in water scarce areas and with the increasing distance to the nearest good quality water source.

Analysis revealed that chemical and physical quality parameters of stored rainwater meet the Sri Lanka Standards (SLS) of potable water quality but, the biological parameters such as total Coliform count are always above the expected SLS. Further, biological condition of stored rainwater was always lower when compared to the quality of other water sources.

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INTRODUCTION

Domestic Rainwater Harvesting (DRWH) is not a new concept as most of the rural as well as sub urban houses in the Asian region collect water at times of rain. In most cases, this collection has been mainly for reasons of convenience for the household rather than a planned supply option. Rainfall in all zones of Sri Lanka is adequate to initiate rainwater harvesting (Chandrapala, 1996; Rajkuma, 1998). A feasibility study of DRWH revealed that DRWH could be successfully practiced in all parts of Sri Lanka (Hapugoda, 1995). According to the information available in literature, one could observe different types of rainwater harvesting systems adopted by rural people for domestic use in almost all parts of Sri Lanka (Ariyabandu, 1998).

In typical DRWH, rainwater from the house roof is collected in a storage vessel or tank for use during the periods of scarcity. Usually these systems are designed to support the drinking and cooking needs of the family at the doorstep. Such a system usually comprises of the roof, a storage tank and guttering to transport the water from the roof to the storage tank. In addition, a first flush system to divert the dirty water which 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 provided.

Rainwater harvesting has brought much relief during times of drought and water scarcity for many people living in rural areas of the country and also it is an attractive option in areas where adequate quantity of fresh surface water or groundwater is lacking. At present, more than 21,000 rainwater harvesting systems are in operation throughout the country (Ariyananda, 2004).

Though the rainwater harvesting has been accepted as an alternative rural water supply source in Sri Lanka, less than 10% of households consume rainwater out of those who have acquired DRWH systems (Ariyabandu and Aheeyar, 2000). The main reason for this is the perception of users on quality of harvested water during the storage period. Several initiatives have been made by organizations like NGO's to change these misconceptions and the situation is changing rapidly.

In a rainwater harvesting system, if the rainwater is stored for longer periods, then the quality of water may change. Deteriorated water may cause various health problems to the consumer. Hence, it is very important to study how water quality changes during the storage period inside a tank under dry zone conditions. The average tank size suited to Sri Lanka is yet to be found by research as it may differ from location to location according to the length of the dry period, rainfall pattern and the per capita water consumption.

Heijen and Mansur (1998) investigated the improvement in water security of the DRWH beneficiary community and showed that it remains neglected due to lack of awareness and recognition by policy makers on the technology. As a result, the prospect of rainwater harvesting in Sri Lanka would primarily depend on consumer attitudes and user perceptions on roof water as a drinkable domestic source. In the past few years, many studies were conducted to evolve better techniques of DRWH, but less emphasis was given to consumer attitudes and user perceptions for domestic consumption and quality of harvested water during the storage period. This study includes development of an interactive simulation model to determine the dynamics of rainwater collecting tanks based on rainfall distribution in different Agro Ecological Regions. Further, the study also attempts to assess the water quality in stored rainwater through laboratory analysis and by evaluating consumer preference for domestic rainwater by a questionnaire survey in Anuradhapura district in order to suggest the suitability of stored rainwater for domestic use.

MATERIALS AND METHODS

The study area

The study was conducted in Anuradhapura district (DL), which occupies a significant portion of the dry zone. In the dry zone, most of the heavy storms are concentrated in the months of October to December during North East monsoon period (*Maha*). However, a significant dry period can be seen from May to September. Anuradhapura district consists of 22 divisional secretariat (DS) divisions. A population of 746,756 is dispersed among those DS divisions. Majority of households (59.6%) obtain drinking water requirement from protected wells and 13.7% from tube wells and the rest use water from unprotected wells, pipe born water, tanks and reservoirs for their consumption (Census of population and housing, Anuradhapura, 2001).

