



Low-cost methods of rainwater storage

Results from field trials in
Ethiopia and Kenya



Hune Nega
Paul M. Kimeu



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Middle: Excavation for a spherical tank in Mwala, Machakos District (Photo: Paul Kimeu)

Bottom: A ceramic tank in use, Tulimani Location, Makueni District (Photo: Kimunya Mugo)

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Foreword

Rainwater management—harvesting, storage and careful use of the water—is one way of addressing the problems of water shortage in the drier areas of Africa. But its implementation presents a number of challenges, of which storage is one. Many people in the rural areas of eastern Africa who would like to harvest rainwater lack the resources to store it. Tanks constructed of plastic, iron sheets, stone, brick or ferrocement are often too costly, therefore there is a great need for cheap and practical alternatives. This publication gives an account of trials that were carried out in one year (1998/99) in Ethiopia and Kenya to investigate some such alternatives.

A main feature of the tanks described in this book is that they are located underground, which reduces the need for stones, cement and reinforcement as the soil itself provides support for the walls of the tanks. The resulting saving in materials investment may, however, be offset by an increased number of man-hours required for digging and other building work. But many people are prepared to make this investment for their own benefit.

In Ethiopia, five different methods for construction of low-cost tanks were tested in trials carried out in the suburbs of Nazareth town in Adama Woreda. In Kenya, six different methods of constructing tanks were tested during the same period. The trials were conducted at various locations in Machakos and Makueni Districts.

Although no completely satisfactory alternative to conventional methods of water storage has yet been identified, a great deal has been learned about different approaches for which there was little prior information. The findings presented here are an important part of the ongoing search for cost-effective approaches to rainwater harvesting and storage.

This publication is based on separate reports prepared by the two investigators, Hune Nega in Ethiopia and Paul Mutuku Kimeu in Kenya. A general introduction is followed by separate and detailed reports on the investigations in Ethiopia and Kenya. The last chapters bring together general conclusions and recommendations arising from the two studies.

All the structures described in this report are still serving their intended purpose three years after they were installed, but work is continuing to improve the technology. It is hoped that the experience gained can be shared with others to further the implementation of cost-effective methods of storing rainwater. High-quality harvested water suitable for human consumption can, of course, justify more costly storage methods than water meant for irrigation. Therefore, each kind of water harvest and the intended purpose must be taken into account when designing water-storage facilities and calculating their relative economic cost.

Åke Barklund
Director, RELMA

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1. General introduction

Rainwater harvesting can be defined as the collection and storage of rainwater run-off from a variety of surfaces for domestic use or agricultural purposes. The investigations described here are for the storage of rainwater for domestic purposes. This water is collected mainly from roofs, and is sometimes referred to as 'blue water' in contrast to 'green water', which is water that is utilized by living organisms (plants and animals) for production.

Awareness of the need for rainwater harvesting has been growing with the realization that in many areas existing water resources cannot meet the needs of an expanding population. The quality of existing water supplies is often poor and leads to continuing problems of water-borne diseases. In many areas there is little or no likelihood of a piped water supply becoming available. Therefore, roof-water harvesting would appear to offer a feasible way of improving quality and availability.

In Ethiopia it is estimated that out of the total population living in rural communities, only 3–4% have access to a safe water supply. Diseases caused by poor sanitation and lack of hygiene in the home are a constant threat. In addition, much time and energy is taken up with fetching water from distant sources. At least once every day, women, children, and in rare cases men, leave their homes carrying a variety of containers to collect water for domestic use. During the long dry season and in the more arid areas individuals may travel as far as 10–15 km to fetch water. In Kenya it is not uncommon for girls to be withdrawn from school during dry periods to help with fetching water.

According to an Ethiopian study, the average household draws 43 litres and 47 litres of water per day in the dry and the wet season, respectively. This is equivalent to an average of 9–10 litres per person per day.

A variety of methods are used to transport water. Traditionally clay pots and gourds have been used as they are available locally. Clay pots have the advantage that they keep the water cool and can be purchased cheaply in the local market. More recently, plastic jerrycans have become popular because they are lighter and relatively durable. Donkeys are commonly used to transport water in jerrycans, tyre tubes and skin bags.

Larger quantities may be transported in barrels by rolling them along the ground or in animal-drawn carts.

Rainwater harvesting has the potential to reduce this enormous burden of collecting and transporting water and at the same time to provide a cleaner supply. However, major limitations to the expansion of rainwater harvesting have been the lack of suitable roofs and the lack of storage facilities. The most suitable roofs for rainwater harvesting are those with corrugated iron sheets or clay tiles, which are relatively costly when compared with grass thatch. However, there has been a rapid increase in the number of houses with iron-sheet roofs and the potential for collecting relatively clean water has therefore increased greatly. In addition to a suitable roof, there must obviously be gutters and pipes to collect the water. Though adding to the cost, these can be fabricated locally from sheet metal. The biggest obstacle to the expansion of rainwater harvesting at the present time is the cost of storage.

Two training sessions on roof-water harvesting were held in Ethiopia in 1997 and 1998. Technical staff from relevant government and non-government organizations participated in these sessions. During this practical training, storage tanks made of masonry, brick and ferro-cement were constructed. Though many appreciated the training sessions, the adoption and diffusion of the technology has not been encouraging. Responsibility for household water harvesting is not well defined within the government machinery or among NGOs. However, it appears that the major constraint to the promotion of rainwater harvesting schemes in rural areas is the high cost of storage structures. Lack of the necessary building materials is also a constraint.

The main aim of the investigations reported here was to find low-cost, appropriate and sustainable methods for rainwater storage. For this purpose, trials were carried out in Ethiopia and Kenya. Five different methods of tanks construction were tested in Ethiopia and six different methods in Kenya. The Ethiopian trials were conducted in the suburbs of Nazareth town in Adama Woreda. The Kenyan trials were conducted at different locations in rural areas of Machakos and Makueni Districts. The trials in the two countries were not identical because of the different materials that were available and the different ideas of what might be workable in the local situation.

2. Field trials on rainwater storage in Ethiopia

2.1 Introduction

Preparation for the trials involved the following steps:

- Literature review of documents pertaining to rainwater harvesting technology
- Visits to low-rainfall areas to assess indigenous and improved practices for rainwater harvesting
- Discussion with relevant government and non-government organizations involved in the production and analysis of building materials
- Selection of households for demonstrations, sites for trial tanks and building materials
- Laboratory testing of soils for their suitability in tank construction
- Identification of the most appropriate design for water tanks (shape, capacity, etc.) taking into consideration the culture of the beneficiaries.

Site selection

Adama Woreda (District) is located about 100 km south-east of Addis Ababa at an altitude of 1,620 m. The climate is semi-arid with a rainfall of 700–800 mm per year. The short rains come in March and April, while the long rains come from July to September. Temperatures range from about 25°C during the rainy season to 34°C during the long dry season. The potential evapotranspiration can be as high as 2,400 mm per annum.

Adama District is located in the rift valley and the people living in this district suffer from scarcity of rainfall. It is, in fact, one of the most drought-prone areas of the country with scarcity of land, poor crop yields and critical water shortage. The rainfall is also erratic and unevenly distributed, even during the rainy season. In general, the geological characteristics of the area coupled with severe land degradation have contributed to low soil-moisture storage and the absence of perennial streams and/or shallow groundwater.

The majority of the households in the area spend 4–6 hours per day collecting water from rivers, ponds and other water points. The long distances travelled to fetch

water, and the shortage of clean, potable water, were cited by the people as major problems. Government efforts to tackle the problems have been concentrated in some urban localities.

Currently, low-cost options for harvesting rainwater are gaining more attention. For example, the non-governmental organizations CARE-Shoa and Water Action have been much involved in assisting rural communities in the rift valley on a participatory basis in the construction of storage facilities for water from roof and ground catchments. The Adama District agriculture office, with RELMA support, has also contributed to the construction of storage tanks up to 20 m³ at household level.

In order to select the trial sites for the current study, three Peasant Associations were identified by the Adama district Agriculture Office on the extent of their water problems. Within these associations, five households were selected. The district-based subject matter specialists, together with the field-based development agent, were given the overall responsibility of identifying the five households using the following criteria:

- Households having to travel 5 km or more to fetch water (one-way trip)
- Having corrugated-iron-sheet roofing
- Having a female head of household and a relatively low income
- Willing to cooperate and contribute with local materials and labour and assist with whatever means they had.

During the dry season, the water sources for the majority of the selected households are vendor water points in Nazareth town about 5 km away. Other than these sources, households also use, particularly during the rainy season, water stored in depressions in gullies, from ponds and from roadside ditches. The cost of water from the vendors is 1 cent (0.01 Birr) per litre. The average household's domestic consumption was about 50 litres per day, which costs about 50 cents. In addition to the cash expenditure, a member of the household, usually a women or girl, has to travel up to 20 km per day carrying a 25-litre jerrycan to meet the household's minimum daily water requirement.

2.2 Tank design

The storage structures that were considered most appropriate for investigation were individual household tanks placed below ground level. Dams and ponds have a role to play, but where they are under communal use they often suffer from poor management due to lack of well-defined roles and responsibilities. Individual household tanks eliminate the need to trek for long distances, thereby saving time which could be used for more productive purposes. Since individual tanks are small, they reduce losses from evaporation and the risk of pollution. They also introduce the possibility of using some water for supplementary irrigation of a homestead vegetable garden.

Design criteria

The following points must be taken into consideration when designing a storage tank:

Seepage

In order to minimize the loss of water due to seepage, different designs and the use of impervious materials must be considered. The cheapest possible way of reducing seepage in ponds is by puddling the soil. The use of such materials as cement, gypsum and plastic lining can also reduce seepage, though the cost and availability of such materials are major constraints.

Evaporation

If water is exposed to direct sunshine and wind, a large proportion of it can be lost by evaporation. These losses can be minimized by providing the storage tank with an appropriate cover.

Length of the dry season

Since the purpose of the tank is to store water for use during the dry months, the longest expected dry season in the various climatic zones will determine the size of the required storage tank. A smaller tank will suffice in areas with a prolonged rainy season and short dry season.

Daily consumption

The size of the storage tank to be built will also be dependent on anticipated use, the number of users and the estimated daily consumption. The provision of water close to the house is also likely to increase the level of consumption.

Construction costs

Experience shows that several designs could be suitable for a given area. The utilization of locally available construction materials will minimize costs and could in turn help the spread of the technology. However, care must be taken because what is cheap may not necessarily be durable.

Underground tanks were chosen for investigation in these trials because it was assumed that the ground itself would provide support, it would eliminate the need for reinforcing and it would reduce the cost of materials used. Secondly, the method of construction would be user-friendly and could be managed by the users with their own skills and knowledge. Lastly, an underground water tank would offer the possibility of collecting water from ground surfaces where houses do not have iron roofs.

In many parts of Ethiopia, rural household utensils such as *enjera mitad* (a circular clay griddle for baking the traditional bread), *ensera* (a large clay water pot used to carry water from rivers and other sources), *wonfet*, *moseb* (a container for storing bread made from plaited grass), *sefed* (a large circular platter made from plaited grass frequently used in the kitchen), as well as traditional huts and underground grain-stor-

age pits, are circular in shape. Since this is a familiar shape in the culture, a circular (spherical/hemispherical) type of water tank was considered for the trials. A spherical (ball) shaped storage structure has the advantage of exerting uniform pressure on the walls. In view of the culture, traditional knowledge and skill available, as well as engineering considerations, a hemispherical (half-ball) shape was selected for four out of the five tanks to be constructed. The remaining tank was rectangular. The capacity of the tanks varied from 6 m³ to 14 m³.

Tank linings

As mentioned earlier, the use of stone or ferro-cement was ruled out in order to minimize costs. An attempt was made to find an alternative method of lining the excavated tank to prevent seepage. Three of the hemispherical tanks had different soil/termite-mound–cement linings, the fourth was lined with polythene sheeting (0.5 mm thickness), and the fifth was lined with cement–sand mortar. Details of the linings used are given in Table 2.1.

Table 2.1 *Materials used for lining underground tanks*

Tank	Materials used	Cement: soil ratio by volume	Thickness (t) (cm)
1	Cement–termite mound	1:8	6
2	Cement–soil	1:8	5
3	Cement–termite mound	1:8	5
4	Polythene sheeting		0.5
5	Cement–sand mortar	1:3	5

For the lining materials, the upper 50 cm layer of topsoil from the excavated pit (trial 2) and 3–5 cm off the top of the termite mound (trials 1 and 3) was removed to ensure that the mixture used would be free from organic matter. The soil and termite-mound material used for plastering was tested at the National Soil Laboratory for particle-size distribution, and the results are shown in Table 2.2.

Table 2.2 *Soil particle distribution test*

Tank	Sample depth below ground (m)	Soil particle size distribution (%)			
		Sand	Silt	Clay	Texture class
1*	–	43	34	23	Loam
2**	0.5–1.72	49	28	23	Loam
3*	–	39	34	27	Loam
4	Polythene lined				
5**	0.5–2.5	49	30	21	Loam

* Termite mound

** Soil excavated from trial pits

Tank roofing

To reduce the loss of water by evaporation and also to minimize the risk of pollution, all tanks were provided with a roof using a variety of materials.

During the first phase of the investigations, the tanks in trials 1, 2, 3 and 4 were covered with polythene sheeting (0.5 mm thickness) over a timber frame. For trial 5, hessian cloth was used as formwork. A manhole 50 x 50 cm was made in all the roofs to facilitate cleaning and the removal of sediment and other foreign material. In addition, a 75-mm diameter PVC overflow pipe was installed.

Water conveyance devices

A V-shaped gutter and splashguard made from corrugated iron sheet (gauge 35) was installed for all roof catchments. All tanks were provided with a PVC overflow pipe (75 mm). The tank inlets measured 20 x 20 cm and were provided with a fine mesh screen to keep out debris and prevent mosquitoes from breeding. A fine mesh screen was placed over the overflow pipe for the same reason.

Trial tanks 1, 2, 3 and 4 were designed so that water could be drawn from the tank by gravity using a pipe fitted with a tap ($\frac{3}{4}$ inch) placed 5 m away from the tank. Trial tank 5 was provided with a direct-action (pull-and-push) hand pump. All of the tanks except tank 5 were provided with a 50-mm PVC pipe to facilitate drainage and flushing for periodic cleaning.

2.3 Tank construction

Hemispherical tanks with soil/ termite-mound–cement linings (tanks 1, 2 and 3)

Tanks 1, 2 and 3 were constructed in a similar manner, the only difference being in the nature of the lining, as indicated in Table 2.1. The following procedure was used for the construction of the tanks.

