Domestic Roofwater Harvesting
Research Programme

VERY-LOW-COST DOMESTIC ROOFWATER HARVESTING IN THE HUMID TROPICS: USER TRIALS

DFID KaR Contract R7833

Report R3

June 2003

Development Technology Unit

School of Engineering, University of Warwick

THE UNIVERSITY OF WARWICK

CONTENTS

1 INTRODUCTION

This document reports on the field-testing of a number of designs developed and described in the report “New Technology for Very-Low-Cost Domestic Roofwater Harvesting” presented in April 2002. The surveys, both technical and socio-economic were undertaken at 8 sites spread over the 3 participating countries Ethiopia, Sri Lanka and Uganda. The original design had identified 3 sites in each country, one urban/peri-urban and two rural/large village. Security problems in N Uganda removed one site near Gulu part way through the programme, leaving 3 urban and 5 rural sites.

The study has been conducted over a period of two years. In the first year various tank designs were developed and socio-gender studies were conducted at each of the study communities to examine water sourcing behaviour and use, complemented by individual household interviews. The latter households formed the core group which participated in the technology trials during the second year. In some instances it was necessary to find replacements because a few of the original households withdrew from the study[1]. Different designs and sizes of tanks, short-listed for their suitability for each site, were allocated to 20 to 25 participating households randomly at that site. In Sri Lanka the allocation was partly stratified by the size of tanks and households: smaller tanks were allocated randomly to smaller households, and larger tanks to larger households.

Table 1.1: Site Characteristics & Households Participating in Technology Trials

Characteristics of site	Ethiopia			Uganda		Sri Lanka		
	Addis	Arerti	Alaba	Kampala	Kibengo, Mbarara	Colombo	Aranayaka Kegalle	Ambanpola Kurunagala
Location	Peri-urban	Big village	Small town	Peri-uban	Village	Railside slum	Scattered settlement	Scattered settlement
Wet months/year	6	7	6	9	6	9	6	5
Wet seasons/year	2	2	2	2	2	2	2	1
Type of tank								
Tarpaulin (12)		7	5	-	-		-	
Barrel (34)	15			4	1	14	-	
Dome (37)			5	13	6		6	7
ELM.R (27)		1	5	-	7		7	7
Tube (22)		7	5	-	4		6	-
Crate (6)				-	-	6		-
Mud (5)				-	-		1	4
Control – no tank (30)	10	5	5	-	1	5	2	2
Total HHs (173)	25	20	25	17	19	25	22	20

This Report was originally scheduled for November 2002. However as its purpose is to report performance, user behaviour and user opinions of newly installed DRWH systems, it was delayed to

[1] Reasons for modifying sample:

(i) fear of being overlooked in alternative water schemes: households in Nabweru, Kampala feared that by participating in the DRWH study they may be missed out in a piped water supply project that was to be implemented by the local leadership;
(ii) unsuitable location: the congested centre of Alaba, a market town, were the Year 1 survey had been conducted, was unsuitable for siting underground tanks; in Colombo, there was insufficient space between some dwellings for tanks and one household was refused permission from the railway authorities to install a gutter because it was too close to railway line;
(iii) lack of interest: households withdrew from the second stage of the study due to a lack of interest (all three sites in Sri Lanka and in Kampala), and misguided leadership (Ambanpola);
(iv) already benefiting from alternative water supplies: in Aranayaka the community requested the sample to be drawn again since some of the households participating in first survey already had access to improved water sources (such as a gravity water supply or permanent tank); and
(v) inability or unwillingness to upgrade to a permanent roof: one HH in Ambanpola.

reflect installation delays. Those in turn had been in part occasioned by climate irregularities and in one country even the delay did not allow final 'dry season' measurements to be made. (In Sri Lanka both wet and dry seasons ran several months behind their normal seasons in 2002-3.)

It should be noted that the 'user comments' upon which this Report is based were obtained from households which had possessed a roofwater harvesting system for at most one year and often only for a considerably shorter time. They were thus all relatively novice users of RWH technology and the systems themselves were 'young'. Experience elsewhere suggests that it often takes two or more seasons for householders to stabilise their usage of, and opinions of, a new water source.

1.1 Comparative Review of Key Country and Site Characteristics

This section sets the study in the context of key economic variables at country level and the socio-economic characteristics of the eight study sites.

Country characteristics

The partner countries fall into two groups: the predominantly agricultural economies of Ethiopia and Uganda, where over 80% of the workforce is engaged in agriculture generating almost half of the GDP, and Sri Lanka where the industrial and service sectors are much more important within the economy (Table 1.2). Nevertheless, all three countries are predominantly rural with less than 25% of their populations living in urban areas, although population densities vary markedly.

Table 1.2: Key Country Characteristics

Characteristics	Ethiopia	Uganda	Sri Lanka
Total population (millions) 2000[1]	63	23	19
Average annual growth rate in population (% pa) 1975 – 2000[1]	2.6	3.1	1.3
GDP per capita $ (PPP US$) 2000[1]	668	1208	3530
Average annual growth rate in total GDP (% pa) 1990 – 2000[2]	4.7	7.0	5.3
Average annual growth in per capita GDP (% pa) 1990 – 2000[1]	2.4	3.8	3.9
Incidence of poverty (% population below $1 a day (1993 PPP US$) 1983 – 2000[1]	31	no data	7
Percentage of workforce engaged in agriculture[3]	83	81	46
Percentage contribution of agriculture to GDP[4]	59	45	21
Population residing in rural areas (percentage of total population) 2000[2]	82	86	76
Rural population density (people per km^2 of arable land) 1999[2]	520	368	1660
Percentage of population with access to improved drinking supply, 2000[5]	Urban: 81 Rural: 12	Urban: 80 Rural: 47	Urban: 98 Rural: 70
Adult literacy rate (percentage of population aged 15 and above) 2000[1]	39	67	92
People living with HIV/AIDS (percentage of population aged 15 – 49) various dates[6]	Addis Ababa: 18 Rural areas: 4	Kampala: 12 Mbarara: 11	< 1
Life expectancy (years) 1995-2000[1]	45	42	72
Country ranking by Human Development Index, 2002 (out of a total ranking of 173 countries)[1]	168	150	89

PPP purchasing power parity expressed in US $

Sources:

1 UNDP (2002) Human Development Report
2 World Bank (2002) World Development Indicators
3 FAO (2001) FAOSTAT
4 World Bank (2000) World Development Indicators
5 WHO-UNICEF (2002) reported by UNDP
6 Ministry of Health, Ethiopia (2002); Ministry of Health, Uganda (2001)

The quality of life, as reflected in UNDP's Human Development Index, is much higher in Sri Lanka than the East African countries, in terms of per capita incomes, adult literacy and life expectancy. Sri Lanka also experiences a substantially lower incidence of HIV/AIDS than is found in East Africa. All three countries enjoyed positive rates of growth in total GDP and per capita GDP during the 1990s.

Based on national data, the need to adopt low cost water systems would appear to be greatest in Ethiopia and Uganda. These countries are experiencing considerable increases in population and the majority reside in scattered settlements in rural areas. Only a small proportion of their rural populations have sustainable access to improved drinking water (as defined by WHO-UNICEF as 20 litres per person per day from an improved water source within 1 km of home), let alone access to piped water supply. HIV/AIDS is a major threat to labour availability and opportunities to reduce the burden of daily workloads will be highly relevant[2]. However, the ability of these populations to adopt even low cost DRWH systems is constrained by their low purchasing power, the high incidence of poverty and their low levels of literacy (which influences their exposure to new technologies).

Characteristics of study sites

The data for the field sites are presented separately for the urban/peri-urban and rural sites. The three urban communities were situated on the periphery of their respective capital cities (Table 1.3). Most households were engaged in non-farm activities ranging from employment in either the public or private sectors to petty businesses and daily labouring. Farming activities were confined to livestock rearing in Addis Ababa but also included crop production in peri-urban Nabweru on the outskirts of Kampala. The majority of houses had hard roofs (iron sheets or tiles) and a high proportion had partial guttering, thereby providing ideal conditions for collecting rainwater. Despite the opportunity to harvest roofwater, few households had formal systems and, with the exception of Addis Ababa, informal RWH was rarely practised. In Kampala and Colombo, natural water sources, such as springs and wells, were the most common source of water and were free of charge. In Addis Ababa, most households purchased water from public tapstands.

The five rural study sites were predominately farming communities with a proportion of the population engaged in small-scale off-farm activities (Table 2.3). The majority of houses had hard roofs and whilst the experience of informal rainwater harvesting was widespread, only two sites (in Kibengo (U) and Aranayaka (SL)) had any previous experience of permanent DRWH. In Ethiopia, public tapstands and private vendors were the usual source of water, characterised by excessively long queues lasting for several days during the dry season. In Kibengo (U) most households used natural water sources in both the wet and dry seasons whilst in Sri Lanka, households used wells extensively supplemented by tubewells.

[2] Not only does HIV/AIDS decimate the labour base but it also increases the requirement for clean water for patient care and family hygiene.

Table 1.3: Socio-economic Comparisons of Urban and Peri-urban Study Sites

Site characteristics	Addis Ababa, Ethiopia	Kampala, Nabweru Sub County, Uganda	Colombo, Sri Lanka
Location	Urban, on the periphery	Peri-urban, 4 km from Kampala city centre	Urban, 5 km from city limits
Main forms of employment	All non-farm activities, some in government, others in private sector, petty businesses. Some keep livestock in compound	Mainly non-farm activities in private sector and small businesses; some professionals and daily labourers; some farming activities	All non-farm activities, either in business or labouring (for example, on building sites and in households)
Incidence of tenants in community		> 90% HHs are effectively owner occupiers (with customary lease from King of Buganda)	100% illegal occupation (adjacent to railway line)
Roofing materials in community	100% HHs have iron sheet roofs but few have partial guttering?	100% HHs have iron sheet roofs (although some old) and many (75% of HHs) have partial guttering	90% HHs have iron sheet roofs; 10% have tile or asbestos roofs
Piped water supplies - private		A few HHs have piped water in their homes. Installation costs expensive (US$ 120 excluding labour charges) but only US$ 0.4 per 1000 litres consumed	None
Private vendors	Nil	Some HHs purchase at US$ 3 per 1000 litres	Nil
Public tapstand	Used by all community. Cost US$ 0.5 per 1000 litres. Collect with 100 or 200 litre barrels on daily basis (do not leave barrels in queue).	Some HHs purchase at US$ 1.45 per 1000 litres, particularly when spring water is dirty after rains or long queues at springs.	Long queues at standpipes for several days after rain because well water unsuitable. Water available throughout the year. Good for drinking. No charge. Located within community.
Natural water sources (free of charge)	Stream used occasionally for fetching water for livestock.	Springs: widely used in wet and dry seasons (long queues). Sometimes contaminated. Some unprotected water holes.	Wells: widely used, water available throughout the year. Water becomes turbid after rainfall. Located within community.
Experience of informal rainwater harvesting	Widespread	Practiced by approximately 40% HHs	No
Previous experience of DRWH	No	A few rich HHs have polythene tanks (US$ 550 for 12 m^3)	No

The requirements to enable households to participate in the technology testing resulted in the composition of the sample being skewed in favour of owner occupiers and houses with impermeable roofs. Households headed by women were also sought purposively to ensure they had adequate representation; they accounted for 55% of sample in Alaba (E), 35% Arerti (E), 20% in Kibengo (U) and 10% of sample in Aranayaka (SL). Amongst the urban sites, female-headed households accounted for 20% of the sample in Addis Ababa, 25% in Colombo and 35% in Kampala.

Together the eight sites represent a wide variety of experiences with regards to existing water fetching behaviour, harvesting of rainwater and livelihood activities which were expected to influence response to permanent DRWH systems, at both the community and household levels. Thus opportunities for introducing and promoting DRWH differed quite significantly between the sites depending on the interplay of these key variables (Box 1.1).

Box 1.1: Opportunities for DRWH in Peri-urban and Rural Areas in Uganda

Peri-urban communities, such as Nabweru in the suburbs of Kampala, generally enjoy higher levels of incomes than rural communities, mostly in the form of cash rather than producing products for home consumption. They also have better access to sources of information and easy access to materials for tank construction. Although the coverage provided by piped water supply is gradually extending in these peri-urban areas, the costs of home installation (US$ 120) are often prohibitive even for middle income earners. At present most households fetch water from a spring and some also purchase from a tapstand or private vendor. All households have iron sheet roofs, the majority with gutters, and at least 90% of households are owner-occupiers. The community has had limited exposure to DRWH and less than half of the sample had considered installing a permanent DRWH system whereas many had considered installing tap water once piped water supplies reaches their area. Indeed some households were deterred from participating in the DRWH technology trials in case it compromised their chance to participate in a piped water supply project that was to be implemented by the local leadership.

The rural community of Kibengo, located in south west Uganda, is entirely reliant on natural water sources and fetching water becomes extremely arduous in the dry season. Informal rainwater harvesting is widespread; 80% of houses have iron sheet roofs and many have gutters. Interest in permanent DRWH is very high. The technology has been actively promoted for five years through NGO initiatives, such as ACORD, offering technical advice, occasionally backed up by financial support to women's groups and several households in the community already have permanent systems. Due to this exposure, coupled to the high level of water stress, most households had considered installing a permanent DRWH system but were constrained by: a shortage of funds, the expense of existing DRWH technology (which at US$ 550 represents twice the average annual income in the area), a lack of advice on cheap technologies, and the expense of transporting materials from the regional town to the community.

Table 2.3: Socio-economic Comparisons of Rural Study Sites

Site characteristics	Alaba, SNPPR, Ethiopia	Arerti, Oromiya Region, Ethiopia	Kibengo, Mbarara District, Uganda	Aranayaka, Kegalle District, Sri Lanka	Ambanpola, Kurunegala District, Sri Lanka
Location	Rural community in southern highlands	Rural community in central highlands	Rural community (1200 inhabitants) in south west Uganda	Rural village (1300 inhabitants) located in wet zone, Central Province	Rural village (1500 inhabitants) located in dry zone, North Western Province
Main forms of livelihood	Predominantly farming community; some trading and off-farm employment in small businesses.	Predominantly farming community; some trading and off-farm employment in small businesses.	Smallholder agriculture; some in trading, daily labouring, formal employment, small businesses	Predominantly farming community growing paddy and cash crops; a few work for government or the private sector. Unskilled labouring is main occupation for landless families. Half of HHs receive government welfare assistance.	Predominantly farming community growing seasonal crops. A few livestock keepers. Unskilled labouring is main occupation for landless families. Half of HHs receive government welfare assistance.
Roofing materials in community	95% of HHs have iron sheet roofs	95% of HHs have iron sheet roofs	80% HHs have iron sheet roofs; 20% thatched roofs. Most houses have gutters.	Most HHs have hard roofs; a few HHs have thatched roofs.	Majority of houses have tiled roofs, some with gutters. Others have thatched roofs.