Sampling

Nearly 2800 rainwater harvesting systems constructed by the National Water Supply and Drainage Board (NWS and DB) are dispersed among 10 DS divisions in the study area. These tanks were selected as the study population and within that, six households were selected randomly for a questionnaire survey from each DS division as a sample. For water quality testing, 10 stored rainwater samples were collected on weekly basis for a period of two months using stratified sampling technique. Simultaneously, water samples from main water source of the selected households were also collected once for water quality analysis. Primary data were collected through a structured questionnaire survey and the process of key informant discussions. Secondary data were collected through a literature survey and several institutions involved in rainwater harvesting were approached to obtain data and information.

Model development

The corresponding weekly rainfall in a given Agro Ecological Region and household water demand were key variables, which determines the capacity of tanks. The per capita water consumption, runoff coefficients, and other required data for model development were gathered from secondary data sources. Finally, an interactive simulation model was developed to determine the dynamics of the tank operations for rainwater harvesting for a particular Agro Ecological Region.

Questionnaire survey

A questionnaire was used to gather information about household roof rainwater harvesting situation in Anuradhapura District. The structured questionnaire which was prepared for Moneragala district (Gunawardana *et al.*, 2005) was used for this study with some modifications. Questionnaires were filled by interviewing the households and by observing the existing rainwater harvesting systems.

Water sample analysis

According to the samples selected from the household survey, 10 households were selected based on the roof materials and filter availability for water quality testing of stored rainwater. Simultaneously, water quality of main water source used for domestic purpose was also tested. All water samples were analyzed for important physical, chemical and biological parameters for drinking water at the regional laboratory of NWS and DB in Anuradhapura. The sampling period was nearly 2 months from November to December in 2005.

Data Analysis

The model for tank dynamics, which was developed by Wickramasinghe and De Silva (2004) and modified by (Gunawardana *et al.*, 2005) was further improved to determine the tank capacity with respect to rainfall, roof catchment and water demand in weekly basis for different Agro Ecological Regions. In addition, all the survey data were analyzed by using statistical package SPSS. Water quality was analyzed for stored rainwater and compared with the quality of main water source for that household. At the same time, the effects of roof, filter type and the presence of rainfall during the sampling period on the stored rainwater were investigated.

RESULTS AND DISCUSSION

Model for rainwater tank dynamics

The model is developed in Microsoft Excel environment and it consists of three different worksheets, for data entry, data storing and data processing. Given the capacity, it can also provide information on the required roof size to fill the capacity and consumption level to supply water throughout the year. There are two interfaces (tabular and graphical), which provides dynamic results of the simulation (Fig. 1).

According to the developed model, tank capacity for the five member family residence at DL1e region in Anuradhapura district for whole domestic consumption was nearly 24,000 liters. It was assumed that the roof is asbestos with a catchment of 100 m^2 and per capita water consumption per person is 35 liters. Since there were no significant differences among the water usage in dry and rainy seasons, average water usage during the dry season was taken for all calculations. The model also provides information whether RWH is feasible within the given set of constraints.

Implementation of rainwater harvesting programmes in Anuradhapura district

Agriculture is the main income generating activity of which 75% of the total population is engaged in the district (Census of population and housing, Anuradhapura, 2001). In ancient times, they had usually practiced collecting of rainwater for agricultural purposes by trapping surface runoff. Therefore, a large number of surface water collection reservoirs are available in this area.

By the end of 2005, more than 2800 rainwater tanks had been constructed by NWS&DB, Anuradhapura, under Asian Development Bank (ADB) project. In addition, several other organizations like CARE, *Rajarata Navodaya etc*., had also contributed to the use of rainwater in Anuradhapura.

