RAINWATER HARVESTING FOR DOMESTIC USE IN TANZANIA A CASE STUDY: UNIVERSITY OF DAR ES SALAAM STAFF HOUSES

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ABSTRACT

The bacteriological, chemical and physical analyses of water samples from rainwater cistern system at the University of Dar es Salaam in Tanzania were carried out between October 1988 and December 1989. Faecal coliforms, total coliforms and faecal streptococci were enumerated. The results shows that 86% of the samples were free from faecal coliforms. However, faecal streptococci were obtained in 53% of the samples and 45% of the samples tested for total coliforms were positive. The physical quality of water was found to be appealing during the whole study period with turbidity less than 5 NTU and colour less than 5 mg Pt/l. However, about 54% of the consumers raised objections over the taste of water.

INTRODUCTION

Rainwater harvesting as a source of water supply for domestic consumption has been practiced throughout the world for many years. However, although rainwater is recognized as an alternative source of water supply it has been used on a relatively small scale in Tanzania, mostly in rural areas. Previous practice in Tanzania has been limited to the use of small containers for storage. In places where surface water is not available, rainwater storage in impoundments has been practiced mainly for livestock and to a lesser extent for domestic use.

In a recent development, rainwater cistern systems have been introduced in urban areas, notably at the African Medical and Research Foundation (AMREF) offices in Dar es Salaam, Sungura textile mills and at the University of Dar es Salaam main campus, the latter being the study area. The Sungura textile mills, for example, have a 2000 m³ storage tank which is used to store rainwater and municipal water supply for use during shortages.

Rainwater cistern systems have been introduced in urban areas

Rainwater harvesting for domestic consumption was regarded as one of the vital options for water supply after a long and chronic experience of water shortages at the University of Dar es Salaam main campus. The University main campus, which is located about 12 km west of the Dar es Salaam city centre, is about 100 m above mean sea level, the highest elevation in Dar es Salaam. Due to its topography and more important, shortages of water supplied to the city, the University of Dar es Salaam was the hardest hit area in terms of water shortages in the whole city.

Gondwe [1] estimated that on average 2000 m^3/d of water was required in 1982 at the main campus. However, the water supplied through the municipal system was estimated to be only 793.5 m^3/d [2]. The supply was therefore only about 40% of the demand. Following this shortage two tanks, one with a volume of 45 m^3 and the other 600 m^3 were constructed at the campus to try to alleviate this problem. The main campus, which was originally receiving an inadequate water supply from the Upper Ruvu source alone, was connected to the Lower Ruvu source. In order to boost the water supply, water from the Lower Ruvu was pumped to the 600 m^3 tank before being distributed to the system. It was also decided to include a rainwater cistern system in 16 Swiss sponsored housing units for University staff in order to supplement the municipal water supply which had become very intermittent.

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The two storey Swiss sponsored housing units were provided with a basement tank which has two compartments with a total capacity of 80 m³ and a roof tank of capacity 400 l. Rainwater is collected on the galvanized iron sheet roofs and stored in the basement reinforced concrete tanks through a network of gutters and downpipes. The daily water requirements are pumped through a roughing filter by a hand pump located on the ground floor to the roof tank which then provides water by gravity (see Fig. 1).

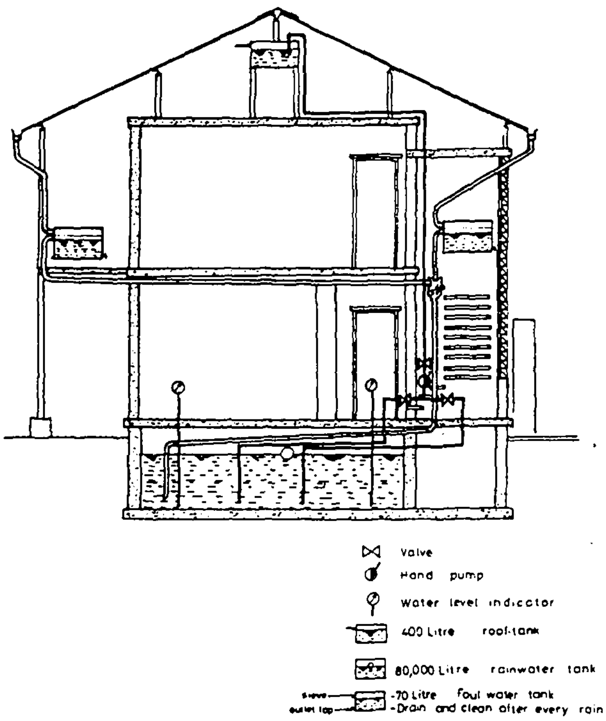

Figure 1. Rainwater cistern system at the University of Dar es Salaam.