1. A site 3 m away from the wall of the house was cleared to a depth of 5–10 cm (see Figure 2.1). The position of the centre of the tank was marked with a wooden peg at $3 + R$ m away from the wall of the house (R = outside radius of the proposed tank). A rope was tied to the centre peg and a nail put through a loop at R m and used to draw a circle.
2. Four pegs, A, B, C and D, were equally spaced around the circle at a distance of $2 + R$ m from the centre, as shown in Figure 2.1. Pegs AC and BD were joined by ropes which intersected at the centre peg. They were tied firmly at this point and the centre peg was removed. Using the radius rope (R) at all times, the soil inside the marked circle was excavated to the shape of a hemisphere (Figure 2.2).
3. A 70-cm wide and 500-cm long trench with a depth equal to the inner radius of the pit (r cm) was excavated to serve as access to the delivery and drainage pipes (Figure 2.3). The values for r are given in Table 2.3. After the delivery and drainage

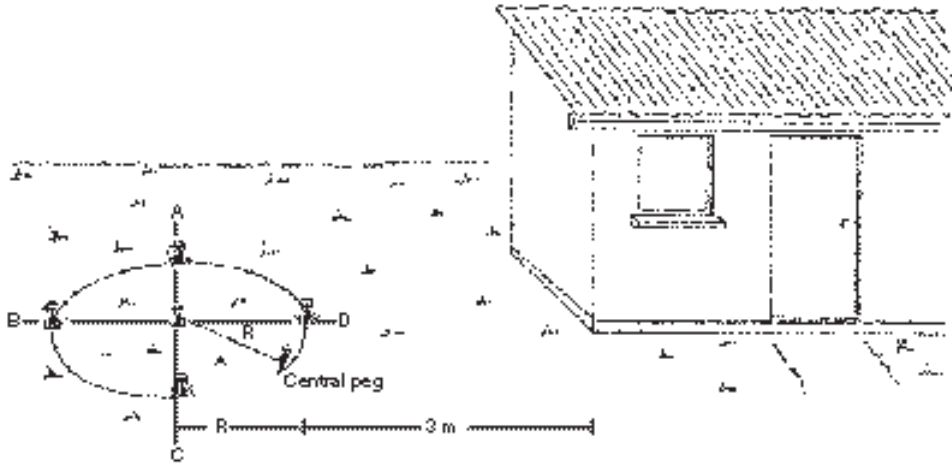


Figure 2.1 Layout of hemispherical underground tank in relation to house (tanks 1, 2 and 3)

pipes were installed, retaining walls of mud blocks (25 cm x 15 cm x 10 cm) were constructed in the trench. The space between the retaining walls was then refilled and compacted. Finally, steps were made to gain access to the delivery pipe (Figure 2.3).

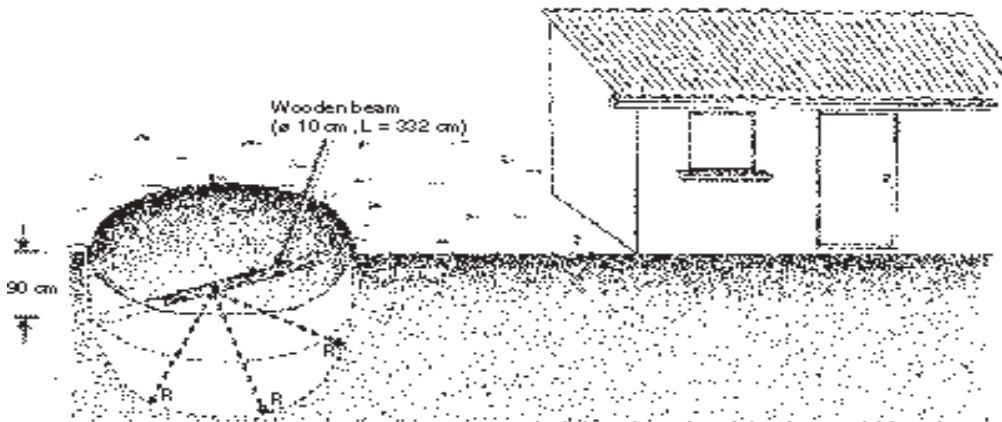


Figure 2.2 Excavation of hemispherical underground tank (tanks 1, 2 and 3)

4. The excavated soil was moderately puddled with a shovel, using the minimum of water necessary, and teff straw. The puddled soil was then plastered on the wall and floor of the tank to a thickness of 4–10 cm and left for a few days to dry.
5. To prevent the wall from collapsing, a masonry ring, 30 cm high and 30 cm thick, was constructed on the upper profile of the pit. An overflow pipe was fitted in an appropriate place in this masonry ring.

6. A layer of cement–soil (1:8) mortar was applied to the compacted puddled layer and a masonry ring to a thickness of 5–6 cm. This was done in two coats to reach the value t cm in Table 2.1. For waterproofing, a coat of cement and water slurry (nil) was applied on the same day as the final coat of plaster.
7. The roof was constructed from two wooden poles each of 10 cm diameter and 352–380 cm length ($2R$ + half the thickness of the masonry ring). They were placed at right angles across the centre of the tank and tied down with black wire embedded in the masonry wall. At the centre, where they cross, a wooden post of 10 cm diameter and 60 cm length was erected. The truss and rafters were installed as shown in Figure 2.3.
8. A polythene sheet for roofing was cut to the required shape, sewn and fitted over the timber supports. Two holes of 50 x 50 cm and 20 x 20 cm were prepared for the manhole and inlet respectively. The edge of the polythene sheeting was embedded in the masonry ring and properly plastered with cement–soil (1:8) mortar. The openings for the inlet and overflow pipes were covered with fine wire mesh and the manhole was provided with a polythene sheet cover.

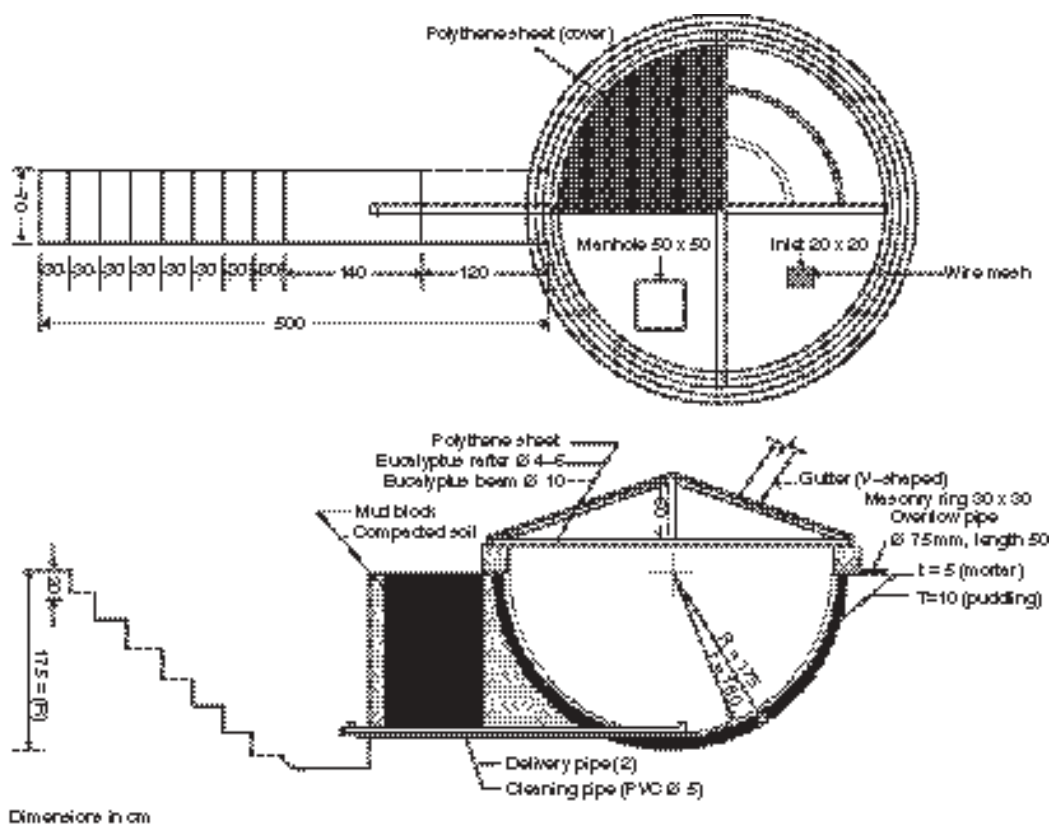


Figure 2.3 Plan and cross-section of hemispherical tank (tanks 1, 2 and 3).

Rectangular tank with polythene lining (tank 4)

1. A site 3 m away from the wall of the house was selected and cleared to a depth of 5–10 cm. Four pegs were used to mark out a rectangle measuring 190 cm x 250 cm at the selected site. The soil inside the pegs was then excavated to a depth of 130 cm (Figure 2.4).

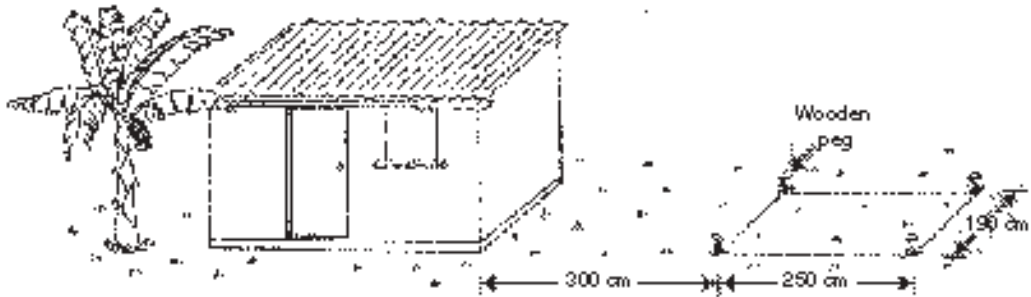


Figure 2.4 Layout of rectangular underground tank in relation to the house (tank 4).

2. A trench 70 cm wide x 500 cm long was excavated to a depth of 130 cm to serve as access to the delivery and drainage pipes. The pipes were installed, retaining walls constructed and steps made as for the hemispherical tank (Figure 2.5).
3. A 2-cm layer of puddled soil was plastered on the walls and floor of the tank and left for a few days to dry completely.
4. A polythene sheet lining was sewn to fit the shape of the tank and installed.

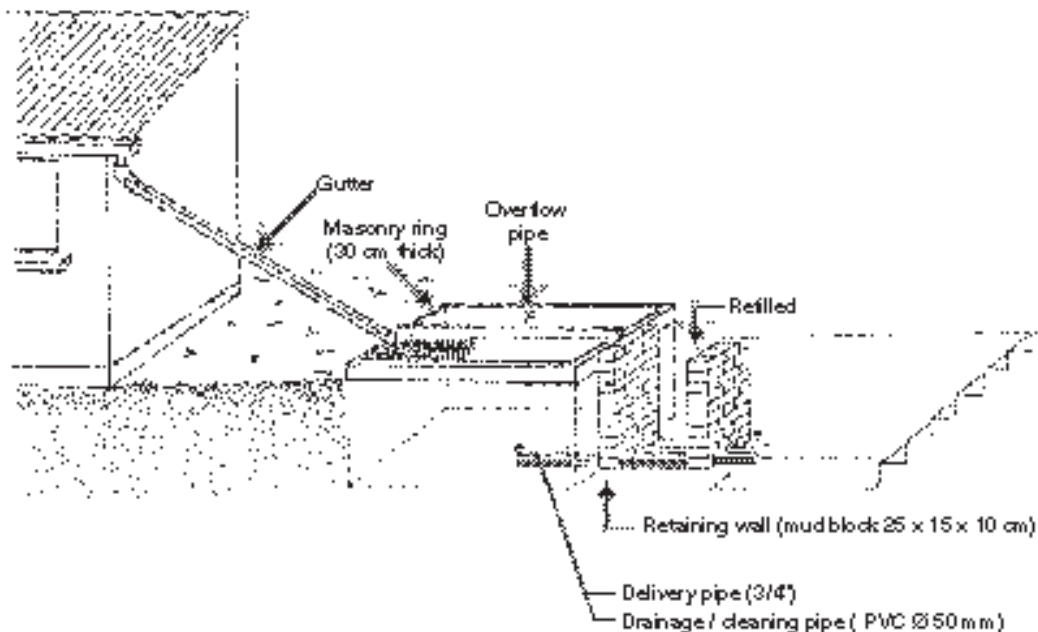


Figure 2.5 Outline of rectangular underground tank with inlet, delivery and overflow pipes (tank 4).

5. To protect the wall from collapsing, a ring wall, 30 cm high and 30 cm thick, was constructed around the upper part of the wall and an overflow pipe installed.
6. The roof was constructed using two poles 280 cm and 210 cm long and 10 cm in diameter. These were placed at right angles from wall to wall across the centre of the tank and fixed with black wire embedded in the masonry. Two wooden posts 60 cm in length and 10 cm in diameter were nailed perpendicularly on one of the poles. Then the truss was constructed and the rafters placed in position (Figure 2.6).
7. A polythene sheet for roofing was sewn to fit the timber supports. Two openings, 50 cm x 50 cm and 20 cm x 20 cm, respectively, were prepared for the manhole and inlet. The edges of the polythene sheeting were embedded in the masonry wall and secured with cement–soil mortar (8:1).

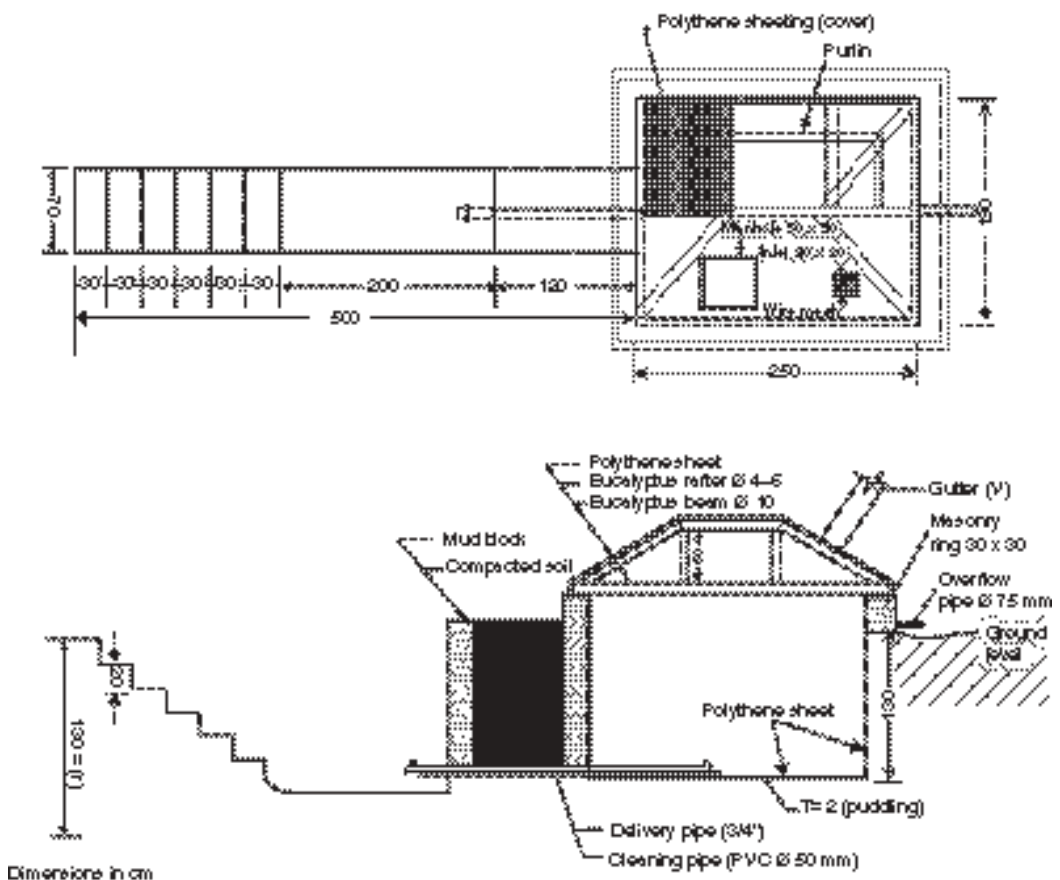


Figure 2.6 Plan and cross-section of rectangular underground tank (tank 4).