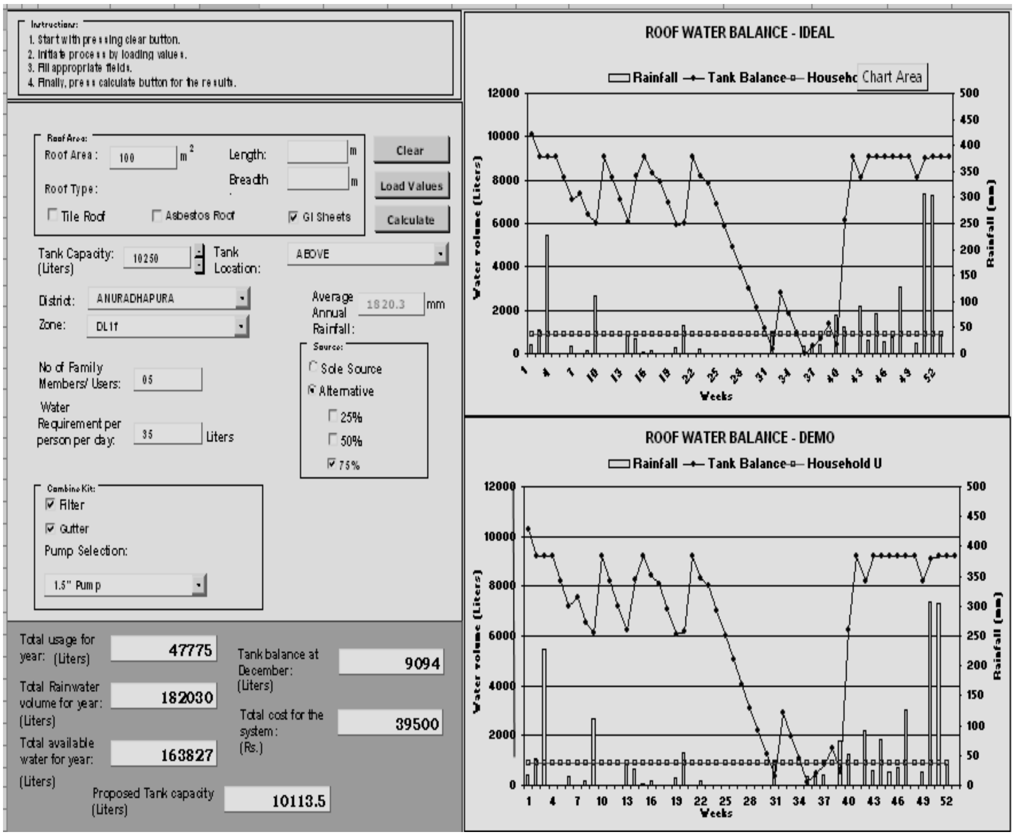

Fig. 1. Rainwater harvesting model (input window).

Source of domestic water

The rainwater user communities do not depend totally on stored rainwater for domestic purposes. Other conventional sources are also used for domestic needs. Table 1 indicates six priority water sources available in the area. Most of the people had given their first priority to open wells because they believe that water in open wells is better in quality and potable.

Table 2 shows that more than 50% of households fetch water from closer distance for drinking purposes but according to the findings of the survey the quality and water availability changed with season. The perception of water quality in those sources was not in favor of rainwater harvesting totally. However, introduction of DRWH has significantly reduced travel time for fetching water and increased the availability of quality water at doorstep while improving quality of rural life.

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

Source	Priority* (%)		
	1	2	3
Open wells	63	03	05
Tube wells	33	02	02
Pipe born water	02	-	-
Lake	-	50	08
River	02	-	05
Rainwater harvesting	-	45	80

Note: *Multiple answers.

Table 2. Travel distance to the water source before introduction of DRWH (% households).

Purpose	Distant (m)			
	<100	100-500	500-1000	>1000
Drinking	50	39	06	05
Cooking	52	39	06	03
Bathing	27	29	26	18

Status of rainwater harvesting units

According to the findings of the survey, there is a wide variety in types of roof, gutters and filters. The used roof area (catchment area) for harvesting rainwater also varies depending on the availability of gutters. Collection of water depends on two main factors, intensity of rainfall and roof coverage. Size of the roof is not very important, because what matters is the roof size that has been installed with proper gutter to collect roof runoff.

However, there are a number of houses at present that use DRWH units to collect rainwater without having proper gutters, down pipes, filters and tank lids. Further, different households use different types of roofs, gutters and tank lids. All these deviations from the standard type affect the quality of stored water.

In most houses the roof coverage for harvesting is only between 25-50%. It indicates that rain is captured from one side of the roof or less than one half. This affects water collection in dry periods because occasional rains during inter monsoonal period do not fill the tank to its capacity. Roof type of the majority households was tile (68%) and the rest was of various other types or a combination of several materials.