Following complaints from rainwater consumers about the taste of water, the Water Resources and Environmental Engineering Section of the Department of Civil Engineering carried out the 15 month water quality surveillance upon which this paper is based.

RAINWATER DEMAND

The potential per capita consumption of rainwater depends on the size of the collection surface, the volume of the rainwater storage tanks, the amount and annual distribution of precipitation, the size of the family and the efficiency with which the precipitation is collected.

According to the 14 year precipitation record available at the University of Dar es Salaam weather station, the annual precipitation in Dar es Salaam varies from 740 to 1260 mm with a mean of 1009 mm. Approximately 50% of this precipitation occurs between March and May.

Considering that the main storage tank is located in the basement, and that the roof catchment is composed of galvanized iron sheets of good quality, with gutters sufficiently large to capture intense rainfall, it is anticipated that at least 90% of the rainfall may be collected in the basement tanks. Since the plan area of the roof is approximately 150 m², the maximum annual rainfall collection is estimated to be:

$$0.9 \times 150 \times 1.009 = 136 \text{ m}^3$$

It is anticipated that at least 90% of the rainfall may be collected in the basement tanks

Family size in the study area varies between 4 and 8 inhabitants with an average density of 5.5 inhabitants per household. This density was found to be consistent with that which Gondwe [1] estimated for the entire University community. The maximum per capita consumption will therefore range from 47 l/c/d in a large family to 93 l/c/d in small families, with an average of 68 l/c/d. Bearing in mind that the houses are provided with full plumbing installation, this consumption rate is too low. The per capita domestic consumption rate at the university of Dar es Salaam has been estimated by Gondwe [1] to be 200 l/c/d, further confirming the possibility of shortages if rainwater is used as the only source.

Consumer views on the quantity of rainwater were sought and the outcome is summarised in table 1.

Table 1: Views of Consumers on Rainwater Quantity

	Number of households with the view that:		
	rainwater is sufficient	rainwater is not sufficient	not certain
*Fully utilized rainwater supply	2	4	–
Partially utilized rainwater supply	2	2	3

*rainwater consumption for cooking, washing, bathing, drinking and flushing toilets only.

From the results in Table 1, only two households who are fully utilizing rainwater for domestic purposes (not for gardening, car washing, etc.) have indicated that rainwater is sufficient throughout the year. Two other households have indicated that rainwater is sufficient, but these households are using rainwater for washing only. The remaining nine of the thirteen household who have filled the questionnaires have indicated that either the rainfall is insufficient or they are not certain about the adequacy of supply. It may generally be concluded that rainwater supply is insufficient for annual domestic consumption unless the roof catchment area and the storage is increased. However, the analysis indicates that based on the present rainfall pattern the tanks will be sufficient even during the years with maximum precipitation. Therefore, there is no need to increase the storage capacity unless the catchment area is correspondingly increased.

RAINWATER QUALITY

The chemical and physical quality of rainwater is generally acceptable but on a few occasions bacteriological quality may be unacceptable, especially when undesirable collection, storage and use of rainwater is practiced. Rainwater quality is influenced by several factors as the rainwater passes through the catchment surface, storage tanks, pumping and plumbing system and finally to the consumers. The quality of the rainwater may be influenced by the quality of precipitation, most notably the acidity of the rain, deposition on the catchment surfaces (which may increase turbidity and colour and introduce bacterial agents) and other contaminants which may be introduced into the system by man himself through the use of contaminated containers for the collection of rainwater. Materials used for construction such as cement and lime may impair the taste of water and scare away consumer. To assess the quality of water for domestic use, the rainwater quality was assessed in terms of its palatability and health risks to human life.

Palatability of Rainwater

The most common criteria used for assessing the palatability of water for drinking purposes are physical and chemical in nature. The parameters which might cause objectionable quality of rainwater at the University of Dar es Salaam such as hardness, colour, turbidity, taste and pH were assessed using laboratory tests and questionnaire techniques.

The most common criteria . . . are physical and chemical in nature

The summary of laboratory results is shown in Table 2 in which they are compared with WHO and temporary Tanzanian Standards.