Hemispherical tank with sand–cement lining and ring wall (tank 5)

1. The site for the tank was prepared and marked out in a similar manner to that for tanks 1, 2 and 3. Then the following procedure was adopted.
2. The soil inside the marked circle was excavated to a depth of 90 cm (Figure 2.7) and a wooden pole 332 cm long (equal to the diameter of the circle plus 10 cm) was placed horizontally across the centre of the pit. A rope measuring 161 cm long was nailed to the centre of the pole and used to excavate a hemispherical pit.

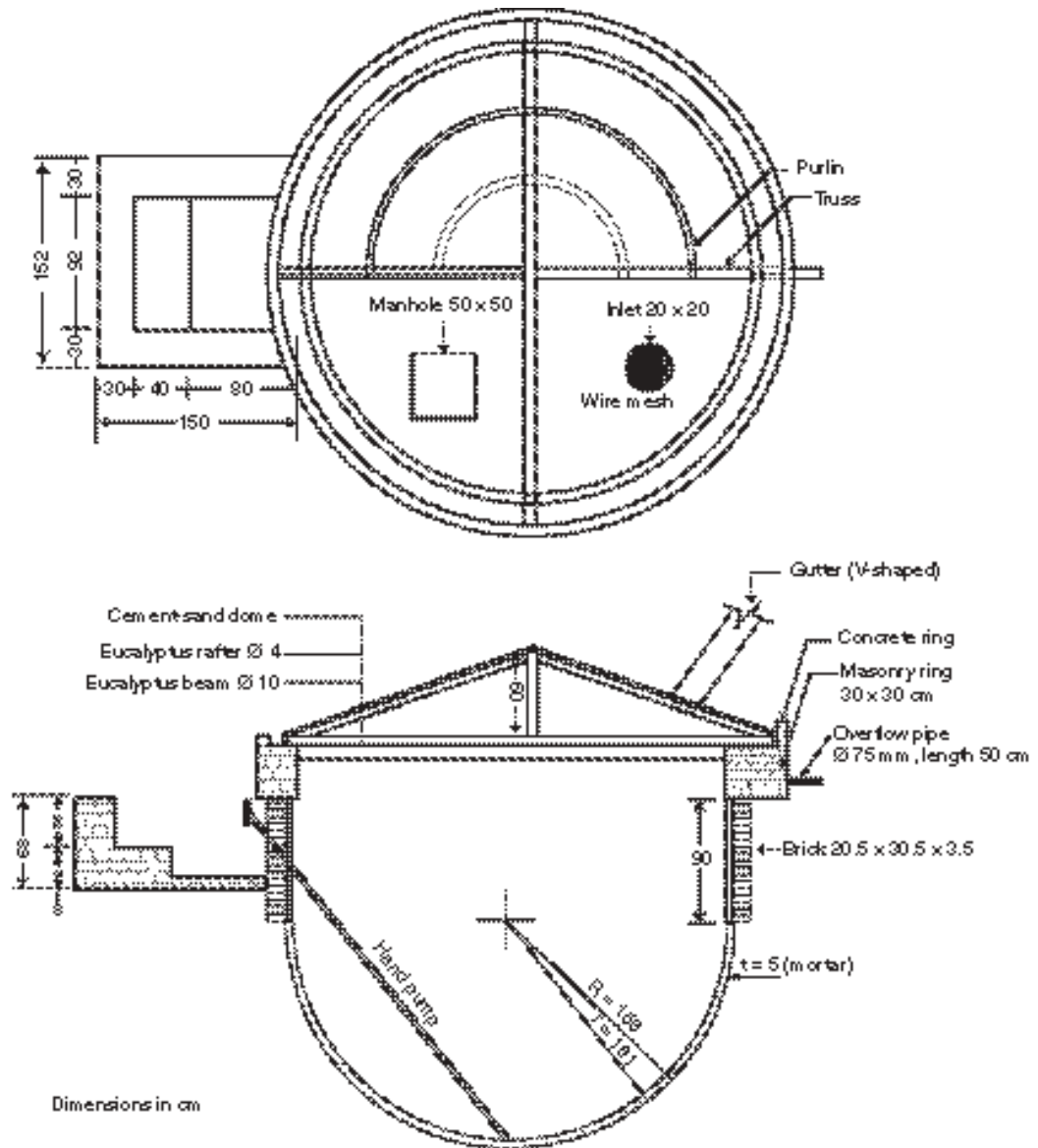


Figure 2.7 Plan and cross-section of hemispherical underground tank with cylindrical upper section (tank 5).

3. To protect the sides of the tank from collapsing, a masonry wall 90 cm high and 30 cm thick was constructed on the upper profile of the pit. A 50-cm wide hessian cloth was embedded in the masonry wall to be used later for attaching the hessian covering of the roof. An overflow pipe was installed in an appropriate place in the masonry wall.
4. On the hemispherical portion of the tank, a 5-cm layer of cement–sand (1:3) mortar was applied. The wall on the upper portion was constructed from bricks made of cement–sand–soil (1:2:3) and plastered with cement–sand (1:3) mortar. For water-proofing, a coat of cement and water slurry (nil) was applied on the same day as the final coat of plaster. A 10 cm x 10 cm ring of concrete was plastered to the edge of the roof.
5. The timber frame for the roof was constructed as for tanks 1, 2 and 3 above. Hessian cloth was then stretched tightly over the timber support and sewn to the portion embedded in the masonry. Cement–sand (1:3) mortar was applied, one coat per day, on three consecutive days. A final coat of cement and water slurry (nil) was then applied. Openings of 50 cm x 50 cm and 20 cm x 20 cm were left for the manhole and inlet respectively. The openings for the overflow pipe and inlet were covered with fine wire mesh and the manhole was provided with a cover made from flat sheet metal.

This tank was not provided with a delivery pipe or a drainage pipe. Instead, a push-and-pull type hand pump (Rower pump) was installed for drawing water (Figure 2.7).

Box 1. Points for attention when installing rainwater harvesting systems

1. Large trees near the tank and overhanging branches near the roof top should be avoided. Roots can penetrate the tank wall and cause seepage.
2. The tank site should not be near a latrine or a waste-disposal area.
3. The tank should be provided with appropriate roofing material. The gap between the roof and the tank extension wall should be tight to keep out wind-blown materials, insects, rodents, frogs and lizards.
4. Openings like overflow and inflow pipes should be provided with screen mesh to prevent the entrance of insects and rodents.
5. The manhole cover should be well fitting to keep out dust, insects or other foreign materials that might enter the tank.
6. The splash guard and the roof top should be washed off with the first shower of rain and the water diverted from the inlet of the tank to prevent dust, organic matter, bird droppings, dead animals and insects being washed into the tank.
7. Gutters must be frequently maintained to prevent wastage due to overflow during heavy rains.
8. The tank should not be allowed to remain completely empty (dry) for any extended period to avoid it cracking.
9. If a crack is observed, the tank should be repaired and re-plastered from inside.

2.4 Capacity assessment

The adequacy of the storage capacity of the tanks was assessed in relation to the estimated annual run-off from the adjacent roofs and the anticipated consumption. The capacity of the tanks is shown in Table 2.3, and the roof size and family size of the adjacent household in Table 2.4.

Consumption was estimated assuming an average of 10 litres per person per day. Run-off was estimated by multiplying the roof area by the annual rainfall (assumed to be 700 mm for all trials) and using a run-off coefficient of 0.8 to allow for losses before the water reaches the tank. To allow for seepage losses or consumption in excess of the estimate, the storage volume was considered to be equal to the demand volume times a factor of 1.2.

Table 2.3 *Storage tank dimensions and capacity*

Tank	Shape	Puddling thickness T (cm)	Mortar thickness T (cm)	Inner radius r (cm)	Outer radius R (cm)	Storage volume (m ³)
1	Hemispherical	4	6	151	161	7.2
2	Hemispherical	7	5	160	172	8.5
3	Hemispherical	10	5	160	175	8.5
4	Rectangular*	2	–	–	–	6.0
5	Bottom hemi-spherical, top cylindrical	–	5	156	161	14.8

*Dimensions = 2.5 m x 1.9 m x 1.3 m

Table 2.4 *Roof catchment size and household family size*

Tank	Catchment size (m)	Catchment area (m ²)	Catchment run-off (m ³)	Storage volume (m ³)	Family size (no. of persons)	Duration of supply (days/month)
1	8 x 4.5	36.0	20.2	7.2	4	150/5.0
2	5 x 4	20.0	11.2	8.5	5	141/4.7
3	8.4 x 4.5	37.8	21.1	8.5	3	236/7.8
4	5 x 5	25.0	14.0	6.0	6	83/2.7
5	9.3 x 4.3	40.0	22.4	14.8	3	> 365/12.0

Table 2.4 shows that the volume of annual run-off is substantially greater than the volume of storage. However, there is no need to have a tank capacity equal to the annual run-off volume as water is being consumed on a daily basis and the tank may be partly empty when rain occurs. On the other hand, if the tank is nearly full when rain occurs, some run-off may be lost through the overflow.

The last column of Table 2.4 indicates the duration that water would last the family assuming the tank was full at the start and that no further rain occurred during the period of consumption. A more sophisticated analysis based on rainfall distribution could be used to determine the optimum size of storage tank.

2.5 Construction costs

The construction costs of the rainwater harvesting trials are summarized in Table 2.5. Taking all the trials, the material costs average 59% of the total and the labour costs 41%. Clearly, if the work can be carried out by the owner and/or in agreement with neighbouring families, and if agreement is made among the households that are to benefit, the construction costs can be substantially reduced.

Table 2.5 Summary of total construction costs (Birr*)

Tank	Materials	% cost	Labour	% cost	Total
1	806	57	612	43	1,418
2	884	54	748	46	1,632
3	810	56	624	44	1,434
4	762	64	426	36	1,188
5	1,168	64	666	36	1,834
Total	4,430	59	3,076	41	7,506

*1 US dollar = Birr 8.2

The cost breakdown of materials and labour is shown in Tables 2.6 and 2.7. The cost of the owner's contribution is shown in Table 2.8. It averages between 29% and 48% of the total cost. If this contribution is deducted from the total cost, a reduced cost is obtained, as shown in column two of Table 2.9.

Table 2.6 Cost breakdown of materials (Birr)

Tank	Materials				Total cost
	Floor and walls	Roofing	Pipes and fittings	Gutter and splash guard	
1	320	270	97	119	806
2	375	309	95	105	884
3	267	325	97	120	810
4	302	288	95	77	762
5	475	430	158	105	1,168
Total	1,739	1,622	542	526	4,430

A detailed breakdown of the cost of materials used in construction is given in Annex A.

Table 2.7 Cost breakdown of labour (Birr)

Tank	Excavation assistants	Mason and assistants	Carpenter and assistants	Puddling and assistants	Assistants for pump assembly	Total
1	200	232	88	92	–	612
2	250	292	88	118	–	748
3	100	292	88	144	–	624
4	100	172	88	66	–	426
5	–	576	60	–	30	666
Total	650	1,564	412	420	30	3,076

Table 2.8 *Owner's contribution in materials and labour (Birr)*

Owner's labour and materials	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5
Stone	60	60	60	60	–
Cement	–	–	–	–	90
Timber	62	86	86	88	62
Sacking	–	–	–	–	36
Sisal string	–	–	–	–	15
Water	105	105	–	–	–
Tailoring services	21	21	21	21	–
Assistant mason	52	52	52	52	96
Puddling	52	78	104	26	–
Carpenter	88	88	88	88	60
Mason	–	–	–	–	180
Puddling assistant	40	40	40	40	–
Excavation	200	250	100	100	–
Total (% of total)	680 (48)	780 (48)	551 (38)	475 (40)	539 (29)

Table 2.9 *Cost of construction per m³ water storage (Birr)*

Tank	Total cost including owner's contribution	Reduced cost excluding owner's contribution	Tank capacity (m ³)	Total cost of construction per m ³ water storage	Reduced cost of construction per m ³ water storage
1	1,418	738.15	7.2	197	103
2	1,631	815.20	8.5	192	100
3	1,434	883.15	8.5	169	104
4	1,188	713.50	6.0	198	119
5	1,834	1,294.80	14.8	124	88
Average				176	103

Table 2.9 shows that the total cost of tank construction averages 176 Birr per cubic metre of water storage, but if the owners' contribution is deducted the average cost is reduced to 103 Birr per cubic metre. However, the cost of construction must be seen in relation to the long-term effectiveness and durability of the tank.

2.6 Technical evaluation

The trials were designed to test local construction materials in combination with industrial products and appropriate technology which could be easily adopted by the local community. The loss of water due to seepage or evaporation and the cost of construction are the most important factors to consider. This evaluation is based on a relatively short period and time is needed to assess long-term performance and reach firm conclusions. However, much has already been learned and the results obtained will be important for planning further investigations. The current investigations should be seen as part of a long-term study.

Construction method

Tanks 1, 2 and 3 were hemispherical with a lining of cement–soil mortar on top of a layer of puddled soil. The cement–soil mix for tanks 1 and 2 was initially 1:12 or 1:10, but during the work the following problems were observed: it was difficult to secure a uniform mixture, and it was difficult to maintain uniform plastering leading to cracks occurring.

Hence, to improve the quality of the mixture, the volume of cement was increased to give a cement–soil ratio of 1:8. With this ratio, the difficulty of securing a uniform mix and plastering was reduced, cracking was less and the stability of the plastered materials improved. To reduce the risk of seepage a coat of cement and water slurry (nil) was applied to the surface. To minimize the risk of pollution and loss of water due to evaporation, the tanks were covered with polythene-sheet roofing. The carpentry work and the general assembling of the polythene-sheet roofing were simple and external labour was not required.

Tank 4 required polythene sheeting for sealing the wall, floor and roof. The assembly and sewing were carried out by the local tailor and presented no problem.

Tank 5 was plastered with cement–sand mortar (1:3) on the lower hemispherical portion, but some difficulty arose in excavating to the required shape and more materials were used for plastering than expected. The upper cylindrical section was constructed with cement–sand–soil (1:2:3) bricks and it was intended to construct a domed roof using bricks. However, problems were encountered and an alternative roof was constructed using hessian and a 5-cm thick layer of cement–sand (1:3) mortar. This was simple to undertake and there were no deep cracks.

Several attempts were made to produce low-cost bricks. In the first trial 305 mm x 205 mm x 25 mm bricks were made using a mould and the following mixtures were tested:

- Cement–soil (1:8, 1:6, 1:5, 1:3)
- Cement–termite mound (1:8, 1:6, 1:5, 1:3)
- Cement–sand–soil (1:2:3)
- Cement–sand–termite mound (1:2:3).

All the resulting bricks developed cracks and were too weak. Increasing the volume of cement could have improved the strength but would have been expensive. Therefore, an attempt was made to strengthen the bricks by increasing the thickness from 25 to 35 mm using the same mixes as before. The resulting bricks did not show cracks, but only those made with the cement–sand–soil (1:2:3) mix were strong enough.

These bricks were used in an attempt to construct a dome for the tank, but the masonry work failed due to the difficulty of layering the bricks.

