Roofwater Catchment for the Rural Poor

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Introduction

This paper concerns the use of domestic roofwater to supply households in the rural areas of low-income countries. It focuses on communities where rainfall is sufficient, roofing is suitable for domestic roofwater harvesting (henceforth DRWH), and where existing point water sources are so widely spaced that fetching water from them is a considerable household burden. The paper is illustrated by data from East African areas where these conditions apply and where incidentally a very complete evaluation of rural water economics was made in the mid 70s (White, Bradley, & White, 1972 – which showed the over 10:1 increase in per capita consumption that can occur when convenient piped water replaced fetched water).

The primary benefit of DRWH in the scenario we are addressing is the time-saving, or more rarely money-saving, obtained by reducing the fetching of water. A secondary benefit is the increase in water consumption that follows any reduction in marginal water costs. The situation has a strong seasonal aspect, since in the dry season the cost of water from point sources rises, due to the failure of more local sources and increases in queuing times, while the yield of DRWH systems falls. There are consequent changes in water consumption.

The main design choices in DRWH concern the size and type of tank used, the area of roof guttered, the water-management strategy and any phasing of construction. This paper addresses these options mainly from an economic standpoint, using a mixture of field data collected in 2000 and modelling. It is based on activities undertaken under two 4-partner DRWH research programmes (one EU-funded and the other DFID-funded) and under a smaller programme funded by the Laing Trust and by Warwick University. The support of these sponsors is gratefully acknowledged. Further details may be found in Rees & Thomas 2000, DTU website & RHRG website.

Cheap DRWH systems

Any economically viable DRWH system needs to yield benefits whose value exceeds the cost of the system. For poor households there is the additional requirement that the initial outlay is small or at least can be incurred in small instalments. ‘Cheapness’ can be achieved by subsidy, by adoption of small components, by restriction to more favourable sites and perhaps by innovative technology.

Subsidy of RWH for the rural poor is a popular strategy with RWH promoters. The debate about subsidy itself lies outside this paper’s scope. However it has been the intention of the research programmes behind this paper to identify ‘economically viable’ forms of DRWH that do not require subsidy. They are therefore predicated upon the necessity of using small components, especially small tanks and restricting attention to climatically favourable areas like the humid tropics. A key requirement, formerly rarely satisfied but now commonly met, is that housing has hard roofing (metal, tile etc.) rather than vegetation roofing. The rural focus also helps, since the benefit of reduced walking time is generally greater in rural than in urban areas.

Moreover there are many extra constraints on the application of DRWH to the urban poor. Initial analyses indicate that we should be considering systems whose storage capacity equals only five to ten days' consumption.

Meanwhile the search for a technological breakthrough to reduce the unit cost of water storage goes on. DRWH is a fairly mature technology and it is probably too much to hope for innovations that would halve system costs. However our own research has identified three strategies as promising. The first is to 'go underground' with storage provided certain soil conditions are satisfied. The second is to separate into different materials the two functions, of strength and water-tightness, required of a cistern. The third is to identify areas like gutter design where a small extra expenditure can allow greater savings elsewhere in the DRWH system (DTU & RHRG websites).

Basic model for evaluation

In any evaluation it is desirable to put as many factors as possible onto a common measure, so that they may be added or compared. That measure is generally money. Usually however there are some factors that do not fit that approach (say equity, environmental impact, gender impact) and need separate treatment (Kamminga 1991). Here we present only a crude economic analysis.

The cost of using DRWH is dominated by system construction costs, compared to which annual operating costs are usually negligible. Construction costs in turn are dominated by tank costs where there are significant economies of scale. Actual costs vary considerably from country to country, with varying local materials costs and labour rates However the cost-to-volume sensitivity is typically 0.7 (Rees 2001, so each doubling of volume reduces cost per litre by 19%). We are here considering a basic systems cost of under US$ 100.

If formal DRWH were to meet *all* the current water consumption, displacing both the fetching of water from point sources and any existing informal DRWH, we could value its annual benefit at

B = [(Existing annual water consumption – informal RWH) x value/litre] + Value of extra water

which requires us to find quantities and a unit value for both the replaced and the 'extra' water. For any location, a survey might yield a fair estimate for current consumption, while we may infer value either from water-carrier's prices or from walking-plus-queuing times multiplied by a value of time. Walking times in turn require measurement of fetch distances, numbers of trips and effective walking speeds. Actually the *value* of the water to the household will on average be higher than its collection cost, since any household can be assumed to have a falling unit-value *v* daily-consumption curve and to have set its consumption at the level where the unit value of extra water equals the unit cost of acquiring it. However it is satisfactory to use current cost rather than (this higher) estimated value in the calculation of benefit *B*. By the same argument, the unit value of the extra water will be less than that for replaced water. However if the ratio of extra to replaced water is small we need make no correction and can treat both as having the same value.