Site characteristics	Alaba, SNPPR, Ethiopia	Arerti, Oromiya Region, Ethiopia	Kibengo, Mbarara District, Uganda	Aranayaka, Kegalle District, Sri Lanka	Ambanpola, Kurunegala District, Sri Lanka
Incidence of tenants in community	80% of community are tenants (mainly in government housing)		Very low	None	None
Piped water supplies	No	No	No	No	No
Private vendors	Widely used at a charge of US$ 1.2 per 1000 litres.	Widely used at a charge of US$ 1.2 per 1000 litres.	No	No	At least one farmer collects water from village tank in his tractor and sells to neighbours.
Public tapstand	Widely used at a charge of US$ 0.5 per 1000 litres. Queues up to two days in dry season. Located in community.	Widely used at a charge of US$ 0.5 for 1000 litres. Queues last for up to one week in dry season. Located in community.	No	Two stand posts located outside the village (> 2 km away downhill). Collect water from stand posts in nearby town and transport home in three wheeler vehicle.	Tubewell in village.
Natural water sources (free of charge)	Blatey river, 2 km away, used for bathing, washing clothes, watering livestock throughout the year, and when tapstands fail.	Pond and Burka river (7 km away) used in dry season and when tapstand fails.	Rock tank (most popular source in wet season) centrally located in village. Baabi spring: 6 km away (used in dry season, long queues). Lake Nakivale: 11 km away (used in dry season once spring dries up, also for bathing, washing clothes, livestock).	Main wet season source is shallow well located within village. Bathing and washing at spring and river outside village.	Use private wells (no charge) but have problems with well owners who limit amount per HH in dry season. In dry season fetch water from shallow wells outside village. Bathing and washing at well and irrigation tank.
Experience of informal rainwater harvesting	Widespread – used by . 50% of community but storage capacity < 250 litres. Some HHs use oil drums.	Widespread - used by . 50% of community but storage capacity < 250 litres. Some use oil drums.	Widespread	Many HHs collect rainwater from roofs, and occasionally from trees.	Many HHs collect rainwater from roofs, and occasionally from trees.
Previous experience of DRWH	None	None	Several HHs have ferro-cement tanks built by ACORD in 1998. Some provide free water to neighbours.	Several HHs have permanent brick tanks 3 m^3.	None

2 SOCIO-GENDER ISSUES IN LOW COST DOMESTIC ROOFWATER HARVESTING

Clare Bishop-Sambrook[3]

2.1 Introduction

The significance of identifying and understanding the social and gender issues associated with the adoption and sustained use of low cost DRWH systems has been recognised since the inception of this research project[4]. Gender and poverty issues lie at the heart of initiatives to address the water sourcing needs of poor households. The impact of collecting water from traditional sources (particularly during the dry season) takes its toll on the livelihood opportunities of women and girls in particular whereas investment decisions to improve water sources at the household level usually rest with men in their role as household head. Small disposable incomes, coupled with limited access to credit facilities, mean that household expenditure is under stress and purchase of essentials such as food and medicines, and the payment of school fees invariably take precedent over medium term investments. However, the need to reduce the burden of labour-intensive tasks is great, particularly in communities where labour is no longer readily available due to migration – usually of the able-bodied youth in search of employment, increased school attendance, and to the impact of HIV/AIDS. In sub-Saharan Africa in particular, the latter is causing a substantial restructuring of communities with an increasing proportion of households headed by single parents (especially women), grandparents and orphans, and a growth in household size through fostering orphans.

Thus the timing for examining the potential of low cost DRWH systems is opportune: the need is great. Moreover many households in eastern Africa and south Asia have invested in impervious roofs, an essential prerequisite for installing DRWH systems, and already practice informal rainwater harvesting. The high capital cost of tanks and gutters, coupled with a lack of information about low cost alternatives, is one of the major factors inhibiting a shift to permanent DRWH systems at present. However, rainwater is recognised as one of the improved water supply technologies for achieving the Millennium Development Target of 'halving by 2015 the proportion of people without access to safe drinking water'.

This section reports on the findings from the main fieldwork conducted at eight field sites in the three partner countries during the period 2001–3. Following a brief review of national and site characteristics to set the study in context, it explores five principal themes:

- identification of the impacts of DRWH on water fetching and water usage behaviour;
- identification of the benefits of DRWH from a gender perspective;
- identification of other benefits derived from DRWH;

[3] Gender specialist (consultant with DTU, Warwick University).

[4] A literature review and community studies were conducted during the inception phase (Bishop-Sambrook, 2001 and Bishop-Sambrook and Akhter, 2001). A case study of the findings from the first year of the main study in Arerti, Ethiopia is presented in Bishop-Sambrook, 2002.

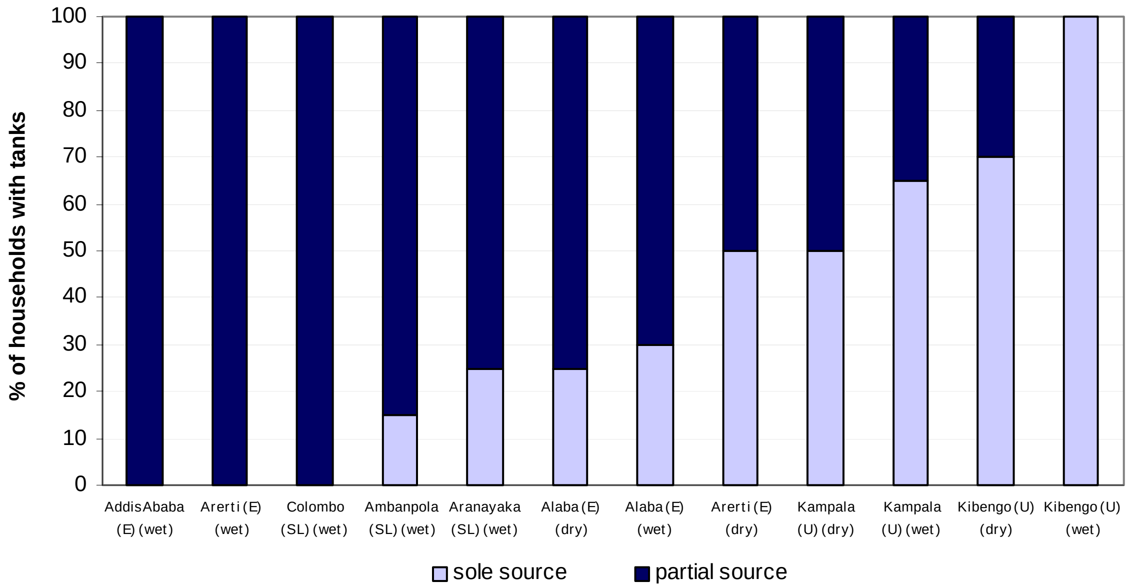
- determination of key gender and poverty characteristics of communities and households which influence the adoption and use of DRWH; and
- recommendations regarding how best to address gender and poverty considerations during project design and implementation.

In the first year of the main study, detailed community studies were undertaken, supplemented by 25 individual household interviews at each site. These households formed the core group participating in the technology trials during the second year. Data were collected about water fetching and water usage behaviour during the rainy season and at the beginning of the dry season from households with (new) tanks and a small control group without tanks. Focus group discussions were held intermittently to examine responses to tank design, water palatability and water source preferences, and to conduct a gender analysis on the impacts of DRWH.

2.2 Impact of DRWH on Water-fetching Behaviour

The impact of DRWH differs between seasons, communities and households (Diagram 2.1). Usually a proportion of households in a community use DRWH as their sole source whilst the majority use it as a partial source, supplementing it with water collected from traditional sources. This scenario holds true in both the wet and dry seasons. Factors influencing the response at community and household levels are discussed below and the full data are presented in Appendix 1.

Figure 2.1: Proportion of Households using DRWH as Sole or Partial Water Source



No dry season data for Sri Lankan sites because they experienced a prolonged rainy season in 2002-3

Water fetching behaviour in rainy season

The main factors influencing water fetching behaviour at community level are the accessibility of alternative sources (in terms of time, convenience, and physical arduousness of water fetching), the monetary cost of alternative sources, and the quality of water:

- **sole supply for all or majority of households in a community**: in only one study community, Kibengo (U), did all households with tanks switch to DRWH as their sole source of water during rainy season. The main motivation was convenience: by using tank water they were able to achieve similar levels of consumption per capita as non-tank households (6 – 8 litres per head) but were able to save at least one hour per day collecting water from the rock tank. A significant proportion of households in Kampala also switched to DRWH as their sole source: collecting water from the alternative sources was either expensive (vendor) or very time consuming (springs).

- **sole supply for a proportion of households in a community**: in several communities, a proportion of households used DRWH as their sole water source, ranging from 15% in Ambanpola (SL) to 25% in Aranayaka (SL) and 30% in Alaba (E) (Diagram 2.1). Nevertheless, the DRWH water was still the dominant source even in the partial supply households where it accounted for more than 50% of the water consumed. In all three communities many households were wary about drinking DRWH water and continued to collect water from traditional sources, albeit in reduced quantities. Partial supply households in Alaba (E) almost halved their expenditure on purchasing water from vendors whilst those in Ambanpola (SL) reduced their collection time by half.
- **partial source for all households in a community**: none of the households in Addis Ababa, Arerti and Colombo used DRWH as their sole source of water and DRWH supplied less than half of the water they used. All households in Addis Ababa and Arerti (E), and a significant proportion of households in Colombo, chose not to drink DRWH and continued to purchase water from vendors and water points/tapstands in similar quantities to those without tanks. At the Ethiopian sites, the main impact of DRWH was to significantly increase the total volume of water used in the home and per capita consumption. In Arerti (E) households with tanks switched to a more convenient source (vendors) which was slightly more expensive but saved time. In Colombo the availability of DRWH water was used to reduce amount of well water collected (which becomes turbid after rainfall) but the overall levels of consumption between tank and non-tank households were very similar.

Water fetching behaviour in dry season

The benefits of using DRWH are more marked at the beginning of the dry season because collecting water from the traditional sources is more onerous, in terms of either time or money. Time savings for households using DRWH as their sole source ranged from almost six hours a day in Kibengo (U) and almost four hours in Kampala from not collecting water from springs, to one and a half hours per day in Ethiopia. Partial-supply households also made considerable savings by reducing the amount of water collected from these sources, thereby decreasing the number of journeys per day. The cost of buying water was also reduced if charges were levied (for example, Alaba (E)). Some households used their dry tanks for storing water from other sources which enabled them to purchase water in bulk to use for water-intensive activities (such as washing clothes or watering livestock in Alaba (E)). A few households in Ethiopia switched from using DRWH water extensively during the wet season to ceasing consumption at the beginning of the dry season in order to preserve the stored water for their livestock in times of scarcity.

Influence of household characteristics on use of DRWH water as sole or partial source

The following analysis is based on comparing household characteristics in communities where a proportion elected to use DRWH as its sole source and the balance used DRRWH as a partial supply. Factors at the household level associated with the use of DRWH as a sole or partial source include:

- **perceptions of water quality**: concerns regarding the quality of tank water was one of the principal reasons why households did not use DRWH as their sole source (in Alaba and Arerti in Ethiopia, and Aranayaka and Ambanpola in Sri Lanka); households were also worried about the quality of stored water once the dry season commenced.
- **tank size**: whilst tank size was not a determining factor during the rainy season, there was a tendency for the sole-source tanks to be of larger capacity than partial-supply tanks. However, tank size became more crucial in the dry season. There would appear to be a critical size of around 2000 litres below which households are not able to stretch the water supply significantly into the dry season. Thus all tanks used as a sole source in the dry season were at least 2000 litres (with the exception of one 500 litre barrel used by a female-headed household in Kampala).
- **sex of household head**: at the Ugandan sites in the dry season, proportionally more of the households headed by women used their tank as a sole source than households headed by men. This may indicate that they are more interested in saving time because they are responsible for collecting water. It was not possible to detect this relationship at other sites in the dry season because all households with tanks in operation were headed by men.
- **undertaking water-intensive activities in the homestead**: such as keeping livestock (Alaba and Arerti in Ethiopia), brewing *tela* (Arerti (E)) and irrigating vegetables (Kampala), as well as household activities (in particular washing clothes), religious observance (for example, *namez*, a form of prayer which is performed five times a day consumes 15 - 20% of household water in Alaba (E)) and the presence of guests (for special occasions and funerals).

Other factors which may influence water-fetching behaviour (but were not possible to examine) are the availability of labour in the household to fetch water, the availability of money in the home to purchase water, and the opportunities for using any time saved not fetching water productively. Interestingly, there was no clear association between the size of the household and the decision to use a tank as a sole or partial source.

Levels of water consumption

During the rainy season, average water consumption (for all activities taking place in the homestead) is at least 20 litres per head at the Sri Lankan sites regardless of source (where many households have water-sealed latrines), around 15 litres per head at the Ethiopian sites and below 10 litres at the Uganda sites (Diagram 2.2)[5]. The use of DRWH as a partial source enables households to achieve higher levels of consumption than they would otherwise experience in both the rainy season (Figure 2.2) and at the beginning of the dry season (Figure 2.3). By using DRWH as a sole source, particularly once the rains stopped, severely restricted consumption to around 5 litres per head at the African sites.

[5] Comparative data for UK: 135 litres per head per day in households with metered water and 150 litres in unmetered households.

Figure 2.2: Daily Water Consumption per Capita during Rainy Season by Household Type and Site

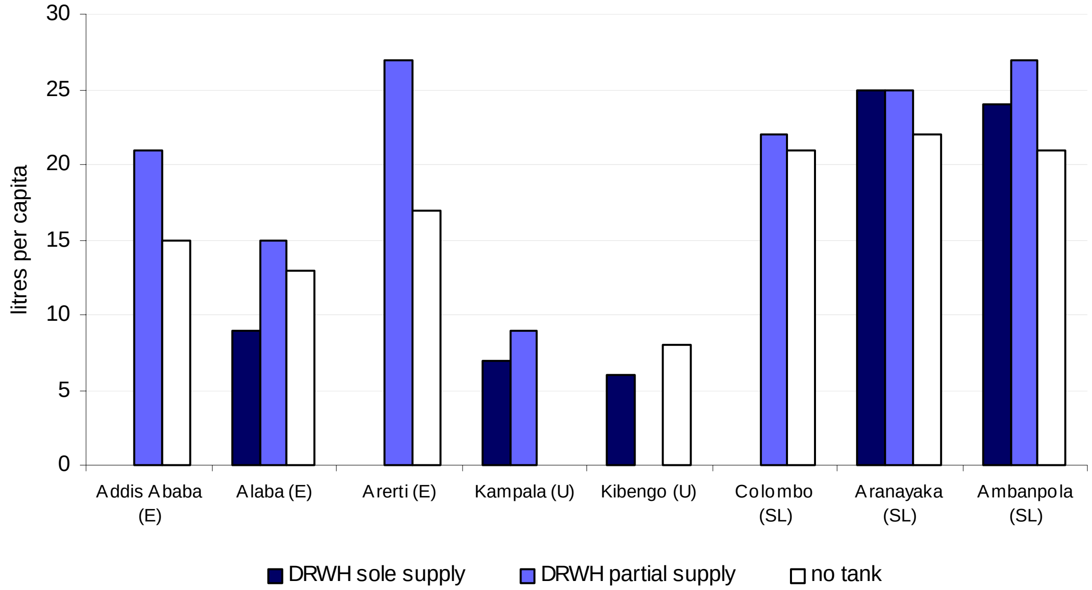
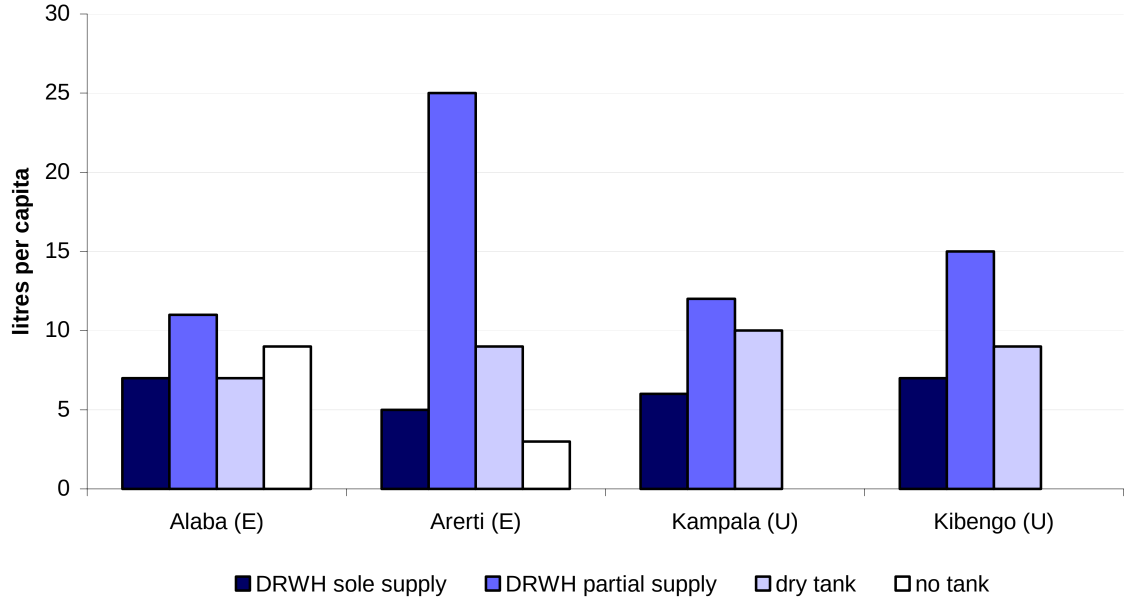


Figure 2.3: Daily Water Consumption per Capita at Beginning of Dry Season by Household



No data for other sites: all tanks in Addis Ababa were dry whilst rains were prolonged in Sri Lanka

Exceptional figure for partial supply in Arerti (E) because household bought water from a vendor to make *tela*

2.3 Use of DRWH Water

Activities

All households used DRWH water in the rainy season for non-potable household activities, such as washing clothes and cleaning the home (Table 2.1). All households at both Ugandan sites used DRWH water for drinking and cooking. In Ethiopia, where there was much less experience of permanent roofwater harvesting and reasonable access to alternative water sources during the wet season, households were much more cautious about the suitability of stored roofwater for drinking purposes. None of the households in Addis Ababa and Arerti (E), and fewer than half of the houses in Alaba (E) drank their DRWH water, preferring to purchase from conventional sources. Similarly, a significant proportion of households in Sri Lanka only used roofwater for cooking. Around one third of the Ethiopian households used DRWH water for their livestock. Many in Kibengo (U) shared (usually sold) water with their neighbours, a practice which they continued into the dry season. Elsewhere a few gave water to their neighbours when it was abundant during the rainy season.