Use of rainwater as a drinking source

The general objective of the Community Water Supply and Sanitation Project was introducing DRWH units at domestic levels to provide a drinking water source at doorstep. This is because all other water supply options like pipe born water, tube wells, groundwater *etc*., have failed to establish a convenient water supply source in a particular area in the district. According to the survey data before introducing DRWH units, most of the households fulfilled their domestic water requirements from open well water (first priority) throughout the year (Table 1). However, after introducing the DRWH units, their priority for available water sources changed particularly in dry periods as shown in Table 3.

Table 3. Prioritization of water source by users during dry periods (% households).

Source	Priority* (%)		
	1	2	3
Open wells	24	40	10
Tube wells	03	32	05
Pipe born water	02	-	-
Lake	-	08	62
River	-	-	10
Rainwater harvesting	71	20	13

Note: *Multiple answers.

In almost all the rainwater harvesters, the households used rainwater as a partial source of water in combination with other sources during some periods of the year. However, after introducing DRWH units, the most crucial water source is stored rainwater during dry periods for 71% of the households (Table 3).

According to the survey results, more than 85% households use stored rainwater for drinking. Easy accessibility of water, cleanliness and quality assurance by project partners are the main reasons for drinking stored rainwater. Those who do not drink rainwater attribute several reasons for non-consumption of rainwater (Table 4). Depletion of water levels in drinking wells and high concentration of Fluoride in groundwater were also given as other reasons for the high demand for rainwater as shown in Table 4.

Quality perception of harvested rainwater

One of the primary objectives of the provision of DRWH systems was to provide an assured supply of quality water at the homestead. The perceptions about the quality of rainwater consuming households are summarized in Table 5. More than 62% of the respondents stated that the quality of rainwater was good and suitable for drinking without boiling.

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

Reason	Households* (%)
Drinking	
Long distance to the nearest water source	06
Easy access of water	40
Cleanliness	39
Quality assurance by project partners	11
Hygienic & healthy	04
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.

Table 5. Quality perception of harvested rainwater by users.

Perception	Household (%)
Quality of water is poor and not good for drinking	10
Quality of water is poor but, can use for drinking after boiling	03
Quality of water is good but can not be used for drinking without boiling	20
Quality of water is good and can be used for drinking without boiling	62
No answer	05

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

Duration of stored rainwater use

Rainwater alone is not sufficient for all domestic purposes due to inadequate storage capacity. However, they manage to keep the water available for drinking throughout the year by understanding the domestic demand. During rainy periods, stored rainwater was used for most of domestic activities. However, during the dry periods with the available storage volume, they restricted the usage for other activities and saved the harvested water for drinking purposes until the next effective rain occurs.

Adequacy of stored rainwater

Storage tank of five (5) cubic meters was designed on the basis of 20 liters per person per day for a family of 5 members to meet the water demand for a 50 - day dry period (Hapugoda, 1995). Water demand can vary between 25 to 30 liters per person per day depending on the season and availability of water (Ariyabandu and Aheeyar, 2000). Under this situation, 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 level of adequacy had adequate water due to judicious water management and control. Those households used water during wet season for domestic activities, understood about water availability of the tank. In case of the dry season, water was mainly used for drinking and also for cooking particular foods. For an example, they believe that the lentil curry could be cooked well with rainwater.

Maintenance of rainwater harvesting units

Maintenance of DRWH units at regular intervals is important to obtain good quality water as well as to ensure the sustainability of the tank. More than 60% of them clean the system at least once a year and 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 the household water security, in case where rains are delayed. The respondents were asked about the problems encountered with the practice of DRWH. They raised several matters and these are summarized in Table 7.

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

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

According to Table 7, most of the households stated that the maintenance of the system was difficult. The other major reasons were technical problems encountered with construction and insects vector problems. The available units are at least without one of the structural components. It was noted that the installations of these structural components (for instance gutters, down pipes, first flush device) were not covered by the subsidy. However, filters and tank lid were later incorporated in the subsidy under the ADB project. In the case of the components that were not covered by the subsidy, the beneficiaries were requested to install from their own resources. The ability to purchase these materials depends on the financial capability of households. The absence of lids and filters has allowed harmful matters to enter into the tank creating health problems to the poor people who cannot afford to have these additional structural components.