The trials with bricks led to the following conclusions:

- The design of brick moulds and the process of their manufacture requires skill and proper workshop facilities

- Construction using bricks requires a skilled mason
- The water requirement for curing of bricks is high.

Further points to note during construction are shown in Box 1 on page 13.

Performance monitoring

Frequent visits were made between June and December 1999 to monitor performance. Table 2.10 summarizes the main observations.

Table 2.10 *Tank monitoring results, July 1999 and February 2000*

	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5
Tank type	Hemispherical, cement–soil lining, plastic roof	Hemispherical, cement–soil lining, plastic roof	Hemispherical, cement–soil lining, plastic roof	Rectangular, plastic lining and roof	Hemispherical, cement–sand lining and roof
End July 1999	Full and overflowing	Three-quarters full	Three-quarters full	Leaking	Three-quarters full
End August	Level decreasing	Level decreasing	Level decreasing		Level decreasing
Mid-September	No cracks visible	No cracks visible	Crack visible		Crack at joint between upper and lower sections
End October	Nearly empty		Nearly empty		Nearly empty
Mid-December		Still retains some water			
February 2000	No major cracks	No major cracks	Deep cracks in wall of tank	Minor holes seen in polythene lining	Deep crack at joint between two sections

Notes

1. End July 1999. Leakage in tank 4 could be due to the quality of the polythene and/or the tailor's workmanship when sewing overlapping parts.
2. End August. The decreasing levels were due to high consumption on account of ease of access, sharing with neighbours and the sale of water (tank 1).
3. Mid-September. The crack in tank 3 could be due to the thick (10 cm) layer of puddled soil.
4. February 2000. The crack in tank 5 was caused by a root penetrating the wall at the joint. The polythene sheet used for covering all trial tanks had disintegrated.

Repair and maintenance

In view of the problems indicated in Table 2.10, the following repair work was carried out.

Tanks 1 and 2

- The polythene-sheet roofing was replaced with cement–sand mortar using hessian cloth as formwork.
- The inside of the tank was coated with plastic paint.
- The step to the delivery tap of tank 2 was repaired.
- Between the live fence and tank 2, a trench (1 m deep) was dug and refilled with gravel and stone to prevent roots reaching the tank.
- An additional masonry ring wall was constructed to collect water from the roof for storage in the tank.

- The tank was provided with a manhole cover 60 x 60 cm made from galvanized sheet (1 mm).

Tank 3

- The cracks were chiselled and re-plastered with cement–lime–sand (1:4:3) mortar.
- The polythene-sheet cover was replaced with a cement–sand mortar dome using hessian cloth as formwork and chicken mesh for reinforcing.
- The inside of the tank was coated with plastic paint.
- Between the live fence and the tank, a trench (1 m deep) was excavated and refilled with gravel and red ash to prevent roots reaching the tank.

Tank 4

- The polythene-sheet roofing was replaced with cement–sand mortar using hessian as formwork.
- The step leading to the delivery tap was repaired.
- The polythene sheet which was used for lining the rectangular tank was replaced with another type of polythene sheet (standard size of 2 m) to further test the effectiveness of this material. Four pieces of polythene sheet were sewn to the shape of the tank and CM–43 glue was coated on the joints to prevent leakage.

Tank 5

- The cracks were chiselled and re-plastered with cement–lime–sand (1:4:3) mortar.
- The inside of the tank was coated with plastic paint.
- Between the live fence and the tank, a trench (1.5 m deep) was excavated and refilled with gravel and red ash to prevent roots reaching the tank.
- The masonry ring wall was reconstructed to enable the collection of rainwater from the roof for storage in the tank.

The repair and maintenance costs are summarized in Table 2.11 and a detailed breakdown of the cost of materials and labour used in repair can be found in Annex A.

Table 2.11 *Costs of repair and maintenance (Birr)*

Tank	Materials	Labour	Total
1	361.00	182.00	543
2	409.25	268.00	677
3	627.40	278.00	905
4	433.00	129.00	562
5	177.00	149.00	326
Total	2,007.65	1,006.00	3,013

2.7 Economic evaluation

The total cost of construction and subsequent repair and maintenance is given in Table 2.12.

Table 2.12 *Total cost of experimental trials (Birr)*

Item	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Total
Construction						
Materials	806	884	810	762	1,168	4,429
Labour	612	748	624	426	666	3,076
Sub-total	1,418	1,632	1,434	1,188	1,834	7,505
Repair						
Material	361	409	627	433	177	2,008
Labour	182	268	278	129	149	1,006
Sub-total	543	677	905	562	326	3,014
Grand total	1,961	2,309	2339	1,750	2,160	10,519
Construction (%)	72	71	61	68	85	71
Repair (%)	28	29	39	32	15	29

These results show that approximately one-third of the total costs were spent on repairs. However, the work was experimental and the experience gained should lead to more sustainable construction methods in future and reduce the need for repairs.

The cost of domestic water supply depends on:

- Cost of construction per litre of water
- The size and durability of the water supply system
- The time and energy required to fetch water compared to the current source
- The opportunity cost incurred every day in fetching water
- The quality of the system.

In the communities where the experimental trial tanks were constructed, domestic water sources were located at an average distance of 5 km from the homesteads. Most of the households at the experimental site purchase water from vendor water points at a price of 0.01 Birr per litre. It is estimated that an average household of five people needs 50 litres of water for daily consumption. Using the local price and amount of water drawn per household per day as the basis of calculation, the average household's annual cash expenditure on water amounts to 120 Birr, covering the long dry season which lasts for eight months.

To fetch 50 litres of water per day to the experimental site, a woman needs to walk twice a day to a water point situated 5 km from her home. Thus, she will spend a total of four hours, or half a day, per day fetching water. Assuming that the time spent could be used for income-generating activities (at 8 Birr per day), the opportunity cost of fetching water is 4 Birr per day or 960 Birr for the long dry season. The total cost of domestic water per household could therefore amount to 1,080 Birr (120 + 960).

As indicated in Table 2.9, the average cost of construction, excluding the owner's contribution, is 103 Birr per m³, or 0.10 Birr per litre. With an average consumption of

50 litres per day per household and eight dry months in a year, a household needs to construct a 12 m³ tank costing 1,236 Birr.

There is a possibility that the storage tanks could be filled twice a year as there are two rainy seasons, short and long. Considering the actual price of water at Nazareth, which is 0.01 Birr per litre, the household could make a cash saving of 120 Birr, plus an additional 120 Birr selling water. Based on this total benefit of 240 Birr per year, the investment, 1,236 Birr, could be recovered in five to six years. Labour saving is not considered on the assumption that a rural household may not always have employment opportunities.

The additional income or benefit from the water harvested is calculated at 1 cent per litre. This is the cost of the water that is saved by installing the tank. If the opportunity cost of labour that would otherwise be spent in fetching water is also considered as a saving, the benefit is even greater. Furthermore, the household will probably grow vegetables and fruit trees at the homestead, which will increase the overall benefit through time.

2.8 Main findings and recommendations

Main findings

The following is a brief summary of the main findings.

- Excavation of hemispherical water tanks requires care, and a skilled mason is needed to keep the use of the materials to the design specifications.
- Applying a 5–7 cm layer of puddled soil as a lining to the tank can correct the uneven shape made during excavation and thereby reduce materials wastage. A crack was observed in tank 3 where the thickness of the puddled layer increased.
- When the cement–soil and cement–termite mound mortar volume is lower than a ratio of 1:8, it is difficult to secure a uniform mix for plastering and cracks and instability occur at all joints.
- Construction using cement–sand mortar (1:3) on natural ground results in some cracks and high material consumption.
- The water tank constructed from polythene sheeting had a leakage problem. The quality of the sheet used and the workmanship of the tailor needed further assessment and analysis.
- Tanks covered with polythene sheeting require fencing to avoid damage. They also need measures to protect them from direct sun and wind.
- Construction of gutters and maintaining the required gutter slope has been difficult because most of the rural buildings are constructed without a standard foundation layout.

- A V-shaped gutter and splash guard manufactured from corrugated iron sheet can be handled with the available local skills, but training and provision of tools are required.
- A gutter constructed from corrugated iron sheet is cheaper by 50% than a gutter made from flat galvanized sheets. However, the workmanship required in joining overlapping parts of the gutters made from corrugated sheets needs attention.
- The dome cover made from cement–sand–soil bricks demands masonry skills which are not common in most rural areas.
- Construction of the tank roofing from cement–sand mortar using hessian cloth as formwork was found to be technically simple and easy.
- A common problem with underground tanks is that of cleaning, but the provision of a PVC drainage pipe makes cleaning easy.
- If users participate in the provision of labour and local materials, the cost of household rainwater harvesting tanks could be reduced by up to 50%.
- The trials conducted indicate that when the volume of the tank increases, the cost of construction per m³ of water stored decreases.
- In the trials reported on here, the average cost of construction of the water tanks, excluding owner's inputs, was found to be 103 Birr per m³, or 10 cents per litre.
- At the experimental sites, the cost of fetching water is estimated to be 1,080 Birr per household per year. The cost of constructing a household rainwater-harvesting tank which is assumed to serve throughout the year is 1,236 Birr per 12 m³, and this amount could be recovered in 5–6 years. Therefore, promotion of such types of rainwater storage tanks at household level could be more economical with time compared to the current cost of fetching water in most dryland areas.

Recommendations

- Promote the use of cement–soil and cement–termite mound mixes with a ratio of 1:8 for making the puddled clay mortar for lining tanks used for domestic purposes.
- Promote cement–sand mortar 1:3 for the roofing of household tanks using hessian cloth as formwork.
- Promote gutter manufacture from corrugated iron sheets.
- Promote the utilization of 50–75-mm diameter PVC pipes for draining underground tanks.
- Carry out further investigations on (a) the durability of the technology applied, and (b) the quality of water stored.
- Organize a workshop to pass on the findings of the experiment.
- Provide training for farmers and agricultural development agents on the methods of constructing cost-effective rainwater harvesting for domestic use at household level.

- Carry out training for the households provided with tanks on tank management and water utilization.
- Popularize effective methods of rainwater harvesting in semi-arid areas.
- Monitor and evaluate household rainwater tanks already constructed in experimental trials.
- Provide assistance where necessary to ensure the effectiveness of the tanks which have been installed by repairing cracks in tanks 3 and 5, replacing the polythene sheet in tank 4 and replacing the polythene roof for tanks 1, 2, 3 and 4 with a cement–sand mortar dome.



Plate 2.1 *Excavation of hemispherical tank.*



Plate 2.2 *Completion of tank lining.*



Plate 2.3 *Construction of roof.*



Plate 2.4 *Completed tank with gutters and delivery pipe installed.*



Plate 2.5 *Rectangular tank with polythene lining.*

Kenya



Plate 3.1 Self-standing underground ceramic tank after firing but before back-filling with soil.



Plate 3.3 Oval tank lined with cement-sand mortar reinforced with sisal.



Plate 3.2 Completed ceramic tank after back-filling and construction of the neck with brickwork.



Plate 3.4 Layout and excavation of sausage-shaped tank.



Plate 3.5 Construction of sausage-shaped tank.

3. Field trials on rainwater storage in Kenya

3.1 Introduction

Water, along with food, is one of the basic essentials of life. Perhaps because of its importance and scarcity in many parts of the world, its use is often encompassed by very strong cultural and social precepts. Human settlements have in the past been along or near water sources, but as populations have grown and outstripped the space available, people have migrated to marginal-rainfall areas where water is scarce. Many people in Kenya are forced to spend a large portion of their productive time and resources in fetching water. The supply is often contaminated and water-borne diseases are on the increase. Despite the Kenya Government's commitment to providing clean water to its population, it faces severe constraints due to shortage of funds for development and the cost of maintaining existing water supply projects. Furthermore, the problems facing consumers in tapping water from existing distribution points have created a demand for a more realistic approach which can be implemented with their own resources.

The focus of this study is on the low-cost options for rural water supply among resource-poor farmers. The potential benefits of rainwater harvesting include the availability of relatively clean water close at hand and the reduction in time and labour for fetching it. However, in spite of the benefits, the cost of construction of rainwater harvesting and storage structures has been prohibitive for the majority of farmers in the arid and semi-arid (ASAL) areas. The conventional stone or ferro-cement tanks require industrial materials that have been either too costly or not readily available. This study focused on minimizing the cost through appropriate planning, design and construction of roof/ground run-off water harvesting systems coupled with the use of available storage technologies and local materials within the reach of the farming communities.

Soil is the most abundant material on the earth's surface. It has been used in the construction of buildings and roads, for making utensils and water-storage structures. The performance for water storage depends on the quality of soil because some soils

are very permeable, some have poor resistance to abrasion or impact, and some have low tensile strengths.

Different types of clay occur widely within the tropics and can be identified by their mineralogy. In Kenya, clay soils occur from sea level to at least 2,100 m above sea level, and the use of each type depends on its physical and chemical characteristics.

Much history has been written on pottery clay, and ancient civilizations can be differentiated by the type of their pottery artefacts. Clay pots have been used for thousands of years, but not for storing large volumes of water, e.g. over 30 litres.

The specific objectives of this study were to:

- Evaluate the use of ceramic clay alone or in combination with other materials for lining underground tanks
- Determine the appropriate combination of soil-based materials and cement for construction of water storage tanks
- Evaluate the performance of different structures
- Carry out a cost analysis.

The study commenced with field visits to local institutions involved in the use of appropriate technologies, including Karen Appropriate Technology Centre, Kenyatta University Ceramics Centre, HABRI Project of the University of Nairobi, Intermediate Technology Workshops, the Kenya Industrial Research Development Institute (KIRDI), Kenya Clay Works factory and local pottery groups in Machakos and Makueni Districts. The aim of the visits was to collect information on the available technologies and on the use of soil and/or clay for storage structures. In addition, a literature review on the use of clay and other combinations proved useful in deciding the extent to which pottery technology could be used for large-scale water storage.

The background work included the collection and sampling of various materials which were tested in different combinations of clay, sand, cement or lime and compared visually on a test scale. In addition, trials were carried out by the Kavilo Women's group in Kalawani Division who had been making clay pots for many years. With help from GTZ, the group had been making and marketing wood-fuel-saving stoves to other farmers. When approached to assist in identification of different types of clay, they agreed to demonstrate their skills. They also willingly agreed to set up some of the trials and undertake evaluations as requested. Two individual farmers were also identified and trials using sandy soil-cement mixtures in the construction of water storage tanks were set up on their farms. Technical backstopping was sought from the Department of Agricultural Engineering of Jomo Kenyatta University of Agriculture and Technology to validate the findings and assist with physical and chemical analysis of the materials.

Observations were made on the performance of the materials on the basis of workability, effectiveness and community response in using the technology. Design propos-

als and results were discussed with experts from RELMA and from the Soil and Water Conservation Branch of the Ministry of Agriculture and Rural Development.

The following criteria were used in evaluation:

- Material availability and cost
- Excavation works and costs
- Labour requirement for construction – both skilled and unskilled
- Appropriateness of the materials for the designs
- Behaviour of the materials, especially workability during construction and suitability for water storage
- Community preferences for designs and materials.

During the study period, the area experienced extremes of weather due to the El Niño and La Niña phenomena which interfered with the start and implementation of the work and may have influenced certain observations. Much time was spent on iterative formulation of soil combinations and visual observations on what was feasible and how best to make it work. However, more time was needed to carry out mechanical, physical and chemical analysis of the materials. In spite of the progress made, there is still more work to be done to determine the most appropriate material combinations for the construction of water-storage tanks.