Table 2.1: Proportion of Households Using DRWH Water for Various Activities by Season *

Site	Rainy season					Beginning of dry season			
	drink	cook	other HH uses	livestock	neighbours	drink +/or cook	other HH uses	livestock	neighbours
Addis Ababa (E)	-	40	100	35	15	All barrels dry			
Alaba (E)	45	90	100	30	20	25	75	50	0
Arerti (E)	-	80	100	10	10	50	100	0	0
Kampala (U)	100	100	95	25 **	5	100	90	25	25
Kibengo (U)	100	100	100	15	40	90	90	20	40
Colombo (SL)	20 ***	50	100	-	-	No data			
Aranayaka (SL)	35 ***	60	100	10	10	No data			
Ambanpola (SL)	35 ***	60	100	-	10	No data			

* as a percentage of households with tanks in use at each site, rounded to nearest 5%

** includes one household using water to irrigate vegetables

*** actual percentage may be lower

No dry season data available for Sri Lankan sites due to prolonged rainy season

Volume

The amount taken from DRWH tanks for all uses per day varied from 47 litres in Arerti (E) to 74 litres in Aranayaka (SL) during the wet season (Table 2.2). At the rural sites in Ethiopia, daily extraction decreased by half by the beginning of the dry season but the rates were almost unchanged at the Ugandan sites (reflecting the fact that consumption per capita was already extremely low even during the rainy season). On average households used around 35 litres per day for household activities, with the exception of the rural sites in Sri Lanka (almost 50 litres). A further 10 – 15 litres was used for cooking and drinking. Again these figures were higher for the Sri Lankan sites. Livestock typically consumed around 20 litres and water shared with neighbours a further 25 litres. Dry season savings were made across the board, particularly household activities, but water for livestock was unaffected by season.

Table 2.2: Average Volume used per Day per Household by Activity and Season *

Site	Rainy season					Beginning of dry season				
	drink +/or cook	other HH uses	livestock	neighbours	Total (litres)	drink +/or cook	other HH uses	livestock	neighbours	Total (litres
Addis Ababa (E)	10	35	44	23	**57**	All barrels dry				
Alaba (E)	13	31	25	20	**55**	10	28	25	0	**36**
Arerti (E)	7	36	25	25	**47**	3	23	0	0	**25**
Kampala (U)	16	37	8	5	**53**	18	36	15	15	**56**
Kibengo (U)	10	31	10	37	**62**	20	39	15	25	**61**
Colombo (SL)	24	37	0	0	**49**	No data				
Aranayaka (SL)	34	49	20	30	**74**	No data				
Ambanpola (SL)	31	48	0	40	**71**	No data				
Average **	*20*	*40*	*20*	*25*	***60***	*15*	*30*	*20*	*20*	***45***

* Average consumption of households using each source

** Rounded to nearest 5 litres

Potability of DRWH water

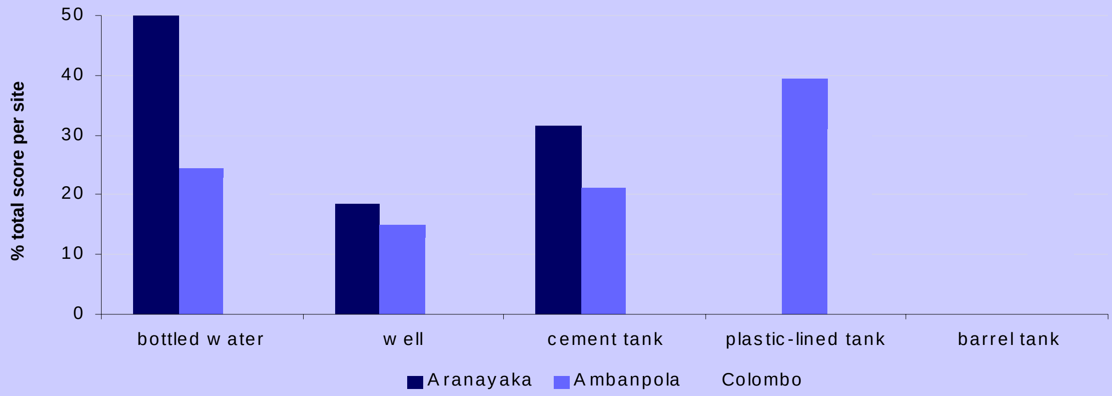
Factors influencing whether households consider DRWH water to be potable include:

- **previous experience of using rainwater**: if households previously used rainwater (collected informally during the rainy season) for potable uses they were more likely to consider DRWH suitable for drinking and cooking purposes than households which had previously used rainwater only for non-potable purposes;
- **perceptions of water quality**: if the traditional alternative was perceived to be 'safe' (for example, from deep tubewells) households were more likely to continue to use that source than switch to DRWH water. The cleanliness of the latter may be compromised by location of the roof in relation to overhanging trees or other structures, roofing materials, tank design and construction materials which permit small animals, vegetative matter, other debris, and runoff water to enter into the tank. Some households were prepared to drink rainwater which had been collected from their roofs and stored in traditional containers, such as pots or jerry cans, but not stored in tanks. Households in Sri Lanka voiced concerns about the quality of rainwater harvested from old tin or asbestos roofs.
- **acceptability of taste of stored water**: the tank design can influence the taste of water, either through the construction materials used or the siting of the tank. For example, in Ethiopia, taints were noted from the cement-lined walls (partially below ground tanks), from the filtering sand in the barrel tanks, and from soil runoff into the tarpaulin and thatched-roof tanks. In some communities with underground tanks, the water was considered to be too cold for fermenting the local liquor (*tela* in Ethiopia). The taste was considered unsuitable for drinking or preparing local dishes (such as *injera* in Ethiopia). Once water had been stored for a length of time, some households used it only for non-potable household activities and livestock.

Box 2.2: Water Palatability Challenge

In the water palatability challenge people were asked to rank different samples of water according to taste and appearance, without knowing their source. In Colombo, roofwater was ranked higher than well water and bottled water (as a proxy for piped water) (Figure 2.4) which runs contrary to the extremely low level of use of roofwater by households with DRWH tanks. At least 60% did not use tank water for drinking purposes based on their perceptions of poor quality and taste. It may also reflect the fact that informal rainwater harvesting is not widely practised in Colombo and households are not familiar with drinking rainwater. Similar results were achieved at the two rural sites where again many households were reluctant to drink roofwater even though some collect rainwater informally. In contrast, well water was rated very poorly at all three sites yet it, together with public tap stands, is a principal source of water.

Figure 2.4: Overall Ranking of Water from Different Sources by Site, Sri Lanka *



* participants did not know the sources of water prior to ranking them according to taste and appearance

2.4 Gender Analysis of DRWH

Gender roles

Gender roles and status not only determine the opportunity to participate in DRWH initiatives but also influence the way in which the benefits of DRWH are realised. Tasks and responsibilities are allocated between household members based on custom and tradition, age, sex, social status, education, and ethnicity. Women are responsible for fetching water, with varying assistance from other household members (usually girls) depending on the season, location of water source and culture. Men help occasionally (travelling to more distant water sources in the dry season) and become active when water collection is an income generating activity (for example, water vendors in Uganda). Collecting water is time consuming, occurs daily, and fragments the use of people's time since several journeys are made each day. The task is physically demanding, particularly on the return journey, and becomes more burdensome during the dry season when water is collected from more distant sources. Women and girls usually travel on foot whereas men and boys travel by bicycle if the terrain permits. In some areas of Ethiopia, women and men use animal drawn carts to fetch water. At some of the study sites, people are exposed to various risks when fetching water (such as attacks by wild animals, abuse and assaults). Although some women enjoyed socialising whilst collecting water, their main concern was the amount of time the activity consumed and losing the opportunity to undertake other productive activities.

As a result of these traditional gender roles, the key beneficiaries of the presence of a permanent DRWH system in a compound were women (particularly in rural communities) and girls (especially in urban and peri-urban areas), to a lesser extent boys, and occasionally men (Table 2.3). Beneficiary patterns did not vary much between the seasons.

Table 2.3: Proportion of Household Members Saving Time by Season and Site *

Site	Rainy season					Beginning of dry season				
	women	men	girls	boys	employee	women	men	girls	boys	employee
Urban/peri-urban										
Addis Ababa, Ethiopia	25	-	70	15	5	Barrels dry				
Kampala, Uganda	35	-	65	65	5	40	-	25	40	-
Colombo, Sri Lanka	40	20	50	40	10	No data				
Rural										
Alaba, Ethiopia	65	-	50	25	-	75	-	-	25	-
Arerti, Ethiopia	65	-	55	-	-	100	-	-	-	-
Kibengo, Uganda	75	40	75	50	10	90	35	80	45	10
Aranayaka, Sri Lanka	70	15	45	-	15	No data				
Ambanpola, Sri Lanka	85	50	15	10	-	No data				

* as a percentage of households with tank in use; may add up to more than 100% per site because there may be more than one beneficiary per household

The amount of time saved per person was site and season specific, with dry season savings often double those made during the wet season (Table 2.4). The amount saved was also influenced by whether DRWH is used as the sole source of water. The greatest savings were made in Kibengo (U) where all households have switched to DRWH as their sole source during the rainy season, and the alternative dry season source lies over 11 km away.

Table 2.4: Average Amount of Time Saved per Day by Household Member by Season

Site	Rainy season (minutes saved)					Beginning of dry season (minutes saved)				
	women	men	girls	boys	employee	women	men	girls	boys	employee
Addis Ababa (urban)	40	-	45	40	60	Barrels dry				
Alaba (E, market town)	35	-	30	30	-	50	-	-	30	-
Arerti (E, rural village)	40	-	55	-	-	75	-	-	-	-
Kampala (peri-urban)	90	-	115	95	240	180	-	60	140	-
Kibengo (U rural)	120	105	105	100	90	210	220	215	195	180
Colombo (urban)	25	20	20	30	20	No data				
Aranayaka (SL, rural)	40	20	60	-	75	No data				
Ambanpola (SL, rural)	40	25	55	60	-	No data				

The way in which beneficiaries used the time saved was highly differentiated by age and sex of the fetchers of water, and the family life cycle. In turn, these were influenced by their traditional roles within the home, opportunities for productive activities to generate income in either existing or new activities (possibly making use of the extra water), the importance of education and access to schools, and the amount of time saved each day. Women and girls in Ethiopia, saving up to 45 minutes per day, were most likely to use the time saved on household activities, such as washing clothes, cleaning the home, cooking and childcare (Table 2.5). Women in Uganda, making time savings of at least 1.5 hours, were more likely to engage in productive activities: non-farm in peri-urban Kampala (such as petty trading, running shops or small restaurants, tailoring, weaving and brewing) and farming and attending meetings in Kibengo. The importance of releasing time for education was most marked amongst Ugandan and Sri Lankan girls and amongst boys in rural communities. Boys were much more likely to use their spare time for relaxing and socialising than other household members. Men in Kibengo (U) largely spent their extra time in casual labouring, farming, trading, brewing or house improvements. Little productive use was made of time saved in Sri Lanka, particularly in Colombo where the amount of time saved per day was less than half an hour. In addition to saving time, householders also benefited from a reduction in their fragmentation of time: even though many households still collected water from outside their compound they made fewer journeys which enabled people to make better use of their time.

Table 2.5: Use of Time Saved by Household Member during Rainy Season *

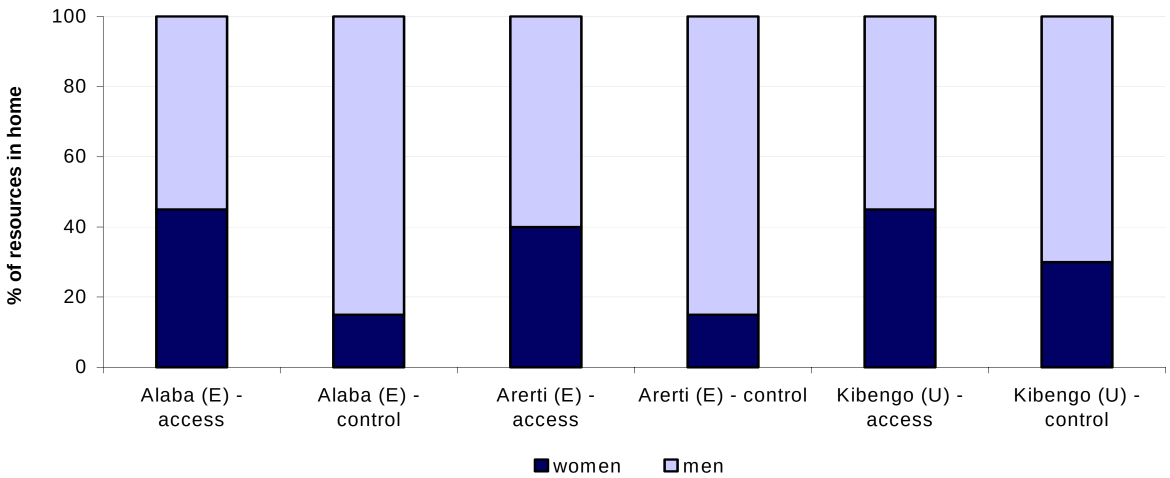
Site	Women				Girls					Boys				
	HH	farm	non-farm	rest	HH	farm	non-farm	education	rest	HH	farm	non-farm	education	rest
Addis Ababa	100	-	-	-	100	-	-	10	10	35	-	-	-	100
Alaba	70	-	25	45	90	-	-	10	20	20	-	-	80	60
Arerti	100	-	35	15	100	20	20	-	-	-	-	-	-	-
Kampala	15	35	85	-	35	20	20	65	35	-	20	10	45	55
Kibengo	45	75	30	25	15	15	15	85	10	-	15	15	65	25
Colombo	25	-	-	100	-	-	-	25	75	-	-	-	-	100
Aranayaka	65	-	10	45	20	-	-	80	40	-	-	-	-	-
Ambanpola	60	-	10	30	50	-	-	-	50	-	-	-	-	100

* as a percentage of number of each type of household member saving time; may add to more than 100% per household member because of their multiple use of time saved. HH = household activities

Access and control over resources, and decision-making

Women had access to, but little control over, practical resources which help with water collection. However, with the exception of Alaba (E) where animal-drawn carts are used to fetch water, women often had very little access to any means of transport which would reduce the burden of fetching water, such as bicycles or motorised transport. Men exercised control over a wide range of household assets associated with water collection and use (Figure 2.5). They also benefited more from external services, such as attending meetings, and access to sources of information and credit. Women's lack of land titles is a major barrier to securing credit. Overall women had access to 40 – 45% of resources but, at best, controlled 30% whereas men controlled at least 70% of household resources associated with fetching water.

Figure 2.5: Access and Control over Resources Associated with Fetching Water



Women played a central role in deciding which source of water to use, how much to collect, and how to cope during periods of water shortage. The decision to install a hard roof or introduce a DRWH system would usually undertaken by men but women would have overall responsibility for the system once it is installed. Whilst stated priorities for household expenditure included improving the home and installing permanent DRWH, the current reality is that expenditure amongst poorer households is dominated by the need to purchase food, pay school fees and meet medical expenses.

Source of empowerment

When women saved time from fetching water, they often merely substituted one household activity for another: rather than fetching water they undertook other household activities (see Table 2.5 above). Women become empowered through DRWH if they have the opportunity to use their extra time on income generating activities and control the benefits from that enterprise (Box 2.3), or if they are able to participate more in community activities and meetings. Girls and boys are empowered if they are able to use the additional time to attend school and study.