Table 2: Physical and Chemical Rainwater Quality

Parameter	Range	WHO	Tanzanian criteria
turbidity (NTU)	0 - 5	25	30
colour (mg Pt/l)	0 - 5	50	50
Total hardness (mg $CaCO^{3}$/l)	25 - 55	n.m.	600
pH	9.3 - 11.7	6.5 - 9.2	6.5 - 9.2

n.m. = not mentioned

The quantity of chemical constituents in rainwater is generally low, although concentration might slightly increase due to contributions from systems materials. The concentration of hydroxyl ions, for instance, was observed to increase pH to unacceptable limits. The pH of rainwater in the basement tanks increased to between 9.3 and 11.7 from a natural rainwater pH of about 7.6 due to the cement mortar remains in the basement tanks and probably due to leaching. The cement remnants which were not removed after construction have unfortunately led to an unpleasant bitter taste which was objectionable to the rainwater consumer. About 54% of the rainwater consumers have raised complaints about the taste of rainwater stored in the tanks. It was, however, observed that rainwater taste improved after cleaning the tanks, although the pH only decreased slightly. This is probably due to leaching from the concrete in the storage tanks.

The analysis has also shown that the turbidity and colour in all 15 rainwater samples analysed from three houses has remained below 5 NTU and 5 mg Pt/l respectively. Due to the use of cement as a construction material, the total hardness of the water was analysed and was found in all cases to be below 55 mg $CaCO_3$/l. Zinc concentration in the rainwater system was analysed by Wegallin [3] who reported it to be less than 0.3 mg/l.

Bacteriological Quality

Bacteriological quality of rainwater generally has more serious consequences than substances affecting palatability. Bacterial intrusion may occur due to the contamination of the catchment surface and storage tanks by animals or human beings.

The growth of colonies of faecal coliforms, total coliforms and *faecal streptococci* were enumerated in this research. Of the three, more emphasis was focused on examination of faecal coliforms because they represent possible contamination of human origin which poses a serious threat to human health.

Rainwater analysis was carried out in 14 houses, but the examination was mostly concentrated on three houses. Samples were collected from a tap supplying water to the kitchen, and on some occasions, when the pump had failed, rainwater was collected from the basement storage tanks in clean sterile glass containers. Samples were tested for total coliforms, faecal coliforms and *faecal streptococci* using the membrane filter technique laid down in the Standard Methods for Examination of Water [4].

Table 3 presents the summary of the results of the bacteriological examination of water samples from rainwater collected over a period of 15 months.

Table 3: Results of Bacteriological Analysis

Organism	Number of samples	Range of bacterial count (no/100 ml)	Number of samples within given bacterial density				
			0	1-3	4-10	11-100	> 100
faecal coliforms	50	0 - 37	43	4	1	2	0
total coliforms	20	0 - 26	11	6	1	2	0
faecal streptococci	17	0 - 135	8	0	3	5	1

The faecal coliform analysis shows that 86% of the samples were free from these micro-organisms. Two samples which were collected from the same household on different days have recorded faecal coliform density above 10 per 100 ml. It is suspected that the contamination was caused by bad water use practice (such as extracting water from the basement tank using contaminated containers) in this particular household. However, further monitoring of the water has shown an absence of faecal coliforms when a subsequent sample was taken from the same house three weeks later. The absence of faecal coliforms may be attributed to the high pH of water in the basement tanks and probably to the low nutrient level in the rainwater.

Total coliform analysis of stored rainwater revealed that only 2 of the 20 samples were above maximum permissible concentration in accordance with the WHO as well as the temporary Tanzanian drinking water standards as shown in Table 4.

Faecal streptococci were observed in 53% of the samples analysed. The cause of the pollution may be due to the inefficient first rain flushing system which allows part of the water containing bird droppings to be carried to the basement tank. Another possible source of *faecal streptococci* is contamination from faeces of lizards and cockroaches which find their way to the basement tank. Serious health hazards from lizards, cockroaches and bird droppings is unlikely, although in rare cases salmonella in bird droppings may be conveyed to human beings [5].

Pollution may be due to the inefficient first rain flushing system

Table 4: Bacteriological Drinking Water Criteria

	class of water	TC per 100 ml	FC per 100 ml	FS per 100 ml
Temporary	excellent	0	0	n.m
Tanzania	satisfactory	1-3	—	n.m.
Drinking Water	suspicious	4-10	—	n.m.
Standards	unsatisfactory	10	1	n.m.
WHO Recommendations	maximum permissible concentration	10	0	0

A survey of faecal coliform contamination in treated municipal water supply in Dar es Salaam carried out by Kubena [6] and which is represented in Table 5 was compared to the faecal coliform pollution in the University of Dar es Salaam (UDSM) rainwater catchment system as shown in Table 3.