The rise in consumption in the wetter months reflects the lower cost of fetching (and queuing) at that time. Because the bulk of the water replaced by DRWH, and almost all of any increased consumption, falls in these wetter months, we should use the (lower) wet season costs in our benefit calculation. The length of the ‘wet season’ depends upon both how we define it and the geographical location. Analysis of daily rainfall records for a typical equatorial location in East Africa indicates that for half of each year rainfall in the last week exceeds 70% of the (annual) weekly mean and for two thirds of the year exceeds 35% of that mean. These thresholds of 70 and 35% were chosen to represent respectively total and partial household water provision from roof runoff in the chosen scenario.

There is a considerable literature (Heggen 1993, Gould & Nissen-Petersen 1999: Chap 5) covering the use of daily rainfall data to predict the annual yield to be expected from a given RWH system (for small tanks monthly data is not suitable unless it is skilfully randomised into ‘pseudo’ daily data). The various models however require the specification of the water management strategy. This can range from “lavishly use what is available” to “conserve water for emergency (drought) use only”. With small tanks the advantages of being prudent are small – calculations suggest that even where dry-season water is valued at *five times* the rate of wet-season water, the “lavish-use” strategy yields more benefit per year than any restrained-use strategy.

Since benefit per year stays constant, it is acceptable to assess viability using ‘simple payback’ and the application of a say 30-month acceptability threshold (corresponding to IRR = 50% pa for a long-life system).

Data gathering

As a rough check on both DRWH usage and economic viability, small jars (capacity = 600 litres) were installed in mid 1999 in 6 rural households near to the trading post of Kyenjojo in western Uganda. For each household the distance to the normally-used point source was measured and mean consumption was estimated by user-tallying of 20-litre jerrycans carried from that source over one month before the RWH jars were commissioned. The tally was continued for 5 months (covering both wet and dry months) after jar commissioning and the drop in water fetched was taken as the estimate of rainwater used. No account was therefore taken of the probable increase in total consumption.

The pattern of use was similar for all the survey participants. No advice had been given on how the jar should, or could, be used to provide increased water quantity or increased water security. In all cases the participants used the water as soon as the rain had fallen and there was water in the jar. When there was no longer water in the jar they returned to using the traditional water source. This approach maximises the water harvested from the roof and minimises walking time during the wet period. Whether it also minimises *annual* walking distances depends on the distance to any secondary point source used if and when the primary one dries up.

A similar but more detailed survey has been set up near Mbarara in S Uganda to cover the period August 2000 to January 2001: its findings will be reported at the Conference.

Table 1 : Findings of the small Kyenjojo (Uganda) survey

	Name of Household	Kandole	Katenta	Mugisa	Kaahwa	Karam'gi	Kayula	Averages
General Data	Distance to trad source (m)	200	500	400	400	300	1500	550
	Number of occupants	6	5	4.5	4	9	8	6.1
	Roof area (m sq)	20	27	24	22	24	30	24.5
	Rainy/Total days considered	25 / 139	43 / 139	33 / 123	20 / 116	33 / 124	25 / 139	30 / 130
Calculated daily averages	Jerrycans carried/consumed	3.0 / 5.2	1.1 / 3.0	1.9 / 5.2	2.0 / 2.9	2.9 / 4.9	3.0 / 5.0	2.3 / 4.4
	lcd consumed	17.2	12.0	23.3	14.7	10.8	12.5	15.1
Estimated daily Savings	Litres	43.8	37.2	58.7	19.2	40.8	41.9	40.3
	Walking distance (km)	0.88	1.86	2.35	0.77	1.22	6.28	2.2
	Walking time (mins)	21.0	44.7	56.4	18.5	29.4	150.8	53.4
	% total water consumed	42.4	61.9	61.6	32.8	41.9	41.7	47.1

The summary shows that particularly high savings can be made in walking time and walking distance when the distance to the traditional source is high (Katenta and Kayula), or where lcd consumption is high (Mugisa). The actual daily time savings are very significant – ranging from 18 minutes to 150 minutes. It is interesting to note that there is no strong correlation between distance walked and lcd consumed, contrary to what is generally believed to be the case. The lcd figures (10.8 to 23.3 litres) do correlate well with estimated consumption figures for the region and with observations made by the authors. The percentage of household water consumption contributed by the jars varied from 33% to 62%. Even the lower of these figures is a significant contribution to domestic water supply given the low capital expenditure.

A separate survey was made of water-fetching by 240 households *without RWH* using 12 point sources in 5 locations in Rwanda, Tanzania and Uganda. The results indicated a high mean distance to point source of ca. 2 km, a mean consumption of 10.6 lcd and a mean walk time of 3.7 hours per day per household. Simulations using daily rainfall records for seven sites in the Region suggest that a small-roof small-tank (600 litre) system would supply at least 60% of annual consumption and therefore save these households an average of 2.2 hours per day. The site-selection for this survey was however not closely controlled: the households may therefore be unrepresentative and the distances may carry a dry-season penalty. For these reasons a more conservative 1.2 hours/day/household is a preferred estimate of savings, which corresponds to a benefit of at least $35 per year.