Box 2.3: Empowering Women through Releasing their Time from Fetching Water

A female-headed household in Alaba (E) extended her petty trading business (baking and selling *injera*) by using her extra time for preparing the local liquor for sale. Another used the extra water for her farming activities (watering seedlings).

Two women, one wife and one widow, in Arerti (E) used their extra time and water to increase their existing off-farm businesses, preparing local liquor, *tela* and *areki*, for sale.

In Kampala, a wife, together with her son, started a poultry venture using the three hours a day they save from not fetching water. A female-headed household used her extra time for paid employment.

In Kibengo (U), one young widow used the extra time and water to start a hotel (selling food). Another female-headed household made local brew for sale.

Some women in Colombo used their extra time in petty businesses, such as making paper bags and sewing, to generate income.

There are other opportunities for empowerment if women, the youth and poorer households have the chance to develop skills as masons, participate tank construction, and learn how to use and maintain the DRWH system. In undertaking this research programme, women accounted for half of the people trained as masons for tank construction in Ethiopia. In Sri Lanka women and men from beneficiary households participated in unskilled construction activities (such as digging pits and mixing cement) whereas all skilled work was undertaken by male masons.

2.5 Other Benefits of DRWH

Use of extra water

The presence of a DRWH system within a compound usually encourages households to use more water, both in the rainy and at the beginning of the dry season, than they would normally do in those seasons. They are able to do so because of the proximity of the water supply (convenience and accessibility), the storage capacity of the tank (much greater than traditional containers such as jerry cans), and the abundance of water during the rainy season. The demand for additional water arises from three sources: an increase in use on existing activities and the frequency with which those activities occur, the relocation of activities into the homestead, and the introduction of new activities. The way in which it is used is often closely related to the way in which women use the time saved not fetching water.

On average, two thirds of the households with tanks increased their use of water during the rainy season when it was most abundant (Table 2.6). The use of extra water was dominated by household activities and personal hygiene, particularly in Ethiopia and the rural sites in Sri Lanka. Traditionally, only water for essential purposes is carried home and activities that use a lot of water, such as washing clothes and bathing, take place at the water source. Many households appreciated the convenience of being able to relocate them to home. Rearing livestock (cows, goats and poultry) and growing vegetables was also common in Ethiopia and Uganda, regardless of urban or rural locations. In Kibengo (U), the most common additional use of water was sharing water with neighbours. If households merely substituted the roofwater for traditional sources (for example, Colombo) or faced water scarcity due to low rainfall (Arerti (E)) then the presence of a tank did not increase water consumption but may have improved water security.

Table 2.6: Use of Extra Water during Rainy Season *

Site	Household activities +/or personal hygiene	Farming	Productive (non-farm)	Share with neighbours	HHs citing an increase but no reason	HHs citing no increase in use of water **	Total number of HHs with tanks in use = 100%
Addis Ababa	80	20	-	-	-	20	15
Alaba	75	10	5	-	10	5	20
Arerti	55	-	20	-	-	35	9
Kampala	30	10	5	-	15	35	17
Kibengo	10	15	10	40	10	20	18
Colombo	20	-	-	-	30	50	10
Aranayaka	50	-	-	-	25	25	13
Ambanpola	50	-	-	-	15	35	13

* percentage of households with tanks in use

** included HHs where demand for water had fallen due to a decrease in HH size or business closure

More effective use of rainwater

Through increasing the roofwater harvesting and storage capacity, households with permanent DRWH systems were able to make more effective use of the rainfall. On average rainwater harvested informally accounted for around 20% of the total water fetched in a non-tank household. This contribution rose to more than 50% in households which used DRWH water as a partial source and 100% in sole source households. Further details are at Appendix 1.

Permanent DRWH displaced informal rainwater harvesting activities in Ethiopia and Uganda. Indeed, at both sites in Uganda, all households ceased to collect rainwater informally once they had permanent tanks whereas it was an important source of water for all non-tank households. The reverse occurred in Colombo where the experience of roofwater harvesting encouraged one household with a tank to collect rainwater informally, an activity which was not traditionally practised.

Other benefits at household level

- **use of tank as a storage medium**: once the tank was empty of rainwater, some households used it to store water collected from conventional sources for later use, thereby freeing traditional water collection containers for re-use, and making economies by purchasing water in bulk.
- **money saved purchasing water**: the amount saved, if any, was influenced by water fetching behaviour before and after the tank. Savings accrued if DRWH water either partially or completely substituted for purchased water.
- **money earned selling water**: in some communities (such as Kibengo (U)) the DRWH system represented an income earning opportunity through the sale of water to neighbours.
- **improvements in the quality of life**: drudgery was reduced through the convenience and ease of collecting water in the home compound (see Box 2.4).

- **improved health and hygiene**: through having access to water which was safe for drinking and readily available for washing clothes and bathing more regularly. Family members were less exposed to water borne diseases present at traditional bathing spots.
- **exposure to new technologies and new skills**: acquired by household members in tank use and maintenance (including roofs and gutters), in assessing water quality, and in recognising the suitability of rainwater for potable uses.
- **improved relations with neighbours**: through sharing water.
- **improved household status**: due to the presence of the tank in the compound.
- **improved safety for household members**: by having the water supply in the compound, mothers did not have to leave young children at home unattended whilst they fetched water from distant sources. Similarly children who usually fetch water, particularly girls, were no longer exposed to any risks associated with travelling to water sources on foot. It was safe to fetch water at all times of day, even early in the morning or late at night.
- **overcome household labour constraints**: a household's ability to fetch water is compromised by the number, age and health of the people in the home. Tanks in the compound enabled water to be fetched by young children, the elderly and those tending to the sick. Children were more willing to assist in fetching water when it was close at hand.

Box 2.4: Easing the Burden of Water Collection

In Alaba (E), one young single mother mentioned the psychological relief from not having to fetch water from any source during the rainy season. An elderly woman looking after her sister's children spoke of her benefit of enjoying a short rest 'because I am a very old, poor lady'.

In Arerti (E), standpipes located in the community are the main water source throughout the year. Queues, lasting one hour in the wet season, extend up to one week in the dry season. Households leave water containers to mark their position in the queue. When standpipes fail or the queues are excessive, households travel 7 km to a river located in the valley.

Women in Kibengo (U) dread fetching water from Baabi spring in the dry season. The spring, over 4 km from the village with a steep descent, is used by many people. Water availability decreases during the dry season so there are many queues. The travel time may take up to four hours. The alternative source, Lake Nakivale is twice as far away and sometimes villagers collect money together to hire a car to carry water from the lake.

In the dry season in Aranayaka (SL), women and children walk over 2.5 km downhill to the nearest standpipe to fetch water. In order to minimise this arduous task, whenever household members go to the nearby town, they take plastic containers to collect water from standpipes, and transport the water home in three wheeled vehicles.

Impact on wider community

The benefits of DRWH may spill over to other members of the community:

- **opportunities for skills development and income generation**: amongst individuals such as masons, carpenters, technicians, casual labourers, and groups providing unskilled or semi-skilled labour for tank construction and maintenance, and materials' suppliers.
- **improved access to water**: in several communities, tank owners were keen to share water with their neighbours, either for payment or as a gift for goodwill. If households with access to tank water significantly reduced the amount of water they collect from traditional sources, queuing times for others could be reduced.

- **reduced costs of water**: if tank owners sell their water below the market rate, there would be downward pressure on the prices charged by conventional vendors. Whilst this would be beneficial for consumers it may be detrimental to the livelihoods of water vendors.
- **improved access to information and advice about DRWH systems**: neighbours who wish to construct their own system have the opportunity to observe tank performance, durability and cost, and seek the firsthand experiences of tank owners.

However, some of these benefits may be tempered by the envy against those households with DRWH systems, particularly if they have been received with technical or financial assistance. Other members of the community may also wish to acquire DRWH systems on concessional terms.

2.6 Sustainability

Household investment

A key indication of a household's interest in DRWH is its ability to maintain the DRWH system in working order and to undertake tank-related additional investment. Most households were capable of undertaking minor maintenance, such as tightening loose pipes, and cleaning the tanks occasionally. For technical problems, particularly with pumps and failures of construction, they tended to rely on the water professionals for advice. However, interest in the tanks, improving quality of water, safety concerns and pride in tank ownership often motivated households to undertake spontaneous additional investment (Box 2.5).

Box 2.5: Household Investment in DRWH System Improvements

Five male-headed households in Alaba (E) improved their DRWH system, taking measures to strengthen the structure or improve their safety (by fencing the area around their tanks in order to protect them from children, or adding covers on the tanks to prevent children falling in).

Two households in Arerti (E) plastered the walls of their tanks.

One female-headed household in Kampala cleaned and repainted her barrel. A male-headed household cemented around his PBG tank and created a drainage channel.

In Kibengo (U), one man scrubbed out his PBG tank and painted the outside with colours of his preference. Another bought cement and hired a builder to repair cracks that were developing in his tank. A third upgraded the tank roof, replacing the thatch with fibres. A female-headed household extended the roof catchment feeding into her tank.

One household in Aranayaka (SL) with the mud tank design built another.

One mason in Ambanpola (SL) bought cement to plaster over cracks in his partially below ground tank, and another mason replaced the polythene lining in his tank. Two households modified the design of their thatched-roof tanks by replacing the thatch with ferrocement and raising the mouth of the tank above ground level.

Adoption of DRWH by wider community

The key criteria used by households when appraising alternative tank designs and traditional water sources provide an insight into the characteristics of DRWH systems which must be considered if the technology is to be adopted by others. The overriding concern was the quality and taste of the water stored in the tank. Other considerations included the capacity of tank, ease of use by household members to collect water from the tank, ease of maintenance, durability of tank materials, child-safe tank design (a consideration which more likely to be raised by women) and compound-specific aspects (such as the size of tank relative to the space available or vulnerability of housing materials to water spillage). Attempts to produce a low cost tank through using locally-available materials for constructing the thatched-roof tank was appreciated in Kibengo (U) but the design generally suffered from safety and water quality considerations. In Alaba (E) cattle even grazed on the thatch during the dry season.

In order to assess the communities' reaction to the permanent DRWH tanks at the end of the study period, the households which were participating as the control group during the technology trials were given the option of receiving a basic 800 litre tank free of charge or upgrading to a design of their preference at their own expense. In Arerti (E), three households elected to receive the base design since they had no capacity to contribute the additional resources (the other two households declined to receive a tank). In Ambanpola (SL) all five households elected to upgrade to 5000 litre tanks: four opting for the dome design (very durable) and one for the PBG with thatched roof (less expensive but there is the option of upgrading to the dome tank at a later date). With the exception of one male-headed household all others had to purchase the additional inputs using informal credit (paying 20% interest per month).

No households in the study communities had spontaneously adopted permanent DRWH systems following exposure to the tank designs through the participatory research programme. However, many of the beneficiary households noted that others had expressed an interest in the more successful designs such as the dome tank but were constrained by economic considerations. Whilst some households were also waiting to assess the long term durability of the tanks prior to committing themselves others hoped that DRWH tanks would be provided free of charge to other members of the community.

2.7 Factors Hindering the Adoption and Use of DRWH

Based on the evidence from the fieldwork, it is possible to discern factors which hinder the process of adopting DRWH systems, either at the community or household level.

Community characteristics

The initial response to initiatives to promote DRWH and the subsequent rate of uptake is influenced by the following:

- **socio-economic composition of the community**: the relative wealth of households influences their ability to meet the costs of installing DRWH systems including their ability to access credit if necessary. Households without impervious roofs were found to be resource poor, hence making it difficult to invest even in very low cost systems whereas households with impervious roofs tended to have more diverse sources of livelihoods, were more involved in the monetary economy and were better educated
- **roofing and housing characteristics**: the proportion of houses with hard roofs and gutters, and their quality; and the density of housing. For example, the congested market centre of Alaba was unsuitable for siting underground tanks whilst in Colombo, there was insufficient space between some dwellings for tanks and one household was refused permission from the railway authorities to install a gutter because it was too close to a railway line. The presence of thatched roofs on poor households is a real barrier to adopting DRWH in rural communities in Ethiopia.
- **satisfaction with present water sources**: in terms of their accessibility and the convenience of fetching water (distance, mode of travel, terrain, travel time, queuing time, safety considerations), cost and quality of water. There may be a tendency, particularly at community level, to overlook the need to address laborious work performed by women.

- **limited previous exposure to permanent DRWH systems**: lack of familiarity with DRWH systems within the community hinders the adoption and effective use of the technology.
- **shortage of skilled masons to construct water retaining structures**: specialist training is usually required to develop the community's skills base in the new technology.
- **lack of responsibility for self help**: in some countries, there is the widespread expectation that water provision is the government's responsibility (Uganda and Sri Lanka). Consequently many communities are unwilling or not motivated to address their water supply problems alone, particularly if it may compromise their subsequent involvement in piped water supply projects (for example, Kampala).
- **rural locations**: the extent to which any of these variables differ significantly between rural and urban areas may also influence the rate of uptake. The need for improving access to water is often greater in rural communities where fetching water from traditional sources is very time consuming, particularly during the dry season. Opportunities for promoting DRWH can be high in urban and peri-urban areas where space is not a constraint. Households usually enjoy higher incomes than in rural areas, most houses have hard roofs, and they have ready access to materials and information for constructing tanks.

Household characteristics

The extent to which any of the pre-requisites for installing DRWH are associated with the socioeconomic status of a household may influence its ability to participate in roofwater harvesting initiatives. Poorer households invariably have poorer quality roofs and gutters; indeed many have unsuitable roofs (thatch) and no gutters. They also tend to be located in more densely populated part of urban communities. Tenants may be unwilling to invest in a permanent structure without compensation from the landlord whilst landlords may not want tenants to make structural improvements to the property. Tenants are also more likely to have difficulty in securing credit through a lack of collateral. Poor and vulnerable households (such as those headed by women or orphans) are less likely to have cash (or access to credit) and spare labour with which to contribute towards the construction of the DRWH system. The death of key household members, particularly the husband, is often associated with the depletion of household resources. Yet many of these households have the greatest need to relieve themselves of the daily burden of fetching water due to the ensuing shortage of family labour. However, they can be the most difficult to reach through traditional extension methods.

The gendered differences in controlling resources and decision-making can pose very real barriers to the process of promoting DRWH systems and providing credit to facilitate purchases. Men may need to be convinced that reducing women's workload through improving water collection in the home should be priority expenditure. Hence both should be involved in discussions regarding water source options.

2.8 Conclusions and Recommendations

Interest in permanent DRWH is high but the absence of affordable systems has been a constraint on their widespread use to date. At the household level there is a dilemma between tank capacity, durability and quality of water on the one hand, and cost considerations on the other. The fieldwork suggests there would appear a minimum size for a tank (of around 2000 litres) in order for DRWH to make significant impact on a household's water fetching behaviour. To reap tangible benefits (in the form of substantial time or monetary savings) tank water must make a significant contribution to dry season water supplies. A smaller tank is sufficient in the rainy season to provide access to a convenient source of water which may also be of better quality than the traditional alternatives. Very low cost, small tanks (such as the tube of 800 litres) may have a special niche in emergency situations where time is of the essence, rather than long-term storage capacity or durability.

Poverty coupled with a lack of opportunity for the remunerative use of time saved may make people unable to invest in DRWH. Although they are concerned about the time they spend collecting water from traditional sources unless they can generate cash from the time saved, they have insufficient money to invest in RHW because there are too many other claims on the family purse. Poorer households, female-headed households and tenants often face additional barriers to adoption due to absence of property ownership, restricted space and limited access to credit and lack of information.