Table 5: Faecal Coliform Density in Treated Water Supply in Dar es Salaam City [6].

Season	Total number of samples	Number of smaples showing given FC/100 ml				
		0	1-3	4-10	11-100	> 100
dry	102	69	30	3	0	0
rainy	102	13	27	27	35	0

Table 5 shows that only 67.6% and 12.7% of the samples collected from the Dar es Salaam city water supply distribution system were free from faecal coliforms during dry and rainy seasons respectively. These values are far below the figure of 86% obtained in the UDSM rainwater roof catchment system.

Gumbo [7] used the S-value shown in Eq. 1 below to determine the relative safety of water sources against bacterial contamination.

$$S = \frac{1}{4} [4 \times (\%0) + 3 \times (\%1\text{-}10) + 2 \times (\%11\text{-}100) + (\%101\text{-}1000)] \quad (1)$$

in which %0, (%1-10), (%11-100) and (%101-1000) represent percentage of water samples with a faecal coliform count within the specified range.

From Eq. 1, the relative safety of the UDSM rainwater system and the Dar es Salaam treated water supply will be:

rainwater: $S = 0.25 \times [4 \times 86 + 3 \times 10 + 2 \times 4] = 95.5\%$

municipal water: $S = 0.25 \times [4 \times 40.2 + 3 \times 42.6 + 2 \times 17.2] = 80.8\%$.

The S-value for the UDSM rainwater system is higher than the city treated water supply and it even surpasses the S-value for borehole water (85%) which was regarded by Gumbo [7] as the best source of water in Tanzania. This analysis, based on the faecal coliform count, clearly shows that rainwater is a better source of drinking water than the Dar es Salaam city water supply and that generally no treatment is required if proper health precautions are practiced during collection, storage and use of the rainwater.

Consumers Views on Water Quality

In order to assess the reactions of rainwater consumers to the quality of rainwater, questionnaires were distributed to all 16 households. Thirteen of the 16 households responded to the questionnaires. The outcome is summarised below:

- 8 out of 13 households use rainwater for drinking. However, four households use rainwater for drinking only after filtering and/or boiling.
- 3 out of 13 households use rainwater for washing only.
- 6 out of 13 households are using rainwater for both cooking, drinking and washing.

From the data given above, it seems rainwater is not preferred as a good source of water supply, as anticipated by many. The reasons for this setback are:

It seems rainwater is not preferred as a good source of water supply

(a) the households were provided with an alternative source of water, namely, the municipal water supply. In recent years municipal water supply at the campus has improved in terms of quantity and reliability. This factor has influenced some consumers to abandon the rainwater system which requires manual pumping prior to consumption.

(b) the bitter taste of water which is caused by cement mortar which remains after construction of basement tanks has scared away some of the rainwater consumers. Fifty-four per cent of the consumers objected to the bitter taste of water caused by cement mortar, which according to them renders it unsuitable for drinking.

(c) that rainwater does not contain sufficient of the minerals which are required in the human body. Two out of 13 households have indicated this factor as one of their reasons for not using rainwater for drinking purposes.

(d) in one household rainwater was not used for drinking purposes because it was argued that rainwater has not been treated by chemicals as has the municipal water supply.

In spite of the above mentioned setbacks rainwater was preferred by some consumers since it is pure, clean, clear, and softer then the municipal water. About 46% of the consumers prefer rainwater to piped water for these reasons. Whereas clarity of rainwater has been singled out as a reason for preferring rainwater, no single consumer has mentioned bacteriological quality to be of any interest perhaps due to the lack of any means available to consumers for determining this parameter. It may therefore be concluded that palatability affecting substances causing objectionable taste and turbidity are probably more important parameters to consumers than the bacteriological quality of water, although the former parameters do not cause any health risks to consumers.

SUGGESTIONS FOR IMPROVEMENT OF RAINWATER SYSTEM AT UDSM MAIN CAMPUS

In order to improve the quality of water and the rainwater systems at the UDSM staff houses some suggestions were made to the Estates Department of the University of Dar es Salaam for possible consideration in improving the system. The suggestions were [8]:

Flushing the first rain

It is natural that during the dry period, which is about 50 days long according to the 15 years of rainfall data available, dust, bird droppings and other deleterious materials will accumulate on the roofs. These materials will be washed off by the first new rains and accumulate in the storage tanks. To avoid the accumulation of these deleterious materials in the storage tanks, the rainwater system should be provided with foul tanks so that the first water from each shower can be allowed to run to waste.