3.2 Tank design

Most roof-water storage tanks are constructed above ground and have a cylindrical or cuboidal shape. The floor and walls require reinforcement and the mortar used is normally a strong cement–sand mixture. Such tanks are costly and discourage resource-poor farmers from attempting to harness and use water from their roofs or compounds.

Structural considerations

The designs used were based on the assumption that an underground tank would be the least costly in materials because the ground itself would provide the structural strength for the wall of the tank. Furthermore, if the shape is circular or spherical the water pressure is distributed more uniformly on the sides.

The excavation of underground tanks must take account of the strength of the soil. A vertical face can be excavated in many soils and will remain without support provided that the height does not exceed a critical value, which varies with the type of soil and moisture content. When dry sands and gravels are excavated they assume a natural ‘angle of repose’ no matter what the depth.

Collapse of a vertical wall of soil (slip failure) usually occurs along a circular arc. To prevent such failure it is necessary either to ensure that the height of excavation does not exceed the critical value or to cut the soil in a circular arc. Circular cutting relieves the soil of any undue stress and enhances the stability of the walls. It is for this reason

that four of the trial tanks were made with a hemispherical shape below ground. Of the remaining tanks, one was cylindrical in shape but not so deep that the walls might collapse. The other, a self-standing tank, was made like a traditional ceramic water jar but much larger. It was constructed in an excavated pit and fired *in situ*. Table 3.1 gives details of the tanks constructed.

Table 3.1 *Design, siting and capacity of trial tanks*

Tank no.	Type and material	Site	Volume (m ³)
1	Self-standing ceramic tank made from clay and fired <i>in situ</i>	Kalawani	1.5
2	Oval tank with clay slab (tile) lining	Machakos Farmers' Training Centre	5.0
3	Oval tank with sand–cement lining reinforced with sisal fibre	Machakos Farmers' Training Centre	5.0
4	Spherical tank with <i>nthangathi</i> –cement lining	Mwala	9.8
5	Sausage-shaped tank with <i>nthangathi</i> –cement lining	Mwala	10.0
6	Cylindrical tank with soil–cement lining	Machakos Farmers' Training Centre	12.0

Tank linings

The effective lining of tanks is critical to success. Clay is available locally and people already have much experience in the use of different types of clay. It was logical, therefore, to try and utilize clay for lining the tanks. However, clay which has not been fired is subject to shrinking and cracking when it dries. Obviously, as a tank is emptied during dry weather, the walls will start to dry out and cracking is likely. Even clay which is fired can be somewhat porous, and tank 1, the large water jar, was coated on the inside with a cement–water slurry (nil) to make it watertight.

As an alternative to using clay alone, it was tried in a mixture with cement and lime. This showed no advantage even when sisal fibre was included to increase strength. A more successful approach was to make clay slabs (tiles). These were used in tank 2. Table 3.2 gives observations on the use of clay. The permeability of the slabs was investigated in the laboratory and the results are given in Annex B.

Due to problems associated with using clay alone, trials were carried out with mixtures of soil and cement. For this purpose two types of soil were used. One, known locally as *nthangathi*, is a very sandy soil consisting of 89% sand and only 6–7% clay. This soil was found at Kivulusa in Mwala and was used to make a cement–*nthangathi* (1:8) mortar for lining tanks 3 and 5 (Table 3.1). When stabilized with cement and lime it produced good results.

Table 3.2 Observations on the use of clay in water storage

Procedure	Observations	Comments
Clay plastered directly on the soil surface	Cracking	There was rapid movement of water from on the wet clay to the dry soil surface. This method is not recommended.
Self-standing tank made and fired <i>in situ</i>	No cracks	Slow drying for several weeks after construction allows for shrinkage without cracking prior to firing.
Clay mixed with cement lime and plastered directly on the soil surface	Big cracks	Difference in the setting nature of the materials used. Mixture unreliable, though it can be improved if sisal fibres are incorporated.
Clay slabs (tiles) made at clay source and stored in shade till dry	Easy to make and handle	This method was preferred by farmers, but storage of the slabs can be a problem.

The second type of soil used in trials was the red, sandy clay soil found at the Machakos Farmers' Training Centre. On average it consists of 46% sand and 48% clay. It was used to make a cement–soil (1:7) mortar for tanks 2 and 4. This red soil is very similar in texture to the black, sandy-clay soil used in tank 1. Table 3.3 gives the texture analysis of the different soils used. Further information on soil texture is given in Annex B.

Table 3.3 Soil texture analysis

Sample	Site	Sand (%)	Silt (%)	Clay (%)	Class*
<i>Nthangathi</i> 1	Kivulusa, Mwala	89	5	6	Sand
<i>Nthangathi</i> 2	Kivulusa, Mwala	89	4	7	Sand
Black clay 1	Kalawani	43	8	49	Clay
Black clay 2	Kalawani	45	6	49	Sandy clay
Red soil 1	Machakos, FTC	49	6	45	Sandy clay
Red soil 2	Machakos, FTC	43	6	51	Clay
Kalawani	Kalawani	68	16	16	Silt loam

* Based on USDA texture classification (Landon 1991, p. 322).

3.3 Tank construction

Self-standing, ceramic tank (tank 1)

The tank was made by members of the Kavilo Womens' Group in Kalawani Location, Makueni District, from the following three types of clay that are used traditionally for making pots.

- Reddish brown clay found higher in the soil profile and known locally as *muthala*. It is loose, non-plastic and is generally used to lower the plasticity of black clay.
- Black clay known locally as *yumba*. It is plastic, heavy and cracks when used alone.

- Whitish clay with shiny particles. It appears to be recently weathered rock with a lot of mica and is known locally as *inyenyea*. It is used to enhance drying structure and gives the fired material a high-pitched note when tapped.

The three types of clay were combined in the ratio of 3:2:1 (black: red: white) with the black one at the bottom and the red and white on top. The clay was soaked with water for 24 hours. Using a pestle, the soil clods were broken down until uniformity in size was achieved. Hands were used to mix and knead the material while adding more water and removing stony material or pebbles until a uniform consistency was achieved. The material was deemed to be ready when the clay no longer stuck to the hands when working it. The clay mixture was then wrapped in a polythene sheet and stored in the shade until required.

A site for the tank was prepared as follows:

- The site was selected at a distance of 0.9 m from the nearby house after ensuring that the area was free from swelling clays.
- The ground was cleared of vegetation and tree roots were removed.
- The centre of the tank was marked with a peg and a sisal string with a nail at the end was used to describe a circle.
- The tank was excavated to a hemispherical shape using the same string to determine the radius. A pillar of soil was left in the centre to keep the peg in position until the excavation was almost complete.
- The pillar was removed and the surface of the tank was skimmed with a jembe or *muro* until it had a smooth surface.
- The base of the tank was then lined with a polythene sheet.

Construction began by placing a 6-cm layer of well-mixed and wedged clay onto the base. This was compacted by trampling with bare feet and smoothed with moistened plastic scrapers. The wall was started with a roll of clay 4 cm in diameter that was placed on the edge and joined to the base by squeezing upwards and downwards until a uniform thickness of 2 cm was obtained. The procedure was continued around the base until the first course was completed. Subsequent courses were added in the same way while leaving a gap of 0.5 m between the new structure and the excavated wall. The aim was to add three courses per day and to keep the edge covered with a polythene sheet between one day and the next for ease of binding with subsequent courses. On completion, the tank was put under a grass-thatched or iron-sheet roof to ensure gradual drying. Finally, it was exposed to the sun for four weeks to dry out completely before firing (Plate 3.1). Box 2 on page 34 gives some tips from the Kavilo Women's group on working with clay.

Firing is done to harden the structure and reduce porosity. There are four stages in firing.

1. Dehydration

This is referred to locally as *kung'anya*, which means evaporation of water from the structure – a step that was needed in spite of the initial air drying. It was achieved by firing with light, dry vegetative materials such as mango and *Casuarina* leaves or sawdust arranged inside and outside the tank. When fired, the structure became black within 30–60 minutes and the moisture evaporated through the surface of the tank.

2. Oxidation

When all the water had completely evaporated from the surface, firewood was arranged around and inside the structure and covered with a thick layer of dry grass. This was covered with ashes so that the wood would burn slowly, and any openings were blocked with vegetative material for the same reason. During firing, organic material in the clay was burned, iron and other compounds were oxidized and sulphur was eliminated. This was detected by a characteristic smell from the structure, which changed colour from dull brown to brownish red. Correct firing led to a structure that gave a high-pitched sound when tapped.

3. Vitrification

If a high enough temperature is reached some of the fusible compounds in the clay melt and fill the pores with a glassy or slag-like substance. It is not usual for such high temperatures to be reached when making the traditional clay pots.

4. Annealing

This is the process of slow cooling which helps to strengthen the structure and prevent cracking. It was achieved by leaving the fired tank under a cover of ashes for at least a day.

After completion of the firing process, the space around the tank was back-filled with soil, which was well compacted to give structural support. The final stage was to construct a mouth for the tank using a double-layered course of bricks up to a height of 0.5 m above the surface using a cement–sand mortar (1:5) (Plate 3.2). Curing of this section was continued by keeping it moist for 28 days. It was then plastered and sealed with a cement–water slurry (nil).

Box 2. Tips on clay from Kavilo Womens' Group

- Select the right material. It can be tested at the source with a *muro* (a panga-like tool used for excavation). It is scooped, moistened and mixed. If the mixture is firm and smooth it is suitable, but if it is light and not smooth it is unsuitable. Pottery clay is either black or brown and is found lower in the soil profile, unlike other types which are found higher up.
- Test the material by making a model, and drying and firing it. If it bursts, the mixture was wrong or it had fragments of rock or pebbles. If it does not burst, it is suitable.
- Ensure that the clay is thoroughly mixed, wedged or squeezed to remove any trapped air and that there are no hard materials in it.
- Store in an airtight environment pending use.
- Keep clay away from salt and avoid use of soapy water in clay mixtures.
- Ensure uniform thickness of the wall throughout the construction, drying and subsequent firing.
- Use dry firewood and grass when firing any clay product.

Oval tank with clay slab lining (tank 2)

Clay slabs were made using two wooden moulds, one measuring 30 cm x 30 cm x 2.5 cm and the other with mating parts to fit into a circular tank. The mould was laid on a plastic sheet in the shade and then filled with clay while ensuring that there was no air trapped inside. A steel float or moistened plastic scraper was used to smooth the upper part of the slab. After 24 hours the mould was removed and the same procedure repeated. Many moulds are needed for work to proceed quickly.

The slabs were dehydrated by firing under light, dry vegetative material or sawdust until they turned black. They were arranged in an upright position with small twigs, grass and branches put between them and completely covered with grass which was fired from all sides. Firing continued for at least a day, after which the slabs were removed and stored.

The tank was constructed at the Machakos Farmer's Training Centre. It was an open tank, 1 m deep and 4 m long with semi-circular ends and cross-section. The depth of excavation was determined using a 1-m long piece of string hung from the centre of the circular ends. After excavation the tank was lined with clay slabs using cement-sand mortar (1:3) to join them to the excavated surface and to plaster the joints between them. The top of the wall was strengthened with three courses of brickwork. The tank was not covered.

Oval tank with sand-cement lining using sisal fibre (tank 3)

This tank was constructed at the Machakos Farmers' Training Centre. It was an open tank measuring 4 m long and 1 m deep and was excavated in the same manner as the previous tank (Figure 3.1). The construction process was as follows:

- Cement and sand in a ratio of 1:5 were mixed thoroughly with 1 kg sisal fibre per bag of cement, and a thick mortar was prepared by adding water.
- Using a steel trowel and bare hands, the mixture was cast onto the excavated surface while ensuring a uniform cover.
- Twenty-four hours later, another coat was superimposed on the previous one ensuring that the fibre criss-crossed.
- A smooth coat of cement–sand mortar was cast to cover up the fibre.
- The surface was sealed with a cement–water slurry (nil) and cured by keeping it moist for a period of at least 28 days.
- The top of the wall was strengthened with brickwork.

This tank was not covered (Plate 3.3).

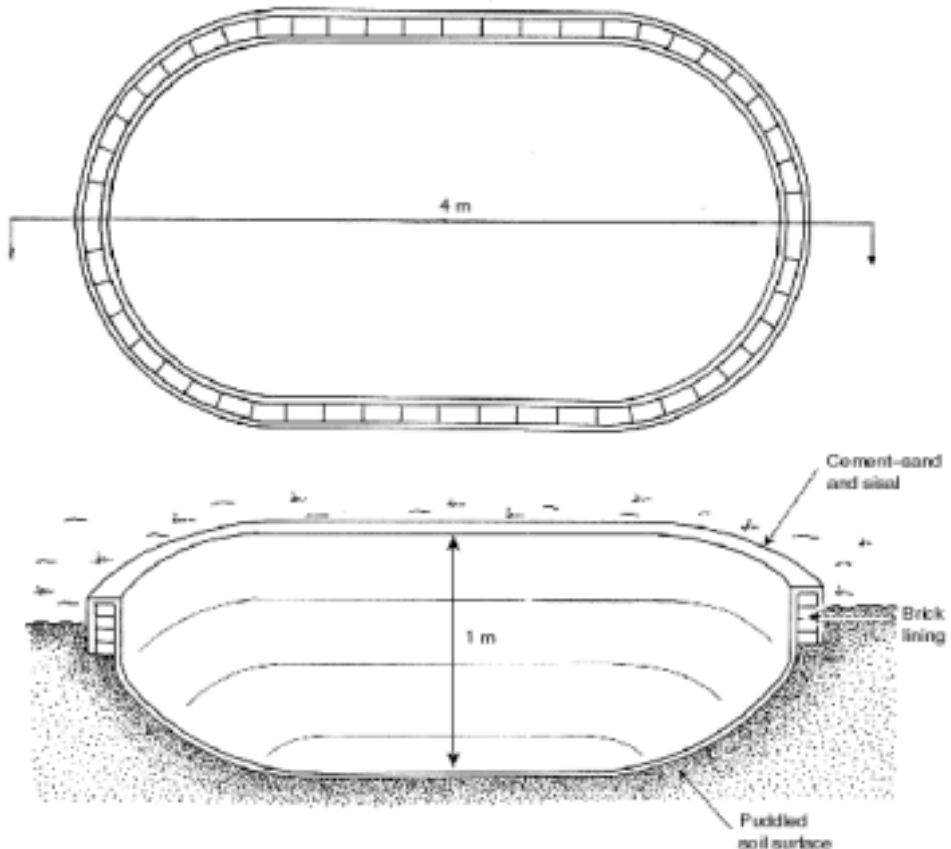


Figure 3.1 Oval tank with cement–sand lining using sisal fibre

Spherical tank with *nthangathi*–cement lining (tank 4)

In Mwala Location, Machakos District, *nthangathi* is used extensively by farmers to plaster the walls of their houses, with good results due to its resistance to abrasion even when used alone without a stabilizer. It is found on land with poor soil fertility where cropping had been abandoned. For this trial, having identified a suitable site, the topsoil containing organic matter was removed and heaped on one side. The sub-soil was then dug out and spread out to dry in the sun for a few days. Large clods were broken down and roots were removed by passing the soil through a 10-mm sieve (at least 1 m² in size), which was shaken horizontally. The resultant material was stabilized with cement (ratio 1:7) for lining. It was also used for lining the sausage-shaped tank (see below).