Drawing on the findings from the study, the following recommendations are made to promote and disseminate DRWH technologies:

- **work through the local structures**: ensure they understand the practical requirements of permanent DRWH systems and the contributions required from beneficiary households, to ensure false expectations are not raised;
- **know the community**: conduct community meetings in order to understand the community: their socioeconomic composition, their current sources of water and their perceptions of them (water quality, convenience, cost, safety), their experiences of roofwater harvesting; and foster their trust;
- **understand and take account of gender roles**: within the home with regard to decision-making, resource use, use of time, role in fetching water and participation in tank construction and maintenance;
- **raise technology awareness**: prior to introducing DRWH technologies in communities where many households are not familiar with roofwater harvesting, inform them about the benefits and potential limitations of DRWH systems;
- **establish demonstration DRWH systems**: the presence of various tank designs in use in a community stimulates interest in, and demonstrates the benefits of, permanent roofwater collection;
- **reach out to vulnerable groups** (such as female- and orphan-headed households, poorer households, women): ensure all segments of the community have the opportunity to learn about the new technology through encouraging their attendance at meetings and ensuring they have access to further information;
- **empower weaker members of the community**: the introduction of DRWH systems offers many opportunities for empowering women and the youth through developing new skills and making productive use of their time saved fetching water.
- **overcome barriers to participation by more vulnerable households**: keep the cash component of materials small and ensure materials are available locally;
- **ensure the contribution of free unskilled labour is not prohibitive**: particularly for households facing severe labour stress as a result of the loss of family members to HIV/AIDS and other diseases, education, or migration. Encourage such households to work in mutual support/welfare groups;

- **arrange credit or microfinance**: establish links with a local organisation to ensure households have access to funds to cover the construction costs, with collateral requirements suited to the resource base of households and repayment terms suited to local income flows;
- **provide full grants for severely labour-stressed households**: to enable AIDS-stricken households to benefit from a labour-saving technology which addresses a basic necessity (water), grants to cover the full cost of materials may be more appropriate than partial subsidies (especially in communities with prevalence rates of typically 30%, and can be as high as 40 – 50 %, in east and southern Africa);
- **develop skills base in community**: train masons and technicians in tank construction and maintenance;
- **develop household skills**: in routine care and maintenance of the tanks;
- **maximise the effective usage of DRWH systems**: encourage households to use rainwater for potable as well as non-potable uses;
- **provide prompt technical backup**: for installation and initial operation of DRWH systems;
- **encourage household members to make productive use of the time saved**: support income generating initiatives and encourage attendance at school amongst the youth.

2.9 References

FAO (2001) *FAOSTAT*, Rome: FAO statistics

Ministry of Health (2001) *The Republic of Uganda Online*, Kampala: MOH

Ministry of Health (2002) *AIDS in Ethiopia*, Fourth Edition, Addis Ababa: MOH

UNDP (2002) *Human Development Report*, New York: UNDP

UNDP (2003) *Progress towards achieving Millennium Development Goals*, www.undp.org

World Bank (2000) *World Development Indicators*, Washington DC: World Bank

World Bank (2002) ***World Development Indicators*,** Washington DC: World Bank

3 TECHNOLOGY

3.1 Tank types field tested

A number of designs were selected from those developed in the prototyping phase for wider testing in the field. Overall 4 designs were selected for extensive testing and a further 3 for more limited field-testing. A variation on the existing tarpaulin tank from Uganda was also used in an area of loose soil in Ethiopia that poorly suited other designs.

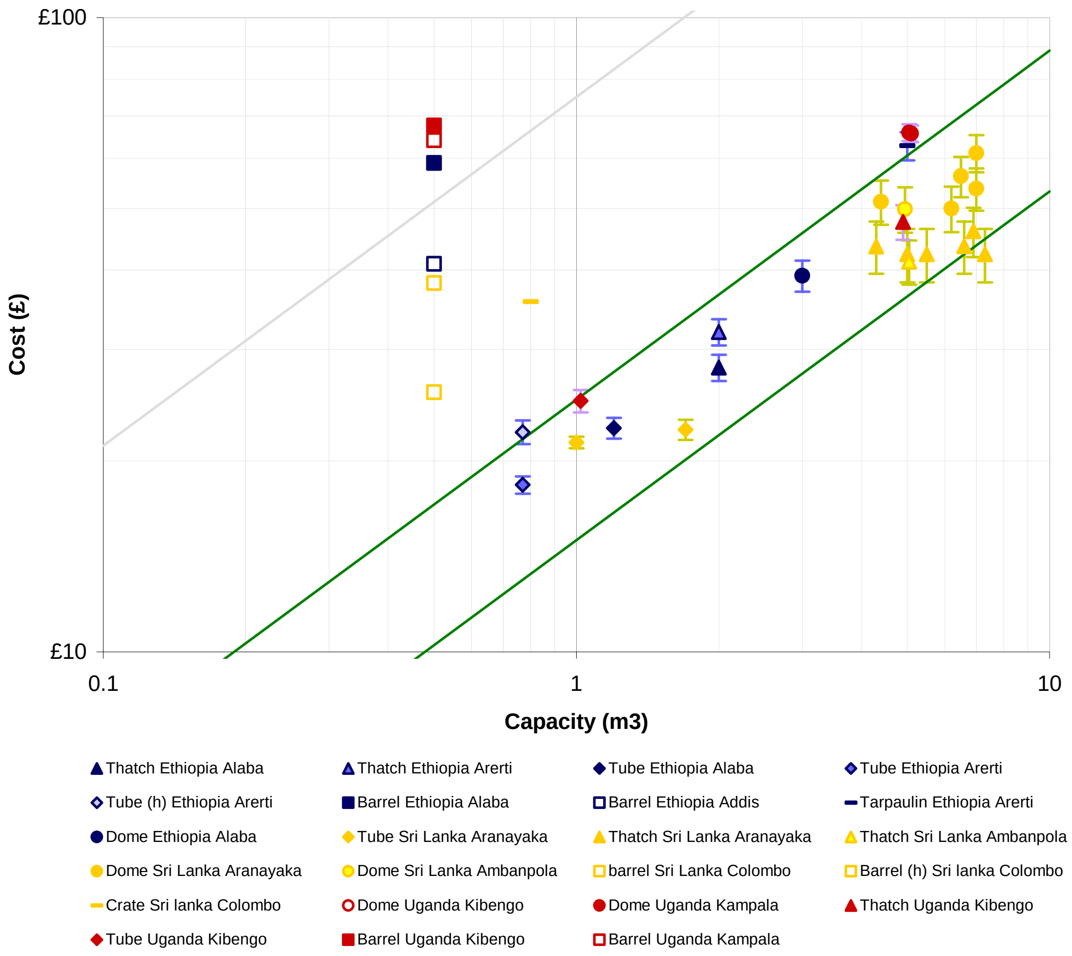
Table 3.1: Tank types installed in each location (total = 128 tanks)

Type	Size (m^3)	Ethiopia			Uganda		Sri Lanka			Total
		Addis Ababa (urban)	Areti (peri-urban)	Alaba (peri-urban)	Kampala (Urban)	Kibengo (Rural)	Colombo (Urban)	Aranayaka (Rural)	Ambanpola (Rural)	
Dome	3			5				1		**37**
	5				13	6		2	7	
	6.5-7							4		
Thatch Roof Ferrocement	2		1	5						**27**
	5					7		4	7	
	7							3		
Drum	0.5	15		5	4	1				**25**
Tube (vertical)	0.8		4	5		5		5		**20**
	1.7							1		
Tube (horizontal)	0.8		3							**3**
Mud	0.8							1	2	**3**
Crate	0.8							1		**1**
Ferrocement built with newly developed mould		5								**5**
Modified Tarpaulin	5		7							**7**

3.2 Final construction costs

Costs of tanks varied not only by country but often by region of the country, particularly in the case of the drum tank which was strongly dominated by the local cost of drums. Figure 3.1 shows the varying costs of construction. Final bills of materials however did not vary greatly. Most tanks fall into the “low cost” range as compared to existing technologies (this range lies between the two solid sloping lines on the graph) with the exceptions of the crate and drum tanks designed to fulfil particular niches in crowded urban areas.

Figure 3.1: Costs of tanks based on field construction



3.3 Problems encountered with particular designs and their solutions

Dome tank

The dome tank has had very few problems and has been well received. Several were built in fairly loose soil in Sri Lanka and developed horizontal cracks as they settled into the soil. Three solutions to this problem were tried:

- Specifying a higher (1:3) cement : sand ratio for the underground section replacing the 1:8 spec for stable soils
- Adding chicken mesh to the underground section
- Raising the section thickness from 1cm to 2cm

So far all of these remedies have proved successful, however use over a period of time may prove one over the other. However laboratory results indicate that raising the cement : sand ratio should yield the greater improvement, so this will be recommended until more experience is gained.

In some circumstances, the water has a “shut in” taste to it as the overflow through the pump prevents adequate ventilation. This was solved by the addition of vents to the dome.

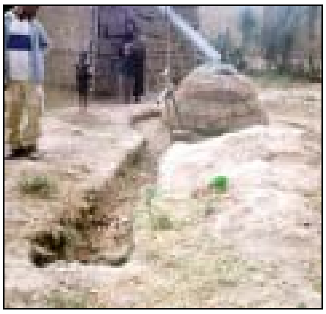
Thatch roof tank

The thatch tank has had 4 main problems.

1. The organic roof can deteriorate if it is made incorrectly or not maintained. This is particularly true in Uganda and Sri Lanka where there were few thatched houses. The design was modified in these cases to use banana leaves in Uganda and Tar sheet in Sri Lanka. These modifications have thus far been successful.
2. Seals have not been applied correctly. There seems to have been some confusion about the functions and necessity for the seals on the cover. This has in some cases resulted in large openings into the tanks allowing entry to lizards, frogs and other wildlife. These have been corrected in a number of cases with good results. Instructions for these tanks will have to stress the necessity and function of these seals if the tanks are to be successful.
3. Overflows have not been placed correctly allowing ingress of floodwater through the overflow. A modification to the overflow inlet has greatly reduced this risk, however the design still requires care in overflow arrangements.
4. Several sites had no trench to divert floodwater, again allowing floodwater into the tank. Others had a trench that became filled with soil. Modifying the trench by lining it with mortar encourages smooth flow of floodwater around the tank, which prevents erosion and reduces the tendency for the trench to fill with soil. It also highlights the need for the trench. Sites with appropriate overflow and floodwater drainage arrangements worked well and water was being used for high quality purposes. Sites with poor overflow and floodwater arrangements tended to be used only for secondary water.

The design has, however been well received in many sites as it is considerably cheaper than other designs and can have a large capacity.

Corrections being made to seals in Uganda



Good drainage practice on thatch tank in Ethiopia

Good top seals and tar sheet cover used in Sri Lanka

Tube tank

The tube tank also suffered from poor installation. Tubes were sometimes installed in rocky ground or in some cases in holes that were too large. This resulted in many failures of tubes from day one. Other tube tanks that were installed carefully and correctly fared better, however tubes in Ethiopia used a thin plastic as thicker material was not available and many failed after one season. There seem to be continued problems with the tube, mainly in handling and installation that make the current design unsuitable for permanent water storage *as is*, however the tubes are inexpensive, easily removed and can be considered disposable.

Several modifications were made to the platter that reduce the cost further so the design is extremely cheap and quick to implement so it is suitable for low-investment higher-maintenance use or for quick temporary water supply such as refugee camps.


Tube tank in use in Sri Lanka


Tube tank made without overflow in Sri Lanka


Mould developed in Ethiopia for making platters which reduced time to make a platter from 1 day to 1 hour

Barrel

The barrel tank had few problems, it was, however fairly expensive in most instances compared to the other designs although its costs were competitive with many existing tanks. Some households had roofs that were too low to accommodate the standard vertical design. A horizontal design was developed for these households that also reduced the cost, as it did not incorporate as much welding. Some tanks suffered from rusting as they had not been painted inside and some users complained of a "gas" taste to the water, which faded with time. The filters worked well and rarely overtopped.


Barrel tanks being delivered by truck


Horizontal variant in use in Sri Lanka

Crate tank

Fewer crate tanks were tried than other designs due to uncertainty about their longevity. Crates were tried in urban areas, particularly in Sri Lanka in both vertical and horizontal configurations. Several tanks failed due to water pressure pulling out nails, however these tanks were made with fewer nails than initially specified. Later tanks were modified and stood up to the water pressure well. The horizontal design, however suffered problems with the waterproof insert puncturing on the inside of the tank and with water rotting the boards. The tanks were also not particularly cheap when manufactured under field conditions.

Mud tank

The mud tank was tried in a few households in Sri Lanka. Only smaller tanks were tried in this instance as no reliable method of joining plastic sheet in the field was found and it was felt best to prove the design with smaller capacities before larger models were tested in the field. One tank failed when the bamboo reinforcing sheered off at the base. Others, which used timber for reinforcing rather than bamboo, are standing and holding water. The mud walls are liable to washing from rain, however they are easily repaired and a larger roof will reduce this problem. Some doubts remain over the longevity of the design, however thus far results are inconclusive. The tanks are very inexpensive, however and if they prove reliable over a period could reduce the cost of ownership considerably.

Tarpaulin tank

The tarpaulin tank was tried in one location in Ethiopia which ill suited underground cement-based tanks. All tanks held water well but ingress of stormwater and openings allowing entry of small animals caused problems. The tanks also took a large amount of space in the compound. A modification was made to the design to sacrifice some capacity to allow better use of land. The smaller footprint also allowed better sealing of the roof area to prevent entry by vermin.

3.4 User opinions

After use of the tanks, users were asked their opinions about them and to rank the designs as well as their other water sources. The results are in Table 3.2. The larger designs fare best, followed by the above-ground designs. This was borne out by a further exercise whereby participants were offered a flat subsidy that would cover a tube tank but could upgrade to any other design by contributing themselves. Of those that upgraded, most upgraded to Dome tanks or thatch tanks with a view to further upgrading to dome tanks in the future. There have also been reports of replication of dome, thatch and mud tanks from surrounding households.

Table 3.2: Users rankings of designs

Type	Fraction of votes									comments
	Ethiopia			Uganda		Sri Lanka				
	Addis Ababa (urban)	Arerti (peri-urban)	Alaba (peri-urban)	Kampala (Urban)	Kibengo (Rural)	Colombo (Urban)	Aranayaka (Rural)	Ambanpola (Rural)	**Average score**	
Dome			0.27				0.38	0.40	**0.35**	• Well received. Clearly the "winner"
Thatch Roof Ferrocement			0.15				0.25	0.20	**0.20**	• Mainly seen as a step to the dome tank
Drum			0.15			0.33			**0.24**	• Well received but could be expensive • seen as too small
Tube		0.18	0.10				0.13		**0.14**	• Still some unresolved problems, • seen as too small • concerns about children falling in
Mud							0.19	0.30	**0.25**	• Well liked as water is cool – but not seen as "permanent"
Crate						0.17			**0.17**	• Difficult to clean and maintain, • seen as too small
Modified Tarpaulin		0.27							**0.27**	• Water quality problems
Tap stand	1.0	0.33	0.33			0.50			**0.54**	
Well						0	0.06	0.1	**0.05**	
River		0	0				0		**0.00**	
Pond		0.07						0	**0.04**	

3.5 Final design recommendations

After field trials, several designs have proved themselves. The **dome tank** and **drum tank** are ready for release. No real problems have been found with these designs and they have been well received. Despite installation problems resulting in poor sealing, the **thatch tank** is being adopted, particularly as an interim step towards the dome tank. Improvements in sealing arrangements, if adopted will solve most of the reported problems. Changes to the roof design, incorporating a greater range of materials has also helped its acceptance – In light of these changes the designated name has been changed to the "enhanced local materials roof" (ELM.R) tank

The **tube tank** has had several failures in the field, mainly due to poor installation; however well installed tanks are functioning well and costs are much lower than for other designs, particularly where cement is expensive. Therefore, while the design cannot be recommended for permanent water supply, it can be used for fast, inexpensive short-term supply if trained persons handle installation.

A few **mud tanks** have been installed but at present, results are inconclusive. The structures are proving sound against water pressure however there are some problems to be solved before larger versions are viable. If the designs prove themselves over the next couple of years, they have great potential to reduce the cost of above-ground storage.

The **crate tank** has had a number of problems in the field that, while solvable, will increase the cost to a level where it will be too high to justify the design.

The modifications carried out to the **tarpaulin tank**, particularly the addition of a pump have proved successful and have allowed the development of a range of sizes reducing both cost and land use.

4 WATER QUALITY

4.1 Methodology

There have been a number of studies of water quality of roofwater systems over the years, however none have properly captured the changes that take place in a rainwater tank over time. In this study, frequent (approximately every two days) water quality tests were carried out at two sites per country, one urban and one rural to capture differences over time, location and tank type.

The tests used the Del-Aqua field-testing kit to test for Microbiological contamination using *Escherichia coli* as the indicator and for turbidity. Acidity (pH) and total dissolved solids were also measured by electronic instruments.