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 standard in Sri Lanka (Sri Lankan Standards; 614, 1983). Those parameters are Colour, Turbidity, Electrical Conductivity (EC), total Alkalinity, Nitrate, Nitrite, Chlorides, Sulphate, Phosphate, total Iron, BOD, Fluoride and *Escherichia Coli.*

Colour and the concentration of Nitrate, Fluoride and total Iron are beyond the desirable level of acceptance in one or two occasions, more specifically in household numbers 2, 3, 4 and 9. However, those were within the acceptable range according to the Sri Lankan potable water quality standards. Parameters of pH, Ammonium Nitrogen and total *Colifom* observed are not acceptable in a number of samples. Table 8 marks the occurrence times and samples which are above permissible levels.

According to Table 8, the water quality parameter most frequently affected was Ammonium Nitrogen (NH_4-N). pH, Ammonium Nitrogen and total *Coliform* have shown higher concentrations above the permissible levels in most of the rainwater samples. The pH levels range from 8.25-10.71 (Fig. 2). Release of cement by products during hydration of cement mortar may be a reason for high pH value. All the recorded high pH values were collected from tile roofs. Normally, rainwater becomes acidic mainly by mixing with atmospheric CO_2 and producing carbonic acid. In addition, during thunder storms, large amounts of nitrogen are oxidized to N_2O_5 and its union with rainwater produces Nitric acid.

Table 8. Water samples with higher values for some of the tested water quality parameters.

Household No	Colour	pH	Ammonium Nitrogen	Nitrite	Fluoride	Total Iron	Total *Coliform*
1							
2	*		*		*		*
3		**	**			*	
4	*		*				
5							**
6			*				*
7			*				
8			*				
9		**		*			
10		*					

Note: *Just above the permissible level (2-3 occasions); **Records were obtained above the permissible level (>3 occasions).

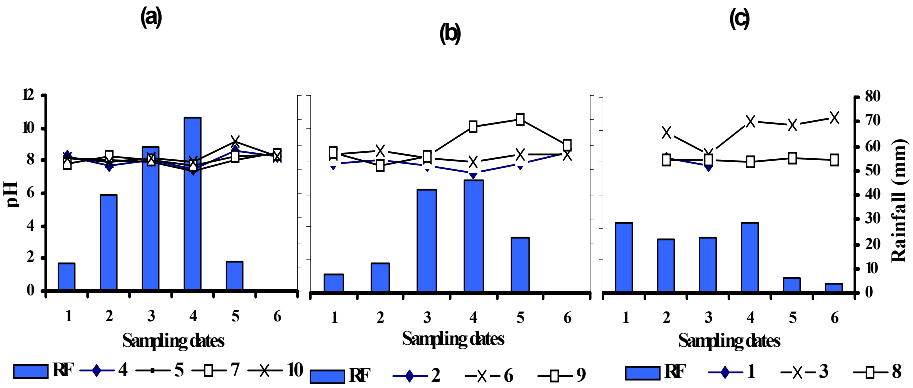

Fig. 2. Variation of pH values of stored DRWH units during sampling periods.
Note: a - Galenbindunuwewa; b - Medawachchiya; c - Nochchiyagama.

The results of 10 households for Ammonium Nitrogen test are presented in Figure 3. These indicate that Ammonium Nitrogen concentration values vary from 0-0.59 mg/l and are higher than the Sri Lankan Standards 614 (0.15 mg/l). The presence of Ammonium Nitrogen in storage tank may be from the process of biological decomposition of protein substances such as bird droppings and dead insects from roof and gutter and needs precautions to prevent such situations. Results of total *Coliform* test of 10 households are presented in Figure 4.

The total *Coliform* counts were ranged from 0-30, but acceptable level (permissible level) is 10 according to the Sri Lankan standard 614. None of the samples in Nochchiyagama recorded higher total *Coliforms* than the Sri Lankan standard value of 10 Cfu/100 ml (Fig. 4c).

Coliform bacteria can get attached to some of the tiny clay particles dispersed in the atmosphere. When rain occurs, these tiny clay particles mix with raindrops and enter into the tank with rainwater (UNEP, 2000). This may be the one reason for high level of total *Coliform* observed in rainwater samples. The bird's excreta coming from roof litters also can be a contributory factor. The households where higher *Coliform* counts were found did not have any filter, tank lid or both.