On the costing side, international data suggests that the sensitivity of cost to volume for any given type of tank is in the range 0.5 to 0.7 – so there are strong economies of scale. This would seem to discourage piecemeal ('staged') installation of systems. Low-cost designs for small (600 litre) and medium (6000 litre) tanks were recently tested in Uganda (Rees & Thomas 2000) and found to give *system* costs of around $50 and $200 respectively.

Application of model

For the Kyenjojo data given above, the valuation of the roofwater was made on two rival bases. Either walking-plus-waiting time was priced at 50% of the unskilled labour rate, i.e. at USh.150/hour, or water was valued at the local water-carriers' rate of USh.150 - 400 per jerrycan. Valuations for the households nearest and furthest from their respective sources are as follows, assuming a rather high system cost of USh.100,000/-.

Table 2 : Economic evaluation of the Kyenjojo small jar survey
(USh1000/- = $\$_{US}$0.58)

Household	name	Kandole		Kayule	
Dist. to source	m	200 ('short trip')		1500 ('long trip')	
RWH system cost	USh	100,000		100,000	
Mean RWH yield	litres/day	44		42	
Value time saved*	USh/day	88		357	
Value water saved**	USh/day		349		840
Payback time	Months	37	9	9	4

* assuming walking at 3 km/hour plus waiting/filling for 8 minutes per 20-litre jerrycan, all at USh.150/hour.
** assuming water-vendor rates of USh.7.5 per litre for 'short' trips, USh.20/- per litre for 'long' trips.

The payback times are strikingly shorter for purchased water than for water fetched by a household member, which raises questions as to whether the energetic task of water fetching should be valued at more than the rate (50% unskilled labour rate) used here. In the table below, we have forecast the RWH yield for a representative East African household with 40 m^2 of roofing & using 70 litres/day. The inferred value of water is \$.0025 per litre – based on carriage for 1 km.

Table 3 Payback times for small systems (using Saiya, W Kenya rainfall data)
Basic jar (600 liter) costs \$40, single gutter costs \$10, elasticity of tank cost to size = 0.7)

Column:	***a***	*b*	*C*	*d*	*e*	*f*	*G*	*h*
Jars used (no. x liters)	**1 x 600**	2x600	1x1200	1x1800	1x600	2x600	1x1200	1x1800
Roofing (no. x m^2)	**1 x 20**	1 x 20	1 x 20	1 x 20	2 x 20	2 x 20	2 x 20	2 x 20
System cost (\$)	**50**	90	75	96	70	100	95	117
Percent demand met	**67**	75	75	79	79	89	89	92
Payback (months)	**14**	23	19	23	17	21	20	24
Incremental payback* (months)		96				58		

- Incremental payback reflects the return on the latest increment in investment taken alone

Column ***a*** represents a minimal RWH system whereby half the roof is drained via simple, short guttering into a single small jar. The payback is good at 14 months.
By comparing columns *b* & c, we see that for a system installed in increments the overall payback time is longer (worse) than when the same capacity is installed in one go. It still however stays below a 30-month acceptability threshold. The payback on the *increment* in investment (bottom row) is poor, however there are strong other reasons why a household would prefer an investment staged over two or more years – including that water usage itself is likely to grow gradually with adoption of RWH.
Surprisingly, comparing columns *f* & *g* shows only a small advantage when two small jars are replaced by one big one. This is because when harvesting from both sides of a roof there are savings in piping if two jars (one on each side) are used instead of one house-end jar.
By comparing columns *a*-*c*-*d* (or *e*-*g*-*h*), we see that although enlarging the storage volume raises the performance it also lengthens the payback time. This is so despite the economies of scale in tank construction.
Columns *c* and *e* represent two different improvements over the basic system ***a***. With *c* storage capacity has been doubled; with *e* the roof catchment area has been doubled. The latter gives in this case a greater performance improvement at less cost increase

than the former. It is often so that increasing catchment area is more viable than increasing storage, even where extra catchment has to be built rather than merely guttered.

Conclusions

The specimen calculations above confirm our observations in the field in East Africa that very small roofwater harvesting systems are economically attractive in the humid tropics. Payback times for rural systems with tanks as small as 600 litres are commonly under 18 months. Such small systems can provide, under these favourable climatic conditions, over 60% of current household consumption. Larger systems increase this supply percentage but give a lower internal rate of return unless consumption per capita rises as well. Piecemeal installation of systems incurs extra costs and therefore longer paybacks. Maximising collection area (and guttering efficiency) should not lag behind increasing storage volume.

References

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