4.2 Biological Water Quality data and its interpretation

Biological risk

Escherichia coli sampled from different tank designs in the 3 countries recorded an average count of <100 per 100 ml of water. According to WHO recommendations this represents an 'intermediate' level of health risk. This average count was less than that recorded from other sources used in the rural communities studied. However *E.coli* levels in rainwater tanks were higher than in water from the alternative (chlorinated) sources, in urban locations such as Addis Ababa. The same was found in Colombo in Sri Lanka whenever the alternative source was town water drawn from a standpipe, but not where the alternative was a shallow well. Table 4.1 and Table 4.2 summarise our findings (about 1100 FC measurements spread over 6 communities). And Figure 4.1 shows the exceedance curves for all tanks and for rural and urban water supply.

Table 4.1: Average levels of *E.coli* (count per 100 ml) recorded in rainwater tanks and in alternative water sources used by tank-owning households

	Mean Number of *E.coli* per 100ml					
Country	**Ethiopia**		**Uganda**		**Sri Lanka**	
Location	Addis Ababa (Urban)	Alaba (Rural)	Kampala (Urban)	Kibengo (Rural)	Colombo (Urban)	Aranayaka (Rural)
Tank water	40	21	10	5	68	74
Other sources	5	34	20	6	150	76

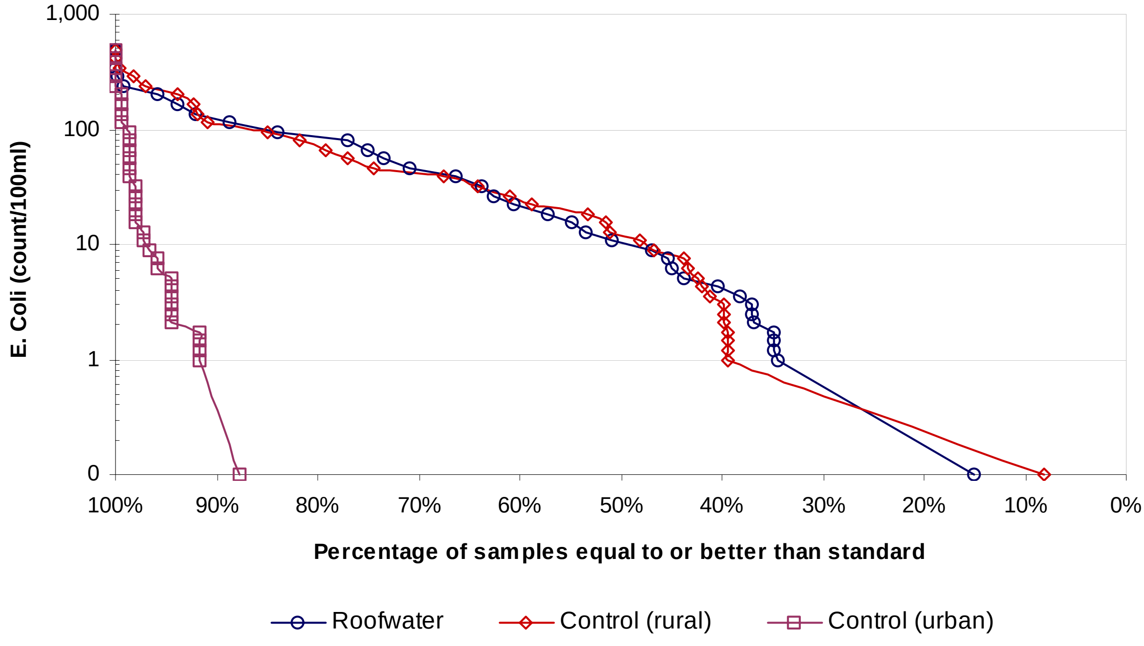
Table 4.2: Percentage of samples at WHO risk grades

Risk category	Roofwater	Other Rural water sources*	Other Urban Water sources*
Zero Risk (0 FCs per 100ml)	15%	8%	88%
Low Risk (1-10 FCs per 100ml)	36%	40%	10%
Medium Risk (11-100 FCs per 100ml)	37%	40%	1%
High Risk (101 –1000 FCs per 100ml)	12%	13%	1%

* Other rural water sources include distributed groundwater, protected springs and shallow wells

** Other urban water sources are treated standpipes

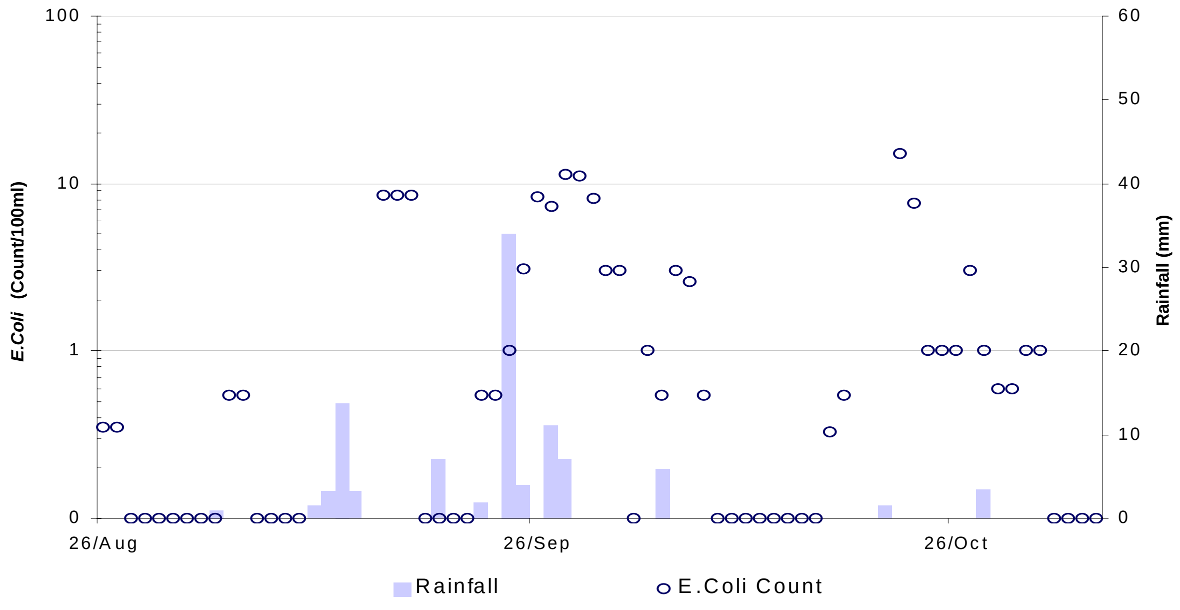
Figure 4.1: Exceedance curves for the *E-Coli* Count in roofwater tanks and in water from other local sources ('control')



Changes over time

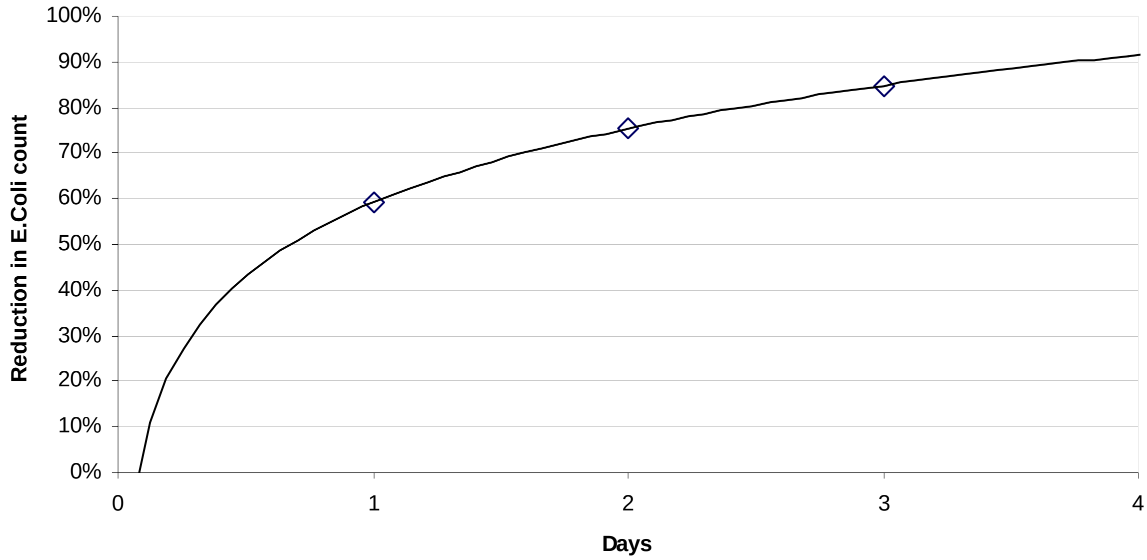
E. coli levels in the tanks are heavily influenced by rainfall .Figure 4.2 shows that high levels are recorded immediately after the rains but that levels reduce within a few days, if no fresh contamination occurs.

Figure 4.2: Figure 3: *E. Coli* recorded from Rainwater Tanks in Alaba (time averaged over 3 days)



Bacteriological die-off is usually described by the time required for a 90% reduction in FC count called the "T_{90}" value. The T_{90} value is also the time required for water quality to pass from one WHO classification to another lower one (i.e. after the T_{90}, Grade III – "intermediate risk" water will become Grade II – "low risk"). A value for T_{90} can be obtained from measurements in the days following a rainfall event. In Figure 4.3 shows the averaged decay in Alaba inferring a T_{90} of about 3.7 days. Average T_{90}s of 3-4 days were found across sites.

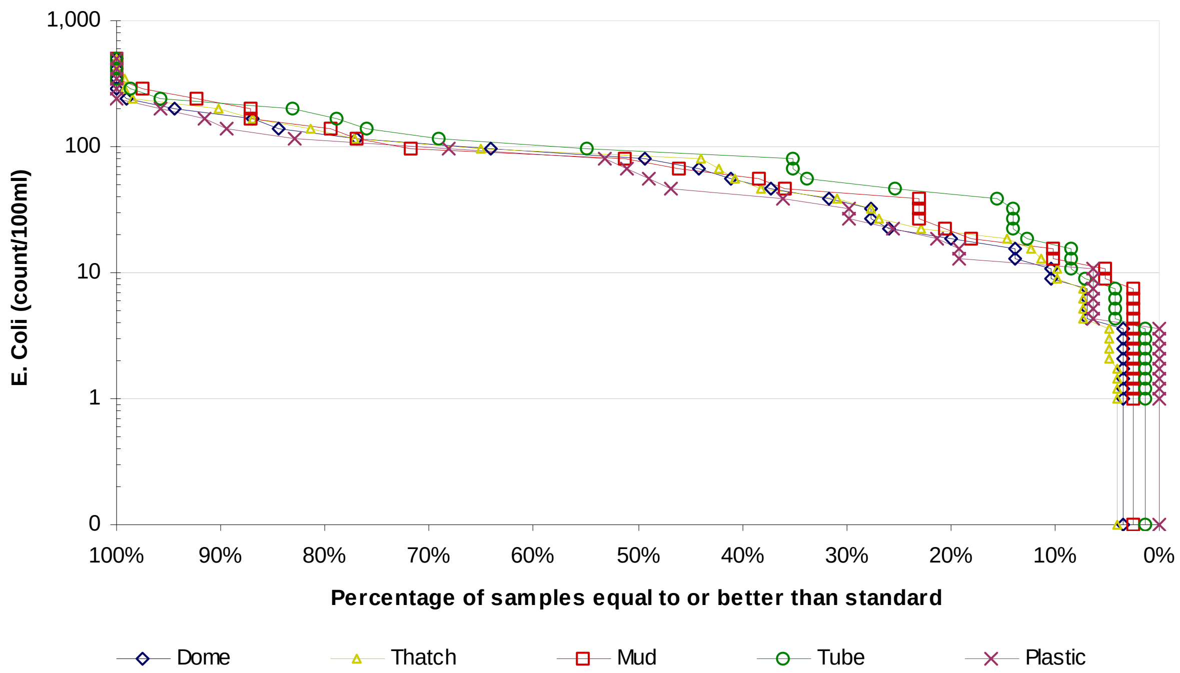
Figure 4.3: Averaged percent Die-off of *E.Coli* in Alaba tanks



Differences in tank type

In terms of bacteriological water quality, there was little to choose between tank types - ferro cement, thatch-roofed, metal barrel or plastic tube. *E.coli* levels in all 4 tanks are high with the onset of rains, levels decrease during the dry period. Larger tanks, generally recorded more zero readings than smaller types as die-off was allowed to continue for longer, however the percentages of other readings were very similar.

Figure 4.4: Exceedance curves for *E-Coli* Count in different roofwater tanks in Aranayaka

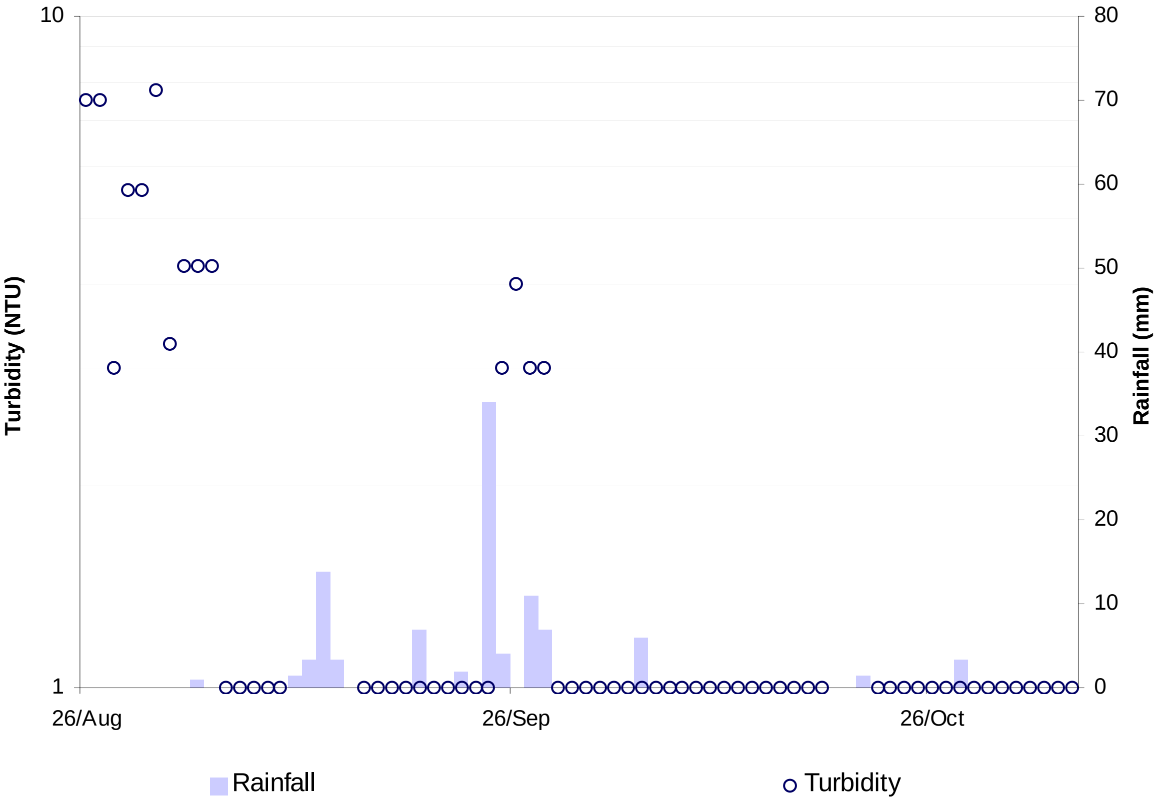


4.3 Physical water quality

Turbidity

Effective disinfection requires that turbidity is less than 5 NTU; ideally, median turbidity should be below 1 NTU. Turbidity recorded from most study locations was below 5 NTU. Tanks with built-in filters such as the barrel tanks recorded high turbidities while new until initial impurities from the filter media washed out. This effect dominated measurements where these tanks ware installed in quantity, for example an average 10 NTU was recorded in Addis Ababa and 7 NTU in Alaba. As with *E.Coli*, turbidity in the tanks correlates with rainfall pattern, high turbidity is recorded soon after rains but quickly falls to a low level as the impurities sediment out to the bottom of the tank (Figure 4.5).