The spherical tank was excavated in the way described for the self-standing, ceramic tank (tank 1). The faces of the tank were made firm using a wooden mallet while sprinkling water. The base was plastered up to a thickness of 5 cm with a clean cement–*nthangathi* mortar (ratio 1:7). The top part comprising the dome was constructed with burned bricks joined with cement–sand mortar (ratio 1:6) as follows:

- The first course was laid at the mid-height of the tank (i.e. 1 m below ground level) with brickwork running along the circumference of the tank.
- The second course was laid with bricks protruding 10 cm and facing the centre of the tank. This was repeated with subsequent courses ensuring overlap of the brick joints (Figure 3.2).

On completion of the construction, the mouth of the tank, which was left at the centre, had been reduced to 1 m diameter. The outside of the tank was rough cast with cement–sand mortar (1:6). The *nthangathi*–cement plaster was extended to cover the inside section under the bricks.

Curing was continued for at least 28 days (with water being applied twice a day). The excavated soil was then returned to cover the outside of the tank. A final course of bricks was then constructed to form the top of the mouth. An overflow pipe and an inlet were also installed. A concrete slab lid was made to cover the opening.

Sausage-shaped tank with *nthangathi*–cement lining (tank 5)

This is a long sausage-shaped structure half of which is underground (Figure 3.3 and Plates 3.4 and 3.5). It is circular in cross-section and slopes gently towards the outlet from where water is drawn. The trial tank in this study was constructed at Mr Kaunda's farm in Mwala Location, Machakos District.

A site was located at least 1 m from the nearest building. The tank dimensions were determined using the size of the roof and the average annual rainfall, as explained below in Section 3.4. The tank was 2 m wide at ground level and was excavated to a depth of 1 m. A piece of wood was placed across the tank with a 1-m length

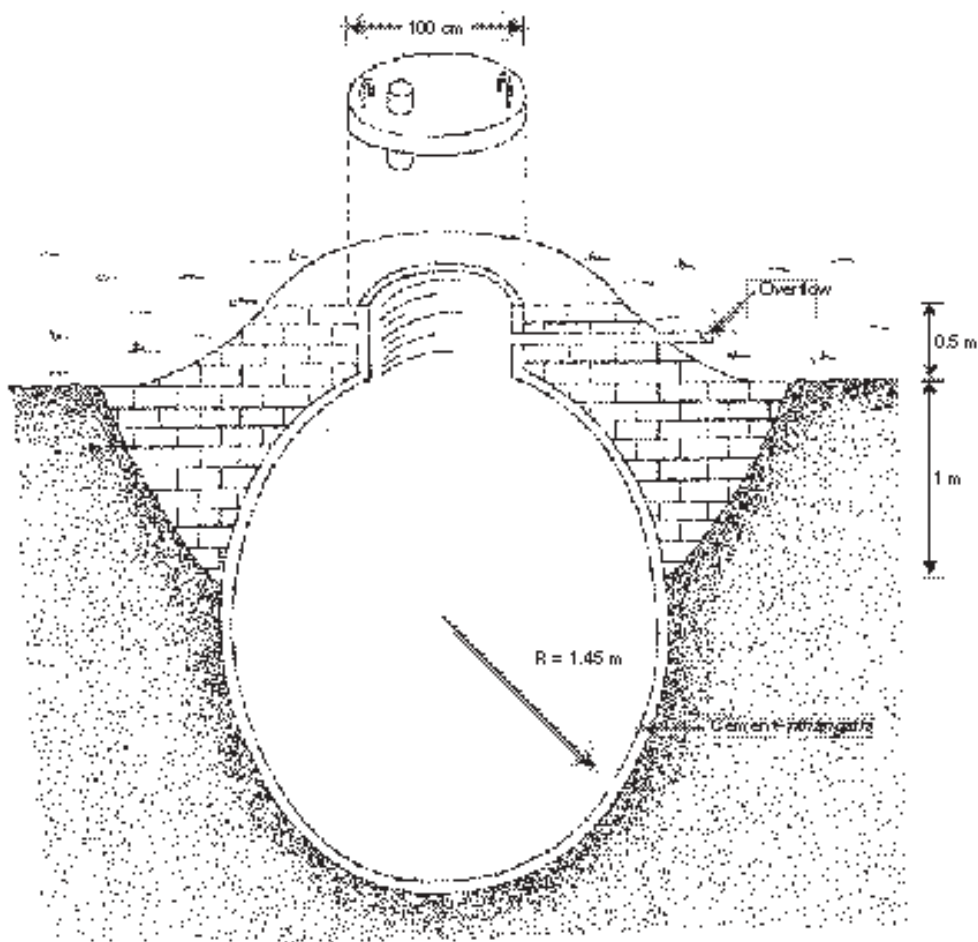


Figure 3.2 Spherical tank with cement–nthangathi lining

of string attached to a nail at the centre. This was used to define the circular shape below ground.

The excavated surface was made firm by sprinkling with water while ramming with a wooden mallet. It was then plastered with a cement–*nthangathi* mortar (1:7) mixed with 1 kg lime and 1 kg waterproof cement per bag of ordinary cement. The plaster was done on all tank faces to a thickness of 5 cm from the soil surface. This was continued on the whole length of the structure up to a height of 1 m, while maintaining a grade of 0.25% towards the outlet.

After three days of curing, the plaster was firm and a 15-cm ledge was excavated around the perimeter of the tank. This was the base for a vertical brick wall which was then constructed at both ends of the tank and along the sides. A cement–sand mortar (1:6) was used to bind the bricks. The dome-shaped roof of the tank was constructed by making successive courses of bricks to protrude 10 cm towards the centre. They were

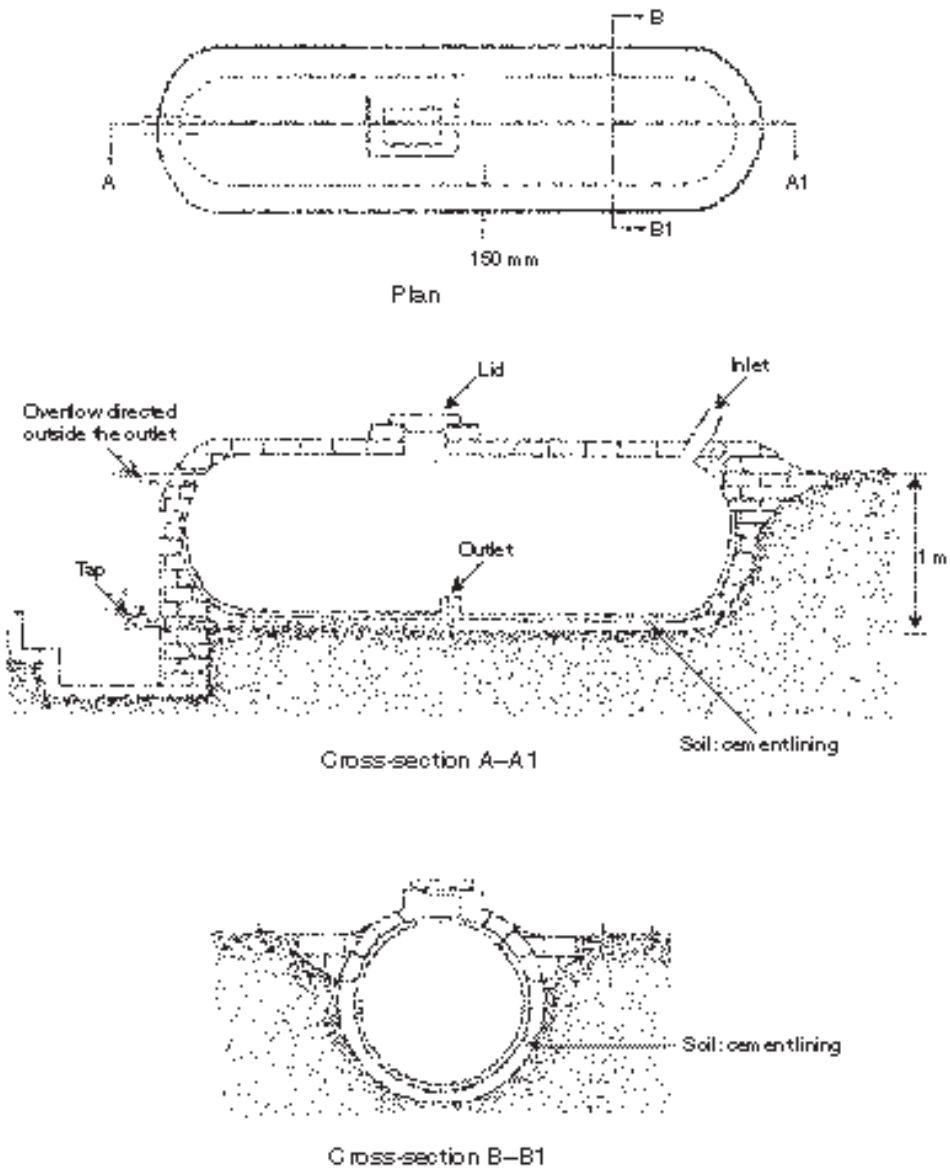


Figure 3.3 Plan and cross-section of sausage-shaped tank with cement-sand lining and brick dome

held in place during construction by formwork consisting of a sheet of plywood bent to shape and supported by posts from underneath. A stronger mix of 1:5 cement-sand mortar was used to bind the bricks. Construction of the dome started from one end and, as it proceeded, the formwork was shifted until the whole structure was covered.

A manhole (0.5 m x 0.5 m) was made in the middle and an inlet was constructed at the higher side of the tank. An overflow pipe was installed at the lower side. When the construction was firm, the plywood was removed and a thin layer of cement-sand (1:7)

mortar was plastered on the inside of the tank. The outside was plastered with a stronger mix of 1:5 and the surface smoothed.

Curing was done on both the inside and outside surfaces by wetting for at least 28 days, after which the excavated soil was back-filled and compacted around the tank.

Cylindrical tank with soil–cement lining (tank 6)

This underground tank was constructed at the Machakos Farmers' Training Centre. It was cylindrical in shape and measured 2.5 m in diameter and in depth. A cement–soil mixture (1:7) was used for lining to reduce seepage through the soil wall (Figure 3.4).

The following steps were used in construction:

- A subsoil devoid of roots and other organic matter was excavated, sun dried and passed through a 10-mm sieve while breaking down the clods.
- A cement–soil mortar (1:7) (with 1 kg lime and 1 kg waterproof cement per bag of ordinary cement) was prepared and applied to the sides of the tank until a uniform coverage was obtained.
- A second coat was applied using a wooden float to even out the surface. Subsequent coats were applied until a uniform thickness of 6 cm was attained. The surface was sealed with a cement slurry and smoothed using a steel float.
- Continuous curing was done for at least 28 days while covering the surface with wet old sisal bags.
- To ensure stability of the tank, the top half was built with locally burnt bricks. This wall was extended 30 cm above ground level to protect the tank from surface runoff. The brick-walled section was plastered with cement–soil mortar (1:7) and sealed with a coat of cement slurry to make it watertight. After complete curing of the tank, a dome-shaped timber frame was erected on top. This was covered with a sheet of hessian cloth secured to the frame with nails. A 2-cm layer of cement–sand mortar (1:3) was applied and the surface smoothed and kept moist until cured.

3.4 Capacity assessment

The size of tank to be constructed depends on the size of the roof area, the rainfall pattern, the potential supply of rainwater from the roof, the amount of water storage needed, the costs of material and labour, and the availability of finance.

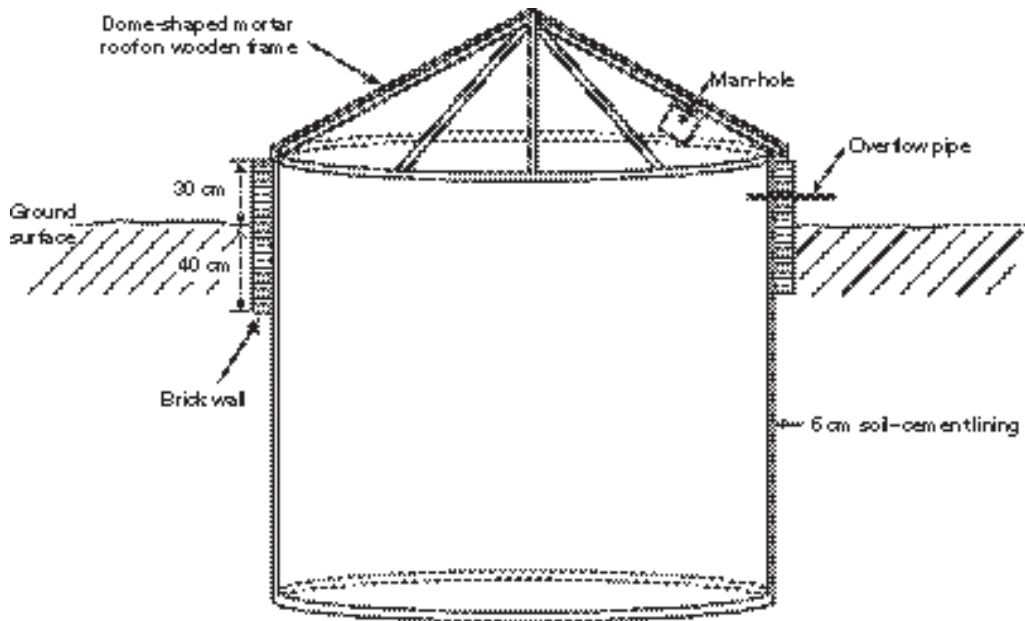


Figure 3.4 *Cross-section of a cylindrical tank with soil-cement lining*

The following are three common ways of assessing the tank size needed.

Balance method

This is a month-by-month accounting method whereby inputs of rainfall are shown in one column, consumption (and overflow if it occurs) in the next column, and the balance remaining in the tank in the last column. Any size of tank can be considered using this approach. If a tank is too small, some rainfall will be lost as overflow and the demand may not be met. If it is too big, it may never fill completely. Deciding on the appropriate size in a given situation is not easy and the balance method is not really as simple as suggested because the probability of getting a certain amount of rain needs to be considered along with many other factors. Computer modelling can help in decision-making.

Cumulative supply or demand method

This method involves calculating the cumulative supply and cumulative demand on a month-by-month basis and showing them as lines on a graph. The maximum difference, during a 12-month period, between the cumulative supply line and the cumulative demand line indicates the optimum size of the tank.

Dry season storage method

This is the simplest and most preferred method for determining tank size for a roof catchment. In this method it is necessary to estimate the longest period during the year without rain and estimate the daily consumption rate. The size of the tank that will be required is the number of dry days multiplied by the daily water use. However, if the volume of run-off estimated from the roof during the rainy season is less than the proposed tank size the latter is reduced accordingly.

Collection of all rainfall

This is common in ASALs and involves collection of all the rainfall from the roof and storing it as a reserve until other sources have dried up and there is an acute shortage. With this method, the required tank size equals the annual rainfall x roof area x 60%. The figure of 60% allows for some losses before collection (10%) and the probability of getting less than the mean rainfall in three years out of ten. If the rainfall figure used is the mean, there will be some wetter years when the tank will overflow and some drier years when it may not fill. Box 3, below, gives an example to show how the size of a hemispherical tank such as tank 4 may be calculated on the basis of the mean annual rainfall.