In the case of main water source sample analysis, Colour, Turbidity, EC, Nitrogen, Nitrite, Chloride, Sulfate, Phosphate, BOD, total *Coliform*, *Escherichia Coli* were in acceptable range and very low concentration levels with respect to the desirable level of each parameters except total Iron. It was shown that high concentration level beyond the desirable level is only in one occasion but that was also within the permissible level. Observed pH, total Alkalinity, Fluoride, total *Coliform* and Hardness values were shown to be higher than the desirable level of Sri Lankan standards. However, these values were within the range of the acceptance level. The Ammonium Nitrogen concentration obtained was higher with respect to the permissible level in potable water.

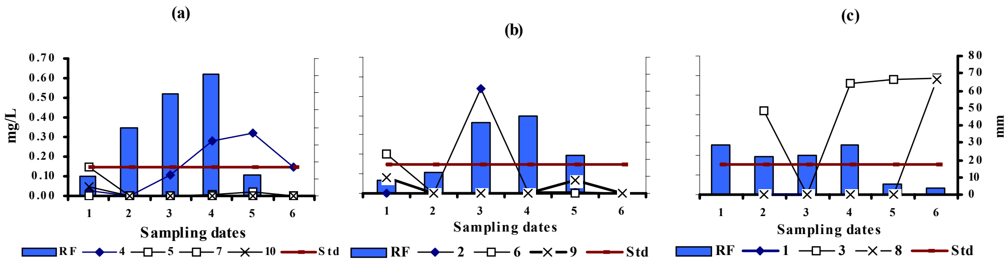

Fig. 3. Variation of Ammonium N values of stored DRWH units during sampling periods.

Note: a - Galenbindunuwewa; b - Medawachchiya; c - Nochchiyagama; std. - Standard level.

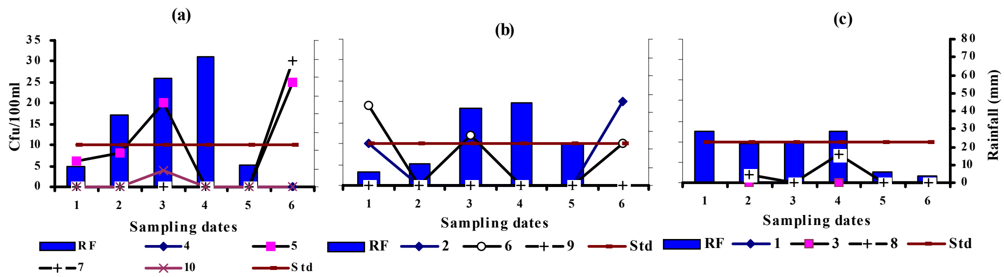

Fig.4. Variation of total *coliform* counts of stored DRWH units during sampling periods.

Note: a - Galenbindunuwewa; b - Medawachchiya; c - Nochchiyagama.

CONCLUSIONS

The accuracy of the modified rainwater harvesting model, incorporating the improved equations for tank balance and household demand permits the prediction of both monthly and weekly tank water balance in rainwater harvesting tank throughout the year. This model can be used in decision making process in domestic rainwater harvesting. The ability to simulate different components in the rainwater tank water balance would also be helpful in understanding the tank dynamics of rainwater tank hydrology in DRWH. The utilization of roof area for collection of rainwater has been less than 50% in most of the cases and this is due to the poor arrangements of water collection mechanism from roofs through gutters. It indicates that there is a potential for improving the total water quantity harvested at each household.

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

Chemical and physical quality parameters of the stored rainwater meets the Sri Lankan potable water quality standard but biological parameter total *Coliform* count was beyond the standards. Therefore, boiling of this water can be recommended before drinking.

The quality parameters of the main water source are within the Sri Lankan potable water quality standards except parameters like EC, total Alkalinity, Hardness, Ammonium Nitrogen, Fluorides and total Iron, which are higher compared to the stored rainwater. This can be taken up as an important finding to justify the use of rainwater for drinking purpose.

However, biological condition of stored rainwater was not up to the standards and it is poor when compared with the main water source. The critical water quality parameter is Ammonium Nitrogen for both sources. The use of proper structural devices, first flushing and periodic treatment (eg. chlorination) of stored rainwater may improve the quality and could increase user trust on rainwater quality.

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