Figure 4.5: Turbidity recorded from rain tanks in Alaba (time averaged over 3 days)*



* The Del Agua turbidity meter can only measure down to 5 NTU, lower turbidity was assumed to be "1"

** High initial turbidities are dominated by barrel tanks' filters washing through

Acidity

For subsequent disinfection with chlorine, the pH should be less than 8.0. The pH values recorded from all locations comply with this requirement except for slightly too alkaline values recorded at rural site at Aranayaka, Sri Lanka. More acidic pH were recorded in the urban sites Colombo, Sri Lanka. This could be due to influenced by local pollution from exhaust fume from vehicles.

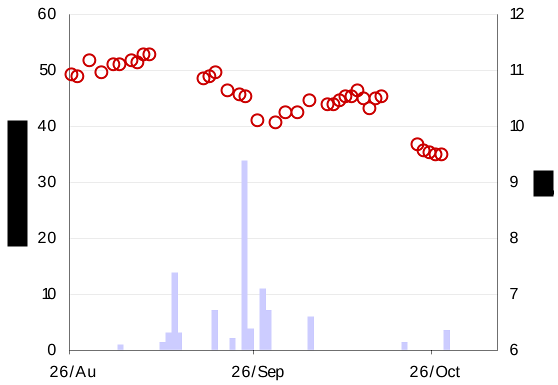
Table.4.3: pH levels Recorded in Rainwater Collection tanks in different locations

	Mean pH recorded in Rain water					
Country	**Ethiopia**		**Uganda**		**Sri Lanka**	
Location	**Urban (Addis Ababa)**	**Rural (Alaba)**	**Urban (Kampala)**	**Rural (Mbrara)**	**Urban (Colombo)**	**Rural (Aranayaka)**
Rainwater	8.2	8.1	8.8	7	5.6	9
Other sources	8.1	8.0	7.5	7	5.5	8

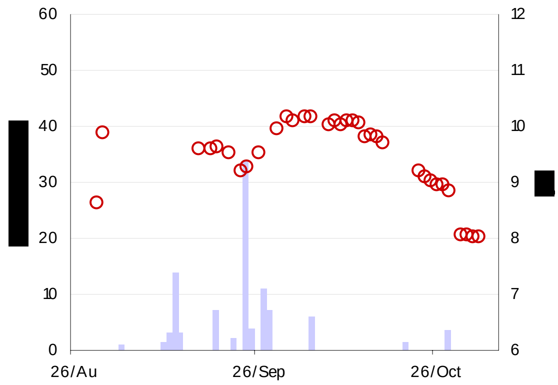
pH in the cement tanks decreases during the wet season and increases during the dry season with an overall fall over the entire commissioning period. Initial pH is high in all tanks, gradually it decreases during the rainy season and increase again after the rains stops (Figure 4.6). This clearly indicates that more alkaline conditions are prevailing in the cement tanks due to cement being dissolved in the rainwater. The alkalinity reduces during the rainy season when water inside the tank is diluted and increases again during the dry season. There is also an overall fall indicating that this effect may be transitory, it will, however take a few seasons to stabilise. In Tube tank, where the tank is lined with polythene the pH levels remains constant. pH in crate tank and barrel tanks remains constant through out the sampling period (figure 6).

Figure 4.6: pH variations in Tube and PBG tanks (diamond symbols & RH scale) with rainfall (bars and LH scale)

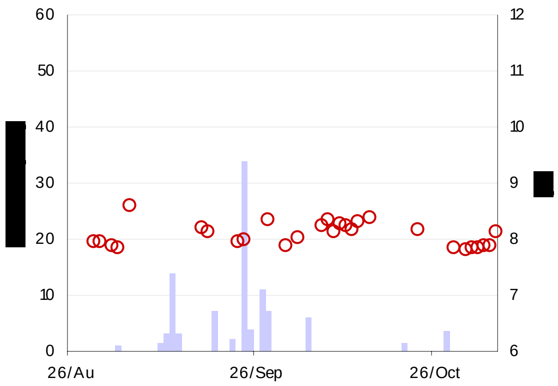
a. Dome tank



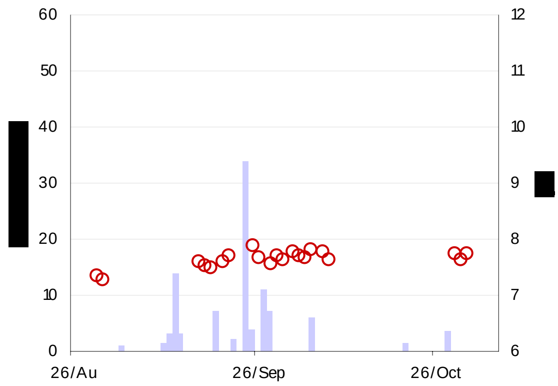
a. ELM.R tank



a. Barrel tank



a. Tube tank



4.4 General mosquito risk data and its interpretation

Since malaria, dengue and filariasis is prevalent in both rural and urban sites in tropical countries the risk of disease-carrying mosquitoes breeding in the rainwater tank is of concern to many practicioners and users. In the 20 tanks sampled in Kampala Uganda, 16 tanks recorded no mosquito presence and 4 tanks (all dome tanks) recorded 3-10 adult mosquitoes, 4-8 larvae and no pupae. In Colombo, Sri Lanka lower numbers of larvae (4-5) were recorded in 4 of the 20 tanks tested (mostly barrel type). Significantly *no* 4th instar larvae or pupae were found. In Aranayaka (SL) no mosquitoes larvae were found through out the study.

Earlier research at IIT Delhi, India had indicated that well-screened roofwater, stored in darkened tanks, has a low nutrition level – too low to permit mosquito larvae to complete their development to pupae and then adult form. These new results are consistent with that observation.

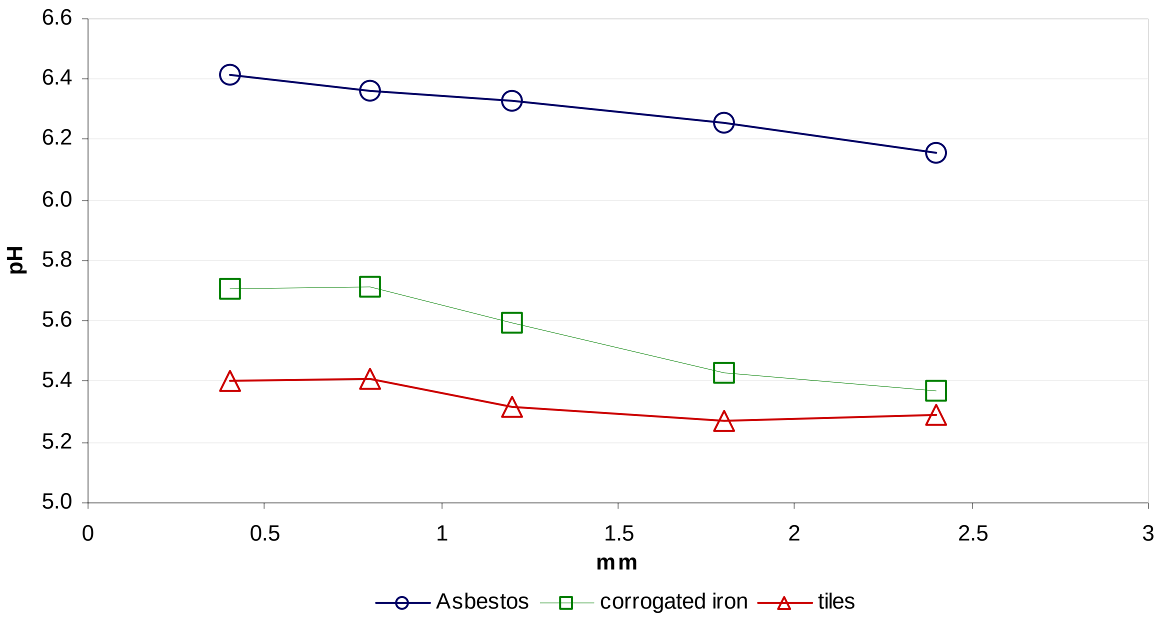
4.5 Results from laboratory work

First flush behaviour

Experiments were set up, similar to those of Yaziz *et al* (1989), to collect first-flush water from different types of roof in Colombo. Roof materials used were asbestos, galvanized Iron (G.I) and tiles. From each roof type of 2.5m^2 area, 5 plastic bottles were linked via PVC piping to collect 3 x 1 litre and 2 x 1.5 litre allocates from each roof. In rainfall terms the successive samples represent: 1 - first 0.4mm rainfall, 2 - next 0.4mm, 3 = next 0.4mm, 4 - next 0.6mm and 5 - next 0.6mm, reaching 2.4 mm in total. The GI (G) and tile (T) samples are similar. Turbidity and pH were measured after each rainfall. Daily rainfall was also measured.

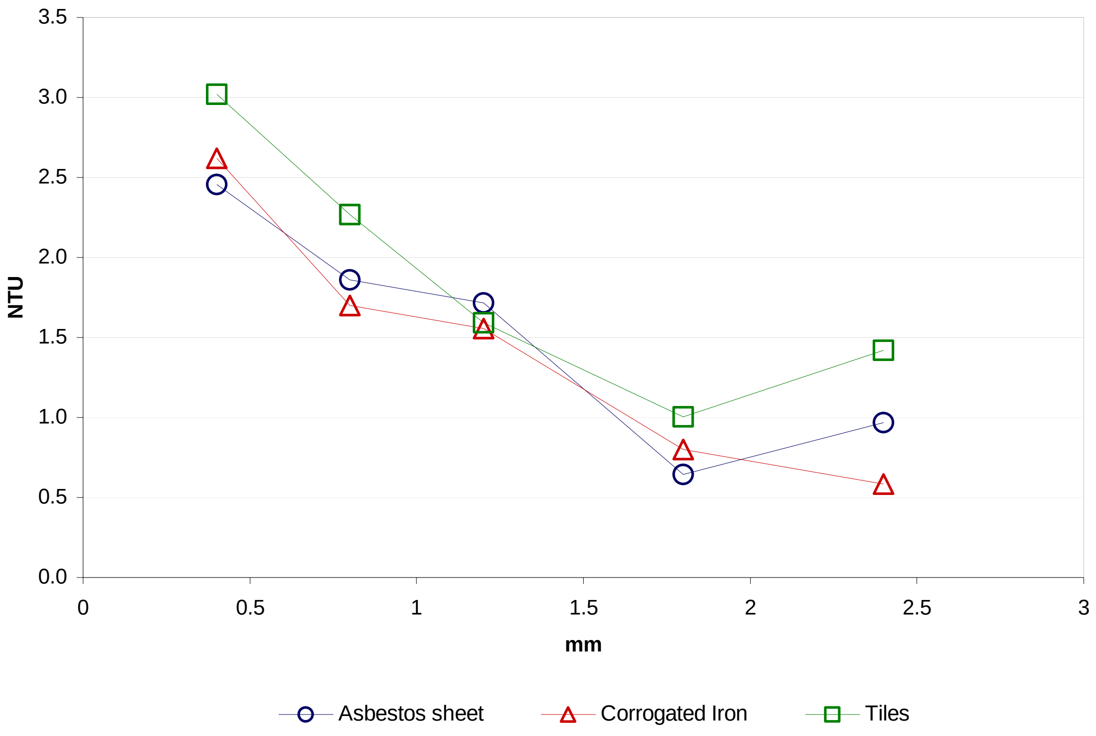
The overall pH of run-off from all roofs was slightly acidic, pH = 5.7 (SD $^+_-$0.7) most likely due to the site's proximity to a major urban road. On average, higher pH values were recorded from asbestos roofs than from GI or tile roofs see Figure 5. Very little variation in pH was observed in successive allocates (A1-A5, G1-G4, T1-T5) from the same roof material, pH drops only slightly during the initial stages of a rainfall event.

Figure 5 Variation of pH of roof run-off water with roofing material



As expected, turbidity reduces as a rainstorm progresses. Surprisingly, GI roofing gives the highest initial turbidity, tile the lowest. However the GI roof cleans itself most rapidly as the rain event continues and after 2mm rainfall gives the cleanest run-off displaying only 1/5th of the initial turbidity.

Figure 4.7: Variation of turbidity for different roof types with stage in rainstorm (cumulative rainfall)



Tank materials (impact on die off)

Continuous work could not be conducted to look at the impact on bacterial die off due to equipment failure. Initial finding indicate that E. coli die off plastic tanks takes 10-14 days where was in cement tanks it takes only 7-10 days. However, more test need to be conducted before a firm conclusion can be drawn.

4.6 References.

WHO, 1993, *Guidelines for the Drinking-water Quality*, (2nd Ed), Vol.1, World Health Organisation, Geneva, 188p

Yaziz MI, Gunting H, Sapari N, Ghazali AW (1989) 'Variation in Rainwater Quality from Roof Catchement'.*Wat. Res*. Vol. 23, No. 6, pp 761-765.

5 ECONOMIC VIABILITY OF LOW-COST DRWH

5.1 Economic issues

Chapter 2 examined survey findings from a socio-gender point of view. That examination inevitable crossed over into economics and the use of household resources. In this chapter only overall ‘economic viability’ as measured by classic financial measures is considered.

Without doubt, the affordability of domestic roofwater harvesting is an important issue and high cost – or an expectation of high cost – constrains the use of the technique. Like many forms of water supply, RWH is capital rather than operations intensive. Annual maintenance and operating costs rarely amortise over the life of the hardware to as much as the first cost of that hardware. In the particular case of DRWH, operating costs are often negligible. Thus a major focus of the study programme has been how to reduce first costs via better hardware design.

Two common features of households practising domestic RWH are (a) multi-sourcing and (b) little sharing between households of the harvested roofwater. With respect to the first there is nothing uncommon – a recent East African study (Thompson, 2001) indicated that an average household uses over 3 water sources in a year, regardless of whether one is RWH. The Sri Lankan partner has long been aware of multi-sourcing of water in rural Sri Lanka. However multi-sourcing rules out some simpler forms of economic appraisal as well as making difficult any formal calculation of water security. By contrast the association of a DRWH system almost solely with a single household simplifies economic appraisal.

Two ‘affordability’ questions are dominant. The first, which views DRWH through the eyes of the householder, asks “Is the benefit to a household (of installing a DRWH system) worth the cost?” The second, which views DRWH from the standpoint of a ‘water provider’, asks “Can, for a specified site and a fully specified service level, the inclusion of DRWH in a water plan result in lower costs than if it is excluded?” Unlike householders, water providers still commonly think in terms of single sourcing, which is convenient for them but is particularly incompatible with DRWH. They may also, to achieve cost recovery, wish to control the daily acquisition of water by households – a requirement very difficult to meet with DRWH. Other stakeholders include those who provide grants or loans to water programmes.

For various reasons the field interventions and surveys undertaken during this programme did not generate good data for answering either question. The main effort was directed at answering the first – namely estimating the ‘payback’ achievable for various sizes and location of DRWH system – rather than the second.

5.2 Field evidence of payback

The DRWH systems installed during the programme totalled about 200, however for other programme reasons (testing of design innovations) they were not purchased by households, nor well-distributed between different tank sizes. More critically the programme was too short (exacerbated by some construction delays) for households to adapt fully to possession of their new facilities. The benefits from owning a DRWH system are strongly affected by the way it is managed, since the value of dry-season water is often a significant multiple of the value of wet-season water. Undisciplined management of a system (such as is normal during the first year of ownership) sacrifices dry-season delivery through wet-season 'extravagance'.

Where DRWH systems are newly introduced into a community, it is reasonable to value the water they yield according the cost of obtaining water of similar quality and volume from the other (existing) sources. There are however two restrictions on employing such a basis for valuation. Firstly seasonal cost variations must be properly allowed for. Secondly any increase in water consumption might command a somewhat lower per-litre value than 'replacement' water. Moreover if implicit *time* costs are included in such analysis, as they need to be when evaluating a 'time-saving' mode like DRWH, the question arises as to what the released time might be used for. This question was addressed in Chapter 2 above, where the survey data discussed showed a wide variety of such time uses. Some clearly have monetary value, others may not. In any case it may take a season or two after the introduction of DRWH before households rearrange their activities fully to make use of the time saved.