Box 3. Example of tank-size calculation

The following is a method used to calculate the size of an underground hemispherical tank using the average annual rainfall of 700 mm for Mwala Location as an example.

- The roof size is 6 m x 3 m = 18 m².
- The annual run-off is 18 x 700/1,000 m³.
- Assume the reliability of getting 700 mm is only 60%.
- The volume of the tank needed is 18 x 0.7 x 0.6 = 7.56 m³.
- Assume that the tank is 1 m below the ground surface, that the mouth has a diameter of 1 m and projects 0.5 m above the ground, i.e. the funnel of the tank is 1.5 m long and has a radius of 0.5 m.
- Assuming the funnel is cylindrical, the volume = 3.142 x 0.5² x 1.5 m³ = 1.2 m³.
- The volume of the spherical section below ground is, therefore, 7.56–1.2 m³ = 6.36 m³.
- The volume of a sphere is $\frac{2}{3}\pi r^3$.
- Therefore the radius of the tank, $r = [(6.36 \times 3) / (2 \times 3.142)]^{1/3} = 1.45$ m

3.5 Construction costs

The cost of constructing the tanks is summarized in Table 3.4. Details are provided in Annex B, Tables B3 to B8.

Table 3.4 Summary of construction costs (KSh)

Tank no.	Type and material	Volume (m ³)	Cost of materials	Cost of labour	Total cost	Cost per m ³ storage
1	Self-standing ceramic tank made from clay and fired <i>in situ</i>	1.5	820	1,600	2,420	1,613
2	Oval tank with clay slab (tile) lining	5.0	1,320	1,700	3,020	604
3	Oval tank with sand-cement lining reinforced with sisal fibre	5.0	1,640	1,700	3,340	668
4	Spherical tank with <i>nthangathi</i> -cement lining	9.8	4,405	2,500	6,905	705
5	Sausage-shaped tank with <i>nthangathi</i> -cement lining	10.0	8,215	3,800	12,015	1,202
6	Cylindrical tank with soil-cement lining	12.0	6,170	4,800	10,970	914

3.6 Technical evaluation

Evaluation was carried out by observation on the performance of the different materials used (Table 3.5) and by consultation with farmers (Table 3.6).

Table 3.5 Material evaluation based on visual performance

Tank type and lining material	Material availability	Skills required	Method of application	Observations
Self-standing ceramic clay and oval with clay slab lining (tanks 1 and 2)	Pottery clay found in isolated places	Clay identification; pottery skills; mason skills for brickwork	(a) Plastering direct on soil (b) Self-standing (c) Clay + cement and lime (d) Clay slabs	(a) Cracking (b) No cracks (c) Big cracks (d) Good performance
Oval with cement, sand and sisal fibre lining (tank 3)	Sand and sisal fibre readily available; limited amount of cement used	Mason skills for plastering and brickwork	Plastered direct on excavated surface with sisal fibres criss-crossing	Performance good
Spherical and sausage shaped with <i>nthangathi</i> and cement lining (tanks 4 and 5)	<i>Nthangathi</i> widespread and available; limited amount of cement used	Mason skills for plastering, brickwork and roofing	Plastered direct on the excavated surface and well cured	No cracks and good performance
Cylindrical with red soil and cement lining (tank 6)	Soil widespread and limited amount of cement, lime and waterproof cement used	Mason skills for plastering, brickwork and roofing	Plastered direct on the excavated surface and well cured	Performance good when well cured; water-retention good

The use of clay for plastering excavated surfaces was not satisfactory even when cement and lime were added. However, fired clay was effective in making self-standing tanks and clay slabs for lining. Red soil with a limited amount of cement was quite satisfactory for plastering provided it was well cured. The best linings were made using *nthangathi* and cement, or using river sand and cement with sisal fibre for strengthening.

Farmers showed a preference for the spherical and sausage-shaped tanks. Table 3.6 lists the advantages of these tanks.

Table 3.6 Major attributes of popular designs

Tank design	Attribute	Applications
Spherical tank	<ul style="list-style-type: none"> • Ensures massive water storage underground • Cool water, no breeding of algae or mosquitoes • The top of the tank can be used for other purposes • Uses mainly locally available labour and materials • Can harvest both roof and compound run-off • No reinforcement required 	<ul style="list-style-type: none"> • Recommended for roof or surface catchments
Sausage-shaped tank	<ul style="list-style-type: none"> • Ensures massive water storage underground • Can be conveniently sited between houses or along a veranda • Uses mainly locally available labour and materials • No reinforcement required • Adds aesthetic quality to the homestead environment 	<ul style="list-style-type: none"> • Highly recommended for roof or surface catchments • Can be used where space is restricted, e.g. in towns, and can be used to enhance urban agriculture

3.7 Economic evaluation

The costs shown in Table 3.4 indicate that the self-standing ceramic clay tank was the most costly, at KSh 1.60 per litre of water stored. Although the total cost of materials and labour was low, the volume of water stored was the least of all the tanks. Furthermore, the volume stored would not be adequate for most homesteads. Although it would be possible for more than one tank of this kind to be installed at different corners of a building, and it could be done with locally available pottery skills, it is clear that farmers prefer the larger hemispherical or sausage-shaped tanks. The cost of the former was KSh 0.70 per litre and the cost of the latter KSh 1.20 per litre.

The unit cost for construction of tanks in the first year is low and progressively reduces with the passage of time. The higher the storage capacity, the lower the cost, and vice versa. This, coupled with the acceptably low seepage rates, makes the technology even more adoptable by resource-poor farmers.

The tanks studied used less external inputs for similar water-storage capacities than any conventional tanks. A decision on whether to construct these low-cost tanks depends on the cost and availability of materials within the locality, the availability of the skilled labour needed, and the requirements for maintenance. The need for purchased materials and skilled labour was low for all the tanks. Given that idle labour has zero opportunity cost, the community could engage themselves in tank construction as an off-season self-help initiative, hiring skilled labour only when absolutely necessary.

3.8 Main findings and recommendations

Main findings

- The cost of construction per unit volume of storage is low compared with conventional tanks. The higher the storage capacity the lower the unit cost. In view of the acceptably low seepage rates, the technology is potentially adoptable by resource-poor farmers.
- The tanks used a low input of purchased materials and had a low requirement for skilled labour. Given that idle labour has zero opportunity cost, the community could engage themselves in tank construction as an off-season self-help initiative, hiring skilled labour only when absolutely necessary.
- The use of clay and other soil materials in the construction of water-storage tanks can be seen as a potential means of easing problems related to water storage among resource-poor farmers.
- Soil-cement-plastered tanks performed quite satisfactorily as long as there was some residual water left to avoid cracking.
- Soil combinations with industrial materials and the use of appropriate designs make the technology more appealing and adoptable by those who often associate water-storage structures with the rich.
- The involvement of the community in construction and in the evaluation of the technology led to some degree of success and sustainability.
- The women's group which had been using clay for making pots and ceramic stoves saw this technology as an opportunity to provide water to their members and make money. To the technicians, it was a challenge.
- The technology, if validated and perfected, could save many hours spent on fetching water, and such time could be put to more productive use.

Recommendations

During construction of tanks, the following precautions should be taken:

- Surface water should be drained away from the tank so that it does not seep into

the ground and cause pore water pressure, which would increase the forces on the tank walls and reduce the stability of the faces. To achieve this, the soil surrounding the tanks should be compacted and the surface cemented.

- Differential settlement should be avoided. Differential settlement occurs over time when one part of a structure settles faster than another. It could be caused by variations in the soil substratum or loading differences of adjacent parts of the structure and variations in site conditions at the time of construction. This problem can be avoided in the following ways:
 - (a) Excavations should be made until a firm and stable substratum has been reached. Rocky and gravelly sites should be avoided due to lack of cohesion.
 - (b) A symmetrical shape should be maintained in clay and other materials to ensure balance in loading and distribution of forces.
 - (c) Soils which are subject to ground movements as a result of seepage or water erosion should be avoided. For this reason hillside slopes which are prone to mass movement should be avoided. Sandy soils underlying high-consistency clay soils or hard surfaces must also be avoided since sandy soils allow water to pass underneath and cause subsidence or mass movement.
- There is a need for further research, especially on the following topics:
 - (a) The physical, chemical and structural characteristics of the clay and other materials used in relation to water-storage requirements. Such investigations should include tensile and compressive strengths, permeability, consistency, and dry density.
 - (b) The effect of moisture and alternative drying and wetting of the storage structures.
 - (c) Economic evaluation and socio-cultural aspects related to the adoption of the technology.
 - (d) The suitability of water stored in the structures as measured by WHO standards.

4. Performance of the experimental structures, 1999–2001

At the time of compiling this report, the structures described had been in place for a period of three years – from the beginning of 1999 to the end of 2001. The period from then until publication has created an opportunity to include some important additional observations regarding the performance of the experimental structures.

In Ethiopia, the structures were tested in a real situation to serve households.

- As indicated in the report, initially the tanks were covered using plastic sheets. These soon disintegrated and were replaced by a thin layer of mortar on hessian cloth.
- Depending on the type of soil, plastering the wall of the underground tanks using a mix of soil and cement in the ratio 1:8 has proved adequate so far. This lining failed where the soil had a heavy clay content (more than 30%) and on flat topography where water tends to stagnate and saturate the soil profile. Soil–cement lining has proved to work effectively on coarse soils (especially gravelly ones) on sloping ground.
- Another observation is the effect of roots in the vicinity of the structure. One of the structures has been affected by roots that penetrated through the soil–cement lining in a hair-like pattern, thus rendering the wall porous.
- Curing the soil–cement structure is another important factor to consider. It is important that the structure is watered for three weeks to let it dry slowly to provide the humid environment for good bonding of the cement. It is also important to note that the tank should not be left dry and empty over a long time. This leads to cracking.
- The tank with cheap plastic lining failed in less than a year.

In Kenya too the soil–cement-lined structures have performed well with the exception of those that were left uncovered and exposed to direct sunlight. Observations on each of the technologies are as follows:

- The tanks that were made from ceramic clay have been adopted by a number of women in Kavilo village. While the structures have remained intact, small cracks

have been observed. The women were able to seal the cracks using a handful of cement, and the problem did not seem to persist. This problem was not observed in those tanks which had water in them all the time or were only dry for short periods.

- The storage structure that was lined with tiles made from burnt ceramic clay proved viable. An important feature of this structure is that weak tiles or failure could be mended by replacing individual tiles without affecting a large portion of the rest of the structure.
- The lifespan of the structure lined with mortar was short because of exposure and direct sunshine. The performance was good at the beginning as long as there was water in the structure, but cracks developed during the dry season.
- As in Ethiopia, the soil–cement-lined tanks were covered and protected from direct sunlight. No cracking was observed as long as there was some water in the tank.
- The sausage-shaped tank made using burnt brick and cement–fine sand mortar is performing well.

With the prevailing change in weather patterns and increasing frequency of dry spells during the growing season, the need for surface-water harvesting for crop and animal production is becoming more urgent. The major limitation to the spread and adoption of rainwater harvesting is the cost and availability of materials in the rural areas. The efforts by the two researchers reported here are an attempt towards addressing these limitations. In as much as there is need for further information gathering and proper evaluation, these trials could serve as a starting point.

Some farmers have adopted the construction of underground hemispherical tanks, which are lined with soil and cement in areas close to where the trial has been conducted in Ethiopia. The tanks are used to harvest run-off water during the rains and the stored water is utilized for supplementary irrigation to grow vegetables and to establish fruit trees. In Kenya, the development of sausage-shaped tanks and spherical underground tanks has become a topic of interest with many farmer's groups in Machakos District.

5. General conclusions

There is a great need to harvest rainwater from roofs for domestic use in order to reduce the burden, mainly borne by women and girls, of fetching water from long distances. There is also a growing potential for harvesting rainwater in view of the increasing number of corrugated iron roofs. Harvesting rainwater can save expenditure for those who are currently purchasing water from vendors. It can also release labour for more productive activities.

Underground tanks with low-cost linings have great potential for storing rainwater from roofs and ground surfaces and can be constructed with a limited amount of skilled labour. Underground tanks are cheaper than above-ground tanks because the soil profile provides structural support. The hemispherical shape allows uniform distribution of water pressure and facilitates lining. A sausage-shaped tank which is semi-circular in cross-section below ground has proved popular with farmers in Kenya. It is particularly suited for homes where the house has low eaves and a conventional upright tank would be difficult to install.

Underground tanks should be sited where there is no risk of root penetration and far enough from pit latrines and rubbish pits to avoid contamination. The soil should be stable and not prone to shrinking or swelling. The area surrounding the tank should be provided with a hard surface to reduce water infiltration and minimize the risk of tank collapse due to high pore water pressures.

The size of the tank to be installed depends on many factors, particularly the roof size for collection, the rainfall amount and distribution, the length of the dry season, the household demand and the availability and distance of alternative supplies. Tank sizes up to 15 m³ have been tested in these trials and have proved quite satisfactory. Installation of tanks has allowed some households to give away or sell water to neighbours. In general, the larger the tank the cheaper the cost per unit volume of water stored.

The excavation for a tank should be done carefully so that the surface is uniform, and it should be smoothed before applying the lining. An effective lining can be made with cement and soil, but the texture of the soil is very important and the mixture should not be weaker than 1:7. It should be well mixed and applied carefully. Sand–

cement mortar can also be used for lining but is expensive as the ratio of cement to sand is 1:3. After applying the lining, the surface should be sealed with a cement–water slurry (nil) and should be well cured by keeping it wet for 3–4 weeks. Any cracks which appear should be sealed.

Soil from termite mounds with about 46% sand and 23% clay has proved useful in mixtures in Ethiopia. Sandy soils (*nthangathi*) with 89% sand and 7% clay have also proved effective in Kenya. Soils with a high content of clay, such as black-cotton soils, and a low content of sand are unsuitable for lining because they are prone to crack.

Polythene linings can be used with rectangular tanks, but heavy-gauge polythene is needed to minimize the risk of holes and leakage. Careful sealing of joints with glue is necessary to avoid seepage, and shading to keep out sunlight.

Roofing of tanks is important to keep out dirt, insects, etc., and to reduce losses by evaporation. Polythene is not suitable as it is destroyed by sunlight and wind. A cement–sand (1:3) mortar spread on hessian cloth nailed to a timber framework is effective. If the outer edge is built up with a concrete rim, it is possible to collect rainwater from the roof and divert it into the tank. Domed roofs made from burned bricks are strong and long lasting, but a skilled mason is needed for construction.

The water-delivery system should be part of the design. A trench with steps leading close to the base of the tank allows water to be drawn through a pipe by gravity. It also allows the tank to be drained for cleaning. However, the tank wall adjacent to the draw-off point must be reinforced with a solid retaining wall. The draw-off point must have a drain to prevent it filling with water during rainy periods. If a piped discharge is not installed, water can be withdrawn by bucket and rope through a manhole or by a hand pump.

Comparative costs of tank installation in Ethiopia and Kenya are given in Table 5.1, but caution is needed in drawing conclusions and making recommendations because the problem of seepage, the need for maintenance and the long-term sustainability of these various kinds of tank still have to be assessed.