The rainwater system should be provided with foul tanks

The rainwater system at the UDSM main campus have been provided with two identical by pass systems, one in front and the other at the back of the house (see Fig. 1). The adequacy of the capacity of these tanks for diverting foul water was not experimentally checked.

The arrangement for diverting the first foul water does not exclusively separate the first new rains, as mixing of the rainwater in the foul tank continues as rain progresses, thus defeating the purpose of the foul tanks. To improve foul tank efficiency, a ball valve should be fixed in the foul tank to a downpipe from the gutters, and a downpipe to the storage tank should be fixed with a p-shaped trap as shown in Fig. 2 in order to completely prevent the first rain from entering the storage tanks. Before the first rain is collected the foul tanks should be emptied and the tap (to waste) closed. When the rain starts, the foul tanks will be filled first, since the p-connection to the downpipe will not allow the flow of water to the storage tank. When the foul tank is filled the ball valve will close and will completely prevent the first rain from mixing with clean rainwater. The rainwater will then start flowing to the storage tank. The procedure described above may be repeated for the next round of diverting first rainwater.

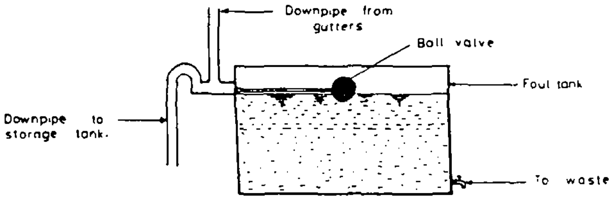

Figure 2. Proposed foul water flushing system.

Improvement of the Taste of the Water

It has been mentioned earlier that the objectionable taste of water is caused by the remnants of cement left after construction. The solution to this problem is to clean the basement tank in order to remove the cement debris. However, leaching from the cement may continue for a few more years, but the water taste is expected to significantly improve after the removal of debris. So far, to the best of our knowledge, only four households have cleaned their tanks, although the system has been in operation for two years. The necessity of cleaning the tanks has, however, been communicated to all consumers since the designers have provided a rainwater system user's manual to all households in both the English and Kiswahili languages.

The solution . . . is to clean the basement tank in order to remove the cement debris

Problems Related to Pumping

Two major problems have been identified in connection with pumps.
These are:

Pump failures and leakages: in response to the questionnaires distributed to consumers and during sampling it was observed that on average about 20% pump failure and leakage occur at any given time. The leakage is generally minor in terms of amount of water loss but causes inconvenience to the users. The solution to this problem would be to report any leakage to the Estates Department of the University of Dar es Salaam for repairs as soon as the leakage is noticed in order to avoid serious damage to pumps. At the same time it is important that the Estates Department keep enough spare parts to repair pumps whenever such cases arise. Failure to repair a pump will force the consumers to use containers to extract water from the basement tank, perhaps leading to contamination of water.

Manual pumping: according to some consumers, it takes roughly 30 minutes daily to pump requirements to the roof tank. Whereas this may be advantageous due to the low water consumption rate, this advantage is overshadowed by the fact that the consumers tend to use the treated municipal water supply provided as an alternative source, instead of rainwater. In a survey conducted in February and December 1989, it was observed that 25% of the household do not use rainwater for this reason. However, from the results of questionnaires filled out in February 1989, only two households demanded replacement of a manual pump with an electric pump. This reaction of consumers did not come as a surprise because they do have an alternative source of water which does not require pumping. Moreover, most of the household have servants, who among other things are responsible for pumping water to the roof tanks, and in some cases electric pumps have been installed by the household owners. It seems that manual pumps may still be effectively used, but the users should be encouraged to pump at least an amount of water sufficient for drinking and cooking since rainwater is bacteriologically safer than municipal water.

Rainwater is bacteriologically safer than municipal water

CONCLUSIONS

The quantity of rainwater from roof catchment system is unlikely to satisfy the needs of consumers, bearing in mind the roof size of the houses at the University of Dar es Salaam.

A rainwater system is probably the best drinking water source in Tanzania provided proper health precautions are taken during collection, storage and use.

Palatability affecting substances are regarded by consumers to be the major factors influencing the quality of water.

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