Surveys of water use in about 25 households in each of the 8 communities were undertaken (1) before DRWH systems were installed, (2) during the first wet season after installation and (3) some weeks into the following dry season. Unfortunately climatic irregularity in Sri Lanka in 2002-3 meant that the planned condition (3) was not reached there. In addition there were some problems with survey quality and with tank construction quality that effectively reduced the sample set by about 15%.

Because water consumption varies seasonally and because the control group used was statistically small, it proved impossible to reliably estimate how much water each household would have used had they not received a DRWH system. Table 5.1 compares the site total consumptions for surveys (2) and (3) with those measured at survey (1) which had been intended as a datum. The variation is considerable and indicates no clear trend of increased consumption after introduction of DRWH. However at the site (Kibengo) dominating the global averages, there was a nearly 5-fold increase in distance to point sources between wet and dry seasons: this clearly invalidates using a dry season consumption as a datum for subsequent wet-season consumption. The mean for all sites shows surprisingly little overall change in usage following introduction of DRWH – under 6% after allowance is made for the absence of Sri Lankan data from survey period (3).

Table 5.1: Variation of total household water use (all sources) by survey period

Survey period	Mean daily use	Addis Ethiop	Arerti Ethiop	Alaba Ethiop	Kampala Uganda	Kibengo Uganda	Colombo SL	Aranayaka SL	Ambanpola SL	*Mean all sites*
1 (dry)	l/hh/day	95.3	63.1	70.8	106.0	32.5	92.6	93.9	93.8	***81.0***
2 (wet)	l/hh/day	130.0	70.3	77.3	60.4	57.4	89.5	88.6	81.7	***81.9***
3 (dry)	l/hh/day	113.3	50.0	70.5	71.8	67.0	-	-	-	***74.5***

Approx 20 households at each site; averaging 6 persons/hh.

The cost of obtaining water in the poor communities studied is dominated by the inferred costs of time spent fetching or queuing. The size of this time was assessed by two methods, namely (a) using householder estimates of time 'saved' as a result of owning a DRWH system and (b) application of an assumed walking speed (2.4 km/hr) to the reported distance to and from the alternative point source and its multiplication by the estimated number of trips foregone. The first method suffered from poor correlation between the reported reduction in water fetched and the time supposedly saved, the second by neglecting (the often long) queuing time. Table 5.2 below compares the two methods and shows a broad correlation between them except for Arerti in the dry season period (3). It seems that the relevant questions were answered differently, with 'time saved per day' being interpreted as 'of late' and 'water drawn from RW tank' being interpreted as 'today'.

Table 5.2: Time saving due to DRWH – (a) = reported, (b) = calculated, (c) = mean

Survey period	Time saved/ hh	Addis Ethiop	Arerti Ethiop	Alaba Ethiop	Kampala Uganda	Kibengo Uganda	Colombo SL	Aranay-aka SL	Amban-pola SL	*Mean all sites*
2 (a)	mins/dy	47	26	47	191	257	32	45	61	*88*
2 (b)	mins/dy	54	28	62	114	149	10	46	41	*63*
2 (c)	mins/dy	51	27	54	152	203	21	46	51	*76*
3 (a)	mins/dy	0	70	11	84	518	-	-	-	*137*
3 (b)	mins/dy	0	4	7	65	352	-	-	-	*86*
3 (c)	mins/dy	0	37	9	75	435	-	-	-	*111*

Approx 20 households at each site.

The value of time may vary with the seasons: in rural areas time generally has a higher value during the wet ('growing') season. However a single value has been used in the ensuing analysis. From the data rows 2(c) and 3(c) above, employing 50% of the local unskilled labour rate as an approximate value of householder time and adding in the monetary charge (if any) that would have been levied if the roofwater had been obtained instead from a point source, we get Table 5.3. The annual benefits in this table have been calculated assuming that the daily benefits observed in (wet) survey period 2 are maintained throughout the wet season. In addition the daily benefits observed in (dry) survey period 3 are assumed to be maintained: either (L) *throughout* the dry season, or (M) *for half of* the dry season or (S) *for none of* the dry season. In effect (L) is an estimate of annual benefit for 'large tank' DRWH, (M) for 'medium tank' DRWH and (S) for 'small tank' DRWH. Unfortunately

Table 5.3: Economic benefit from DRWH (gaps in data make these estimates very rough).

Survey period	Mean daily use	Addis Ethiop	Arerti Ethiop	Alaba Ethiop	Kampala Uganda	Kibengo Uganda	Colombo SL	Aranay-aka SL	Amban-pola SL	*Mean all sites*
Time rate	US¢ per min	0.13	0.13	0.13	0.20	0.20	0.32	0.32	0.32	
Benefit 2 (wet)	US¢ per day	9	6	13	43	41	7	15	16	*19*
Benefit 3 (dry)	US¢ per day	0	5	2	29	87	n.a.	n.a.	n.a.	*25*
wet months / year		6	7	6	9	6	9	6	5	
Benefit (L)	US$/yr	17	20	19	141	230	24	52	59	*70*
Benefit (M)	US$/yr	17	15	17	128	151	22	39	49	*54*
Benefit (S)	US$/yr	17	9	15	115	73	20	26	39	*38*

Now using estimated mean system costs for large (10,000 l), medium (2,000 l) and small (800 l) tank DRWH systems of $135, $62 and $41 respectively (i.e. conventional tank designs combined with $10 worth of guttering), we get payback times as shown in Table 5.4. Thus Payback (L) in months = 12 x $135 / Benefit L etc.

Table 5.4: Payback times using system costs for cheap but conventional tank designs

Survey period	Unit	Addis Ethiop	Arerti Ethiop	Alaba Ethiop	Kampala Uganda	Kibengo Uganda	Colombo SL	Aranay-aka SL	Amban-pola SL	*Mean all sites*
Payback (L)	months	95	81	85	11	7	74	31	27	***23***
Payback (M)	months	44	50	44	6	5	34	19	15	***14***
Payback (S)	months	29	55	33	4	7	25	19	13	***13***

If the 40% lower costs associated with the new tanks are used, payback times fall to those in Table 5.5

Table 5.5: Payback times using system costs for new minimum-cost tank designs

Survey period	Unit	Addis Ethiop	Arerti Ethiop	Alaba Ethiop	Kampala Uganda	Kibengo Uganda	Colombo SL	Aranay-aka SL	Amban-pola SL	*Mean all sites*
Payback (L)	months	57	49	51	7	4	44	19	16	***14***
Payback (M)	months	26	30	26	4	3	20	11	9	***8***
Payback (S)	months	17	33	20	2	4	15	11	8	***8***

Despite the precariousness of the data, the payback times are similar to those forecast from climate models. However they are highly variable, being dominated by distance to alternative water sources. These are high in Uganda, medium in Sri Lanka and low for the Ethiopian site. These values in part reflect the peculiarities of those communities with which the country partners already had close enough relations to facilitate survey.

5.3 Economic viability, seasonality and tank size

As expected, large tanks give a poorer (longer) payback than medium or small ones, and payback is best where fetch distances are high (e.g. Mbarara and peri-urban Kampala). The mean payback times (over all sites) look acceptably low for all but the largest tanks. The smallest tanks are of course the cheapest, however the economics of systems containing such tanks are disadvantaged by the fixed cost of guttering and by their inability to supply any water at the times of year (dry season) when its value per litre is highest. Crude estimates from Ethiopia and Uganda put the cost ratio of dry season water to wet season water in the range 1.1 to 3.8, with an average of 1.6. These calculations would be much more reliable if the time savings and water consumptions had been measured at least 1 year after tank installation, giving time for users' water management strategies to stabilise.

Not included in the costing are the management cost and full transport cost of delivering hardware to individual households. With a commercial mode of system delivery, this could readily be evaluated. With the NGO mode of delivery used in this research, such costs are absorbed into often-high overheads.

The main alternative to the user's measure of payback (or alternative cost:benefit measures) is the supplier's measure of capital cost for a given level of performance. It was not possible to measure this at the target sites, not only because the capital costs of the existing water supplies there were not known, but more importantly because these alternatives gave a lower level of convenience than roofwater harvesting. A suitable cost comparison could have been between 'all-season RWH' (i.e. large tank systems costing about \$20 per capita) and yard taps or water venders yielding 80 litres per household per day. For lower-performance rural water supplies such as protected shallow wells, data for aid agencies in Ethiopia and Uganda, suggests a norm for investment of \$10 - \$15 per capita. A similar investment figure (\$10 per capita) might be achieved with medium-storage DRWH, which gives more convenient water than a well does but not satisfy all dry season water demand. At the hill-top Ugandan rural site any alternative supply of convenience comparable to RWH would have cost over \$30 per capita.

5.4 References

Thompson J *et al*, 2001, *Drawers of water II*, IIED (1 904035 98 1)

APPENDICES

Bills of materials and costings in field trials

APPENDIX 1: WATER FETCHING BEHAVIOUR

Table 1: Water fetching behaviour in rainy season

Water source	Addis Ababa, Ethiopia		Alaba, Ethiopia		Arerti, Ethiopia		Kampala, Uganda		Kibengo, Uganda		Colombo, Sri Lanka		Aranayaka, Sri Lanka		Ambanpola, Sri Lanka	
	with tanks	without tanks	with tanks	without tanks	with tanks	without tanks	with tanks	without tanks	with tanks	without tanks	with tanks	without tanks	with tanks	without tanks	with tanks	without tanks
DRWH as sole source (volume excluding water given to neighbours)	HH: 0%	-	Vol: 54 HH: 30%	-	HH: 0%	-	Vol: 56 HH: 65%	-	Vol: 43 HH: 100%	-	HH: 0%	-	Vol: 120 HH: 25%	-	Vol: 86 HH: 15%	-
DRWH as partial source (volume excluding water given to neighbours)	Vol: 54 HH: 100%	-	Vol: 48 HH: 70%	-	Vol: 44 HH: 100%	-	Vol: 47 HH: 35%	-	-	-	Vol: 49 HH: 100%	-	Vol: 57 HH: 75%	-	Vol: 64 HH: 85%	-
Informal RWH	Vol: 24 HH: 55%	Vol: 39 HH: 80%	Vol: 31 HH: 35%	Vol: 18 HH: 60%	Vol: 28 HH: 65%	Vol: 24 HH: 90%	-	HH: 100%	-	Vol: 20 HH: 100%	Vol: 30 HH: 10%	0	0	0	Vol: 20 HH: 25%	Vol: 30 HH: 20%
Water point/ vendor/tapstand/ pipe	Vol: 57 HH: 100% Cost: $0.03 Time: 85 (water point)	Vol: 55 HH: 100 Cost: $0.03 Time: 100 (water point)	Vol: 37 HH: 55% Cost: $0.04 Time: 35 (vendor)	Vol: 57 HH: 100% Cost: $0.07 Time: 35 (vendor)	Vol: 33 HH: 100 Cost: $0.05 Time: 70 (main vendor)	Vol: 45 HH: 100 Cost: $0.04 Time: 85 (main w point)	Vol: 60 HH: 10% Cost: $0.18 Time:0 (deliv by vendor)	HH: 25%	- -	-	Vol: 48 HH: 70% Cost: 0 Time: 20 (pipe)	Vol: 49 HH: 80% Cost: 0 Time: 40 (pipe)	Vol: 80 HH: 10% Cost: 0 Time: MV (pipe)	Vol: 60 HH: 20% Cost: 0 Time: MV (pipe)	-	-
Spring/rock tank/stream/ Well	Vol: 50 HH: 5% Time: 15	-	-	-	-	-	Vol: 30 HH: 25% Time: 240	HH: 90%	-	Vol: 40 HH: 100% Time: 60	Vol: 39 HH: 40% Time: 40	Vol: 62 HH: 90% Time: 30	Vol: 33 HH: 70% Time: 35	Vol: 56 HH: 100% Time: 40	Vol: 37 HH: 85% Time: 35	Vol: 91 HH: 100% Time: 60
Total volume collected from all sources (excl given to neighbours)	Partial: 127	86	Sole: 54 Partial: 85	68	Partial: 96	63	Sole: 56 Partial: 87	No data	Sole: 43	60	Partial: 101	96	Sole: 120 Partial: 95	68	Sole: 86 Partial: 103	97
Rainwater as weighted percentage of total	Partial: 43%	36%	Sole: 100% Partial: 56%	16%	Partial: 46%	32%	Sole: 100% Partial: 54%	-	Sole: 100%	33%	Partial: 49%	0%	Sole: 100% Partial: 60%	0%	Sole: 100% Partial: 62%	0%
Average HH size	7	6	Sole: 6 Partial: 6	6	4	4	Sole: 8 Partial: 9	No data	7	8	5	5	Sole: 5 Partial: 4	3	Sole: 4 Partial: 5	5
Consumption/ capita	21	15	Sole: 9 Partial: 15	13	27	17	Sole: 7 Partial: 9	No data	6	8	22	21	Sole: 25 Partial: 25	22	Sole: 24 Partial: 27	21
No of HHs = 100%	15	5	20	5	9	11	17	17	18	1	10	10	13	5	13	5

Time: represents total time (in minutes) spent per household collecting water from each source per day (not weighted by whether it is an adult or child collecting water)

Table 2: Water fetching behaviour in dry season

Water source	Alaba			Arerti			Kampala		Kibengo	
	with tanks	dry tanks	without tanks	with tanks	dry tanks	without tanks	with tanks	dry tanks	with tanks	dry tanks
DRWH as sole source (excluding water given to neighbours)	Vol: 40 HH: 25%			Vol: 25 HH: 50%			Vol: 53 HH: 50%		Vol: 66 HH: 70%	
DRWH as partial source (excluding water given to neighbours)	Vol: 35 HH: 75%			Vol: 25 HH: 50%			Vol: 53 HH: 50%		Vol: 33 HH: 30%	
Informal RWH	-	-	-	-	-	-	-	-	Vol: 60 HH: 10%	-
Water point/vendor/ tapstand/pipe	Vol: 35 HH: 75% Av cost: $0.04 Time: 45 min (vendor)	Vol: 79 HH: 95% Av cost: $0.08 Time: MV (vendor)	Vol: 93 HH: 80% Av cost: $0.09 Time: 80 min (vendor)	Vol: 50 HH: 50% Av cost: $0.06 Time: 30 min (vendor)	Vol: 73 HH: 85% Av cost: $0.06 Time: 145 min (vendor + w point)	Vol: 42 HH: 60% Av cost: $0.02 Time: 90 min (water point)	Vol: 100 HH: 10% Av cost: $0.60 Time: MV (vendor at spring)	Vol: 40 HH: 15% Av cost: $0.25 Time: 60 min (tapstand)	-	-
Spring/rock tank/stream/ well	-	-	-	-	-	-	Vol: 60 HH: 40% Time: 150 min (spring)	Vol: 80 HH: 85% Time: 225 min (spring)	Vol: 50 HH: 20% Time: 60 min (rock tank)	Vol: 58 HH: 100% Time: 350 min (spring)
Percentage of HHs not collect water preceding day		HH: 5%	HH: 20%		HH: 15%	HH: 40%				
Total volume collected from all sources (excl given to neighbours)	Sole: 40 Partial: 70	79	93	Sole: 25 Partial: 75	73	42	Sole: 53 Partial: 123	75	Sole: 66 Partial: 87	58
DRWH as %age of total in partial supply HHs	50%			65%			43%		38%	
Average HH size	Sole: 6 Partial: 7	6	5	Sole: 5 Partial: 3	4	7	Sole: 8 Partial: 11	8	Sole: 10 Partial: 6	7
Consumption/ capita	Sole: 7 Partial: 11	Unadjusted: 13 Adjusted: 7	Unadjusted: 19 Adjusted: 9	Sole: 5 Partial: 25	Unadjusted: 16 Adjusted: 9	Unadjusted: 7 Adjusted: 3	Sole: 6 Partial: 12	10	Sole: 7 Partial: 15	9
No of HHs = 100%	4	16	5	2	12	5	8	8	10	9

Time: represents total time (in minutes) spent per household collecting water from each source per day (not weighted by whether it is an adult or child collecting water)

In Alaba and Arerti households are unable to collect water daily during the dry season due to excessive queues: the barrel may spend from two to seven days, respectively, in the queue prior to water collection. Hence the consumption per capita figures have been adjusted on the assumption that the water collected *lasts for two days.*

A collaboration between the DTU and Lanka Rainwater Harvesting Forum, ACORD Uganda and Water Action Ethiopia.

This document is an output from a project funded by the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of the DFID