Table 5.1 Comparison of cost of underground roofed tanks in Ethiopia and Kenya per m³ storage capacity*

Tank type and lining	Capacity m ³	Initial cost	Initial cost less owner's input	Repair cost	Initial cost plus repair cost
Ethiopia					
<i>Tank 1:</i> Hemispherical with soil-cement lining and polythene roof later replaced	7.2	Birr 197 US\$ 24	Birr 103 US\$ 13	Birr 75 US\$ 9	Birr 272 US\$ 33
<i>Tank 2:</i> Hemispherical with soil-cement lining and polythene roof later replaced	8.5	Birr 192 US\$ 23	Birr 100 US\$ 12	Birr 80 US\$ 10	Birr 272 US\$ 33
<i>Tank 3:</i> Hemispherical with soil-cement lining and polythene roof later replaced	8.5	Birr 169 US\$ 21	Birr 104 US\$ 13	Birr 106 US\$ 13	Birr 275 US\$ 33
<i>Tank 4:</i> Rectangular with polythene lining and polythene roof later replaced	6.0	Birr 198 US\$ 24	Birr 119 US\$ 13	Birr 93 US\$ 11	Birr 292 US\$ 35
<i>Tank 5:</i> Hemispherical with sand-cement lining and sand-cement roof	14.8	Birr 124 US\$ 15	Birr 88 US\$ 11	Birr 22 US\$ 3	Birr 145 US\$ 18
Kenya					
<i>Tank 1:</i> Self-standing ceramic tank with brick cover	1.5	KSh 1,613 US\$ 21			
<i>Tank 4:</i> Spherical with <i>nthangathi</i> -cement lining and brick roof	9.8	KSh 705 US\$ 9			
<i>Tank 5:</i> Sausage-shaped tank with <i>nthangathi</i> -cement lining and brick roof	10.0	KSh 1,202 US\$ 16			
<i>Tank 6:</i> Cylindrical tank with soil-cement lining and sand-cement roof	12.0	KSh 914 US\$ 12			

* Calculation based on exchange rate of 1 US dollar = Birr 8.2 or KSh 75.

Further research is needed on the suitability of soils of different textures and the correct ratios for mixing with cement. Research is also needed into ways of reducing seepage and the long-term sustainability of underground tanks with soil-cement linings. The economics of water storage in these low-cost underground tanks should be studied in comparison with conventional, above-ground tanks.

Annexes

Annex A. Ethiopian trials

1. Breakdown of tank costs

Table A1 Breakdown of material costs used in construction (Birr)

Item	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Total
Floor and walls						
Cement	155	210	208	53	475	1,100
Stone	60	60	60	60	–	240
Polythene sheet	–	–	–	190	–	190
Water	105	105	–	–	–	210
Sub-total	320	375	268	303	475	1,740
Roofing						
Purlin and truss	62	86	86	88	62	384
Polythene sheet	167	182	198	159	–	705
Cement	–	–	–	–	300	300
Hessian cloth	–	–	–	–	36	36
Sisal string	–	–	–	–	15	15
Nails	11	11	11	11	8	53
Steel bar	9	9	9	9	9	47
Tailor service	21	21	21	21	–	82
Sub-total	270	309	325	288	430	1,622
Pipes and fittings						
PVC and GI pipes	92	90	92	90	–	364
Pump	–	–	–	–	75	75
Manhole	–	–	–	–	65	65
Inlet	–	–	–	–	13	13
Sieve	5	5	5	5	5	25
Sub-total	97	95	97	95	158	542
Gutter and splash guard						
Gutter	70	56	70	28	56	280
Splash guard	28	28	28	28	28	140
Nails	8	8	8	8	8	40
Black wire	3	3	4	3	3	16
Steel bar	10	10	10	10	10	50
Sub-total	119	105	120	77	105	526
Grand total	806	884	810	763	1,168	4,430

Table A2 Breakdown of material costs used in repair (Birr)

Item	Tank 1	Tank 2	Tank 3	Tank 4	Tank 5	Total
Floor and walls						
Cement	–	–	60	–	30	90
Lime	–	–	25	–	15	40
Plastic paint	86	86	129	–	129	430
Kerosene	3	3	3	–	3	12
Polythene sheet	–	–	–	163	–	163
Glue	–	–	–	24	–	24
Sub-total	89	89	217	187	177	759
Roofing (tank cover)						
Cement	120	150	150	90	–	510
Chicken mesh	–	–	90	–	–	90
Hessian cloth	16	24	24	16	–	80
Purlin	15	23	23	15	–	76
Sisal string	3	4	4	3	–	13
Nails	5	6	6	9	–	26
Manhole	110	110	110	110	–	440
Sieve	3	3	3	3	–	13
Sub-total	272	320	410	246	–	1,248
Grand total	361	409	627	433	177	2,007

Table A3 Breakdown of labour costs used in repair (Birr)

Item	Tank 1	Tank 2	Tank 3	Tank 4	Trial 5	Total
Mason	140	210	210	105	105	770
Painter	10	10	20	–	20	60
Assistant	32	48	48	24	24	176
Total	182	268	278	129	149	1,006

2. Cost of tank roofing

During the repair and maintenance work, the polythene sheet used for roofing of tanks 1, 2, 3 and 4 was replaced with a cement–sand mortar dome. The total cost of construction for the polythene sheet used initially and the mortar dome which replaced it is shown in terms of cost per unit area in Table A4, below.

Table A4 Comparison of material cost for tank cover

Tank	Tank cover area (m ²)	Total cost (Birr)*		Cost per unit area (Birr per m ²)	
		Polythene	Mortar	Polythene	Mortar
1	12.0	358	444	30	38
2	14.7	397	578	27	40
3	15.0	413	620	26	42
4	9.1	367	375	40	41
5	13.2	–	490	–	31
Average	–	–	–	31	40

* This includes only the cost of materials and labour used for construction of the tank cover.

From Table A4, the average cost of construction per unit area of tank cover is 31 Birr and 41 Birr for the polythene sheet and the mortar dome, respectively. Accordingly, the average cost increment per unit area while using a mortar dome is about 29%.

Hence, using a mortar dome for a household water tank cover would provide an economic advantage with the better quality of work. The sustainability and durability of the technology, however, has to be assessed and analysed with time.

Annex B. Kenyan trials

1. Testing of clay slabs

Water loss by seepage through slabs of soil–cement mixtures, sealed with cement, was determined using 1-m and 2-m columns of 5-cm diameter PVC pipe. The pipes were glued to the slabs using silicon glue and supported in an upright position by a cross bar running horizontally between two posts. The pipes were filled with water and the levels taken over a specified duration. Three replicates of each material mixture were tested and the average drop recorded (Table B1).

Table B1 *Water loss by seepage through slabs of soil–cement mixture and clay*

Time from start (hr)	1-m column of water		2-m column of water	
	Soil–cement slab sealed with cement (cm drop)	Clay slab (cm drop)	Clay slab sealed with cement (cm drop)	Clay slab (cm drop)
0	0	0	0	0
0.5	0	0	0	0.15
1	0	0.1	0	0.35
2	0	0.2	0.1	0.58
20	0.12	2.75	1.2	5.10
23	0.22	3.05	–	5.17
38	0.75	8.9	1.7	6.15

The results of the trial showed that:

- No material was 100% impervious. The amount of drop in level was determined by the height of the column, the sealing with cement and the firmness of sealing at the base of the pipe.
- The soil–cement mixture proved efficient when sealed with cement. The negligible drop in the column after 38 hours indicates that the mixture was suitable for the lining of underground storage tanks.
- Freshly fired/burnt clay had some degree of porosity, resulting in a significant drop in column height. For greater efficiency, therefore, it was recommended that a thin layer of cement coating be sprayed on the inside surface of the tank.

2. Soil analysis

The types of soil used as shown in Table 3.2 can be compared with the recommended composition of soil for construction purposes taken from the FAO manual *Farm Structures* (1980).

Table B2 Different soil grades used for construction purposes

Use	Sand (%)	Silt (%)	Clay (%)	Organic matter (%)	Soluble salts (%)
Rammed earth walls	35–80	10–30	5–20	0–0.3	0–1.0
Pressed soil blocks	40–80	15–35	5–25	0–0.3	0–1.0
Mud bricks (adobe)	50–80	10–40	10–30	0–0.3	0–1.0
Ideal general purpose mix	60	20	15	0	0

Source: FAO 1980.

Of the soils used in the experiment, the one which most closely conforms to the FAO recommendations is the Kalawani soil which is used by the Kavilo Women's Group in making clay pots. The clay fraction in the soil is of major importance as it binds the larger particles together. However, soil with more than 30% clay tends to have a high shrinkage/swelling ratio and is therefore prone to cracking. If the soil material being used does not have the right texture, it may be improved by the addition of sand or clay. The best soils for construction are sandy loam and sandy clay loam because the voids between the larger particles are filled with the smaller ones. Soils with a high sodium content are unstable and unsuitable for construction.

3. Breakdown of tank costs

Table B3 Cost of construction of 1.5 m³ self-standing ceramic tank (tank 1)

Item	Specifications	Unit	Quantity	Unit cost (KSh)	Total (KSh)
Materials					
Cement	50 kg	Bag	1	420	420
Bricks		No.	100	4	400
Labour					
Excavation and shaping		Person days	4	100	400
Construction			10	100	1,000
Mason			1	200	200
Total cost					2,420
Cost per litre of water storage KSh 1.60					

Table B4 Construction cost of 5 m³ oval tank with lining of clay slabs (tank 2)

Item	Specifications	Unit	Quantity	Unit cost (KSh)	Total (KSh)
Materials					
Cement	50 kg	Bag	1	420	420
Sand		Tonnes	0.25	200	50
Slabs	30 cm x 30 cm	No.	150	5	750
Water	200 litres	Drum	1	100	100
Labour					
Excavation		p.d.*	2	100	200
Skilled	Mason	p.d.	5	200	1,000
Unskilled		p.d.	5	100	500
Total cost					3,020
Cost per litre of water storage KSh 0.60					

* p.d. = person day

Table B5 Construction cost of 5 m³ oval tank with sand–cement lining plus sisal fibre reinforcing (tank 3)

Item	Specifications	Unit	Quantity	Unit cost (KSh)	Total (KSh)
Materials					
Cement	50 kg	Bag	12	420	840
Bricks		No.	100	4	400
Sand	Clean sand	Tonnes	0.5	200	100
Sisal fibre	1 kg	kg	1	100	100
Waterproof cement	1 kg	Packet	2	100	200
Labour					
Excavation		p.d.	2	100	200
Skilled	Mason	p.d.	5	200	1000
Unskilled		p.d.	5	100	500
Total cost					3,340
Cost per litre of water storage KSh 0.67					

* p.d. = person day

Table B6 Construction cost of 9.8 m³ spherical tank with nthangathi–cement lining (tank 4)

Item	Specifications	Unit	Quantity	Unit cost (KSh)	Total (KSh)
Materials					
Cement	50 kg	Bag	6	420	2,520
Bricks		No.	150	4	600
Sand	Clean sand	Tonnes	1	200	200
Water	200 litres	Drum	6	100	600
Soil	Clean	Tonnes	1.5	50	75
Waterproof cement	1 kg	Packet	4	50	200
Lime	5 kg	Packet	1	180	180
Nails	2 and 3 inch	kg	0.5	60	30
Labour					
Excavation		p.d.	5	100	500
Skilled	Mason	p.d.	6	200	1,200
Unskilled		p.d.	8	100	800
Total cost					6,905
Cost per litre of water storage KSh 0.70					

* p.d. = person day

Table B7 Construction cost of 10 m³ sausage-shaped tank with nthagathi–cement lining (tank 5)

Item	Specifications	Unit	Quantity	Unit cost (KSh)	Total (KSh)
Materials					
Cement	50 kg	Bag	11	420	4,620
Bricks		No.	350	4	1,400
Sand	Cean sand	Tonnes	0.5	200	100
Water	200 litres	Drum	8	1,000	800
Soil	Clean	Tonnes	1.5	50	75
Waterproof cement	1 kg	Packet	6	50	300
Lime	5 kg	Packet	2	180	360
Nails	3 and 4 inch	kg	1	60	60
Plywood	8 ft x 4 ft		2	250	500
Labour					
Excavation		p.d.	6	100	600
Skilled	Mason	p.d.	10	200	2,000
Unskilled		p.d.	12	100	1,200
Total cost					3,800

Cost per litre of water storage KSh 1.20

* p.d. = person day

Table B8 Construction cost of 12 m³ cylindrical tank with soil–cement lining (tank 6)

Item	Specifications	Unit	Quantity	Unit cost (KSh)	Total (KSh)
Materials					
Cement	50 kg	Bag	5	420	2,100
Bricks		No.	200	4	800
Sand	Clean sand	Tonnes	0.5	200	100
Soil transport	Red soil	Tonnes	1	200	200
Waterproof cement	1 kg	Packet	4	50	200
Lime	5 kg	Packet	1	180	180
Nails	3 and 4 inch	kg	1.5	60	90
Hessian cloth		m	15	100	1,500
Timber	3 inch x 2 inch	m	50	20	1,000
Labour					
Excavation		p.d.	10	100	1,000
Skilled	Mason	p.d.	12	200	2,400
Unskilled		p.d.	14	100	1,400
Total cost					10,870

Cost per litre of water storage KSh 0.91

* p.d. = person day

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The revival of soil conservation in Kenya: Carl Gösta Wenner's Personal Notes 1974–81

Arne Eriksson (ed). 1992. TR No. 1. ISBN 9966-896-00-7

The Swedish International Development Cooperation Agency (Sida) has supported rural development programmes in eastern Africa since the 1960s. Through its Regional Land Management Unit (RELMA), Sida promotes initiatives to strengthen the role of small-scale land users in order to enhance food security and reduce poverty.

RELMA, the successor of Regional Soil Conservation Unit (RSCU), is based in Nairobi and operates mainly in six eastern and southern African countries: Eritrea, Ethiopia, Kenya, Tanzania, Uganda and Zambia. RELMA's goal in the region is to improve livelihoods of small-scale land users and enhance food security for all households. In pursuit of this goal, RELMA promotes environmentally sustainable, socially and economically viable farming and marketing systems, and supports policies that favour small-scale land users.

RELMA organizes, on a regional level, training courses, workshops and study tours. It also gives technical advice, facilitates exchange of expertise and produces information material for the dissemination of new knowledge, techniques and approaches. A variety of reports, handbooks, posters and other information materials are published and distributed in the region on a non-profit making basis.

About this book

Rainwater harvesting is one solution to the problems of water shortage in the drier areas of Africa, but its implementation presents a number of challenges, of which storage is the main one. Many people in rural areas who would like to harvest rainwater lack the resources to do so. Conventional stone, brick or ferrocement tanks are costly, and therefore there is a great need for cheaper alternatives.

This publication gives an account of two trials conducted in 1998/99 to investigate some such alternatives. In Ethiopia, five different methods of tank construction were tested in the suburbs of Nazareth town in Adama Woreda. In Kenya, six different methods were tested during the same period at various locations in Machakos and Makueni Districts. A main feature of the alternative tank designs is that they are built underground, which reduces the need for reinforcement materials.

In this book, detailed reports on the investigations are preceded by a general introduction on the problems of water supply and storage. The last chapter makes general conclusions and recommendations.

Although no completely satisfactory alternative to conventional methods of water storage has yet been identified, a great deal was learned about different approaches for which there was little prior information. Work is continuing to improve the technology to further these more cost-effective methods of storing rainwater.

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