Chapter 27
Rainwater Harvesting System Planning for Tanzania

Msafiri Mussa Mtanda, Sakshi Gupta, and Deepak Khare

Abstract Water scarcity is a challenge in many parts of the world including Tanzania. Collecting rainwater wherever it falls from the sky should be considered as valuable technique in areas struggling to cope with potable water needs. The current water shortage in Arusha, Tanzania, is badly affecting the living standards due to the increasing water demands of a growing population. In this study, information based on the context of average number of household, land use, water use and mean monthly rainfall is used in planning and design of the system. The present paper demonstrates analysis for designing a domestic rainwater harvesting system, which identifies the relationship between rainwater potential, demand and storage capacity by bridging demand–supply gap. Rainwater harvesting systems can be adopted where municipal water supply systems have failed to meet community's requirements.

Keywords Rainwater harvesting system · Rainwater potential · Storage capacity · Arusha · Tanzania

27.1 Introduction

Rainwater harvesting is a technique of collecting rainwater that runs off from rooftops, parks, roads, open grounds, etc., and stored into natural reservoirs or tanks, or the infiltration of surface water into subsurface aquifers before it is lost as surface runoff

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for future use to meet the demands of human consumption or activities. According to John Mbugua 1999, "*rainwater harvesting*" can be undertaken through several ways by capturing the rainfall where it falls either in villages, farms and local catchments or towns from watershed management, building roof-tops and taking measures to keep it clean and store that water to be consumed when required. Rainwater harvesting is a good fit option which is technically feasible, easy to operate and affordable even to poor communities (Hatibu and Mahoo 2000; Manyama 2006).

27.1.1 Background

Rainwater harvesting almost practised worldwide with different purposes. According to Baguma, rainwater in Malaysia is used for commercial domestic purposes including car washing in parking lots and also in South Australia used to supplement drinking water supply for nearly 40% of households (Baguma 2012).

27.1.2 The Case of Arusha District

The site visit around the town (Arusha Urban District, Tanzania) has revealed that the current water shortage situation is seriously affecting the residents and the urban centre is experiencing a noteworthy blast in land improvement, new enterprises, neighbourhood and worldwide associations and higher learning establishments. The Arusha Urban Water Supply Authority is hardly working to identify new water sources including recovering nine old wells that were dug in 1980 and however have never been utilized since then. The Authority relies upon filling its water reserves by tapping from natural springs and 16 wells of which are now drying up. The Authority can produce approximately 45,000,000 L of water per day which can simply solve only 50%, whereby total population needs 93,270,000 L per day (AUWSA 2012). According to Water Authority Director, there is a need of adjusting the city's system, including repairing the matured pipelines and tapping alternative sources in order to fully eradicate water issues in Arusha District (NEPAD Water Centres 2014).

27.2 Materials and Methods

27.2.1 Study Area

Arusha Urban District (or Arusha City Council) is one of the seven districts of the Arusha Region Northeast Tanzania, within East Africa.

Geographically, it lies on Latitude 3°22′21″ S, and Longitude 36°41′40″ E. It is bordered to the east by Meru District and by Arusha Rural District surrounding the south, west and north as shown in Fig. 27.1. Despite Arusha being near to the equator, annual temperature differs from 13 and 30 °C with an average around 25° of which cool dry air is prevailing for much of the year which keeps temperatures comparatively low and controls humidity (Deluxe and Mkomwa 2012). Arusha has an elevation of 1387 m (approximately equal to 4600 feet) on the southern slopes of the fifth-highest mountain in Africa, Mount Meru (height of 4562.13 m that is 14,968 feet). According to the 2012 Tanzania National Census, Arusha Urban District has a population of 416,442 with an approximation of 4% growth per year (National Bureau of Statistics 2013; NBS 2014). Master plan covers 267 km^2 with density

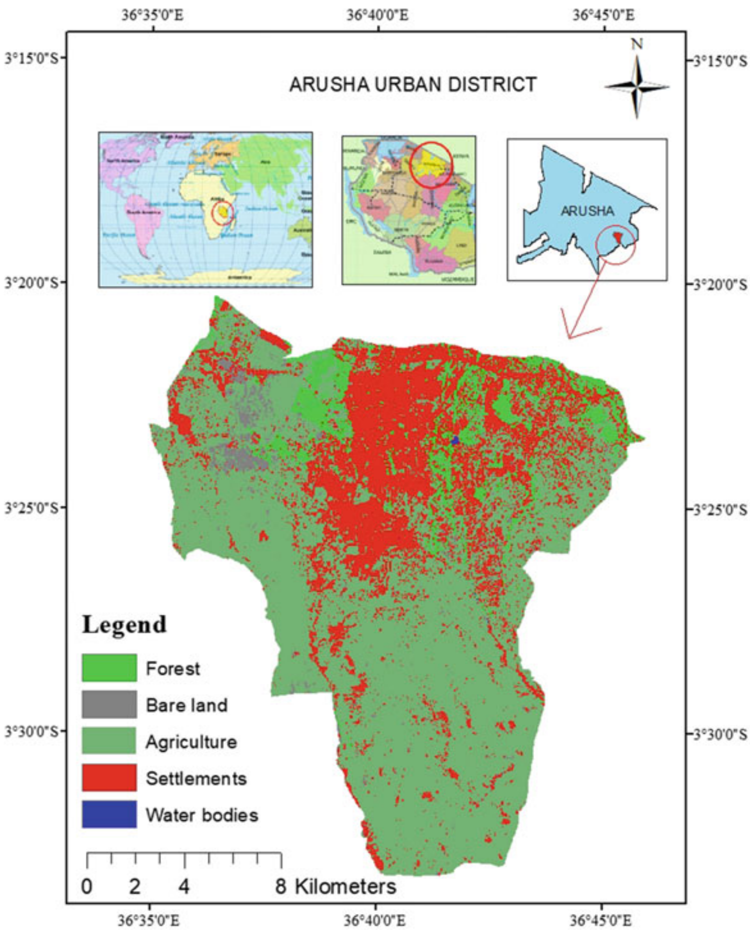

Fig. 27.1 Location and land use map of study area

of 1560 per square kilometre, while more than 70% of the city area falls under unplanned settlements (National Bureau of Statistics 2013).

27.2.2 Methodology

The present study is based on field visit done during May 2017, to acquire primary data of water scarcity status of the study region. The secondary data regarding the availability of rainfall, size and type of roof dominated on the area, population, water demand, etc., were collected from authorized respective departments and analysed with regard to methodological flow chart (Fig. 27.2) (Dwivedi and Bhadauria 2009; Panhalkar 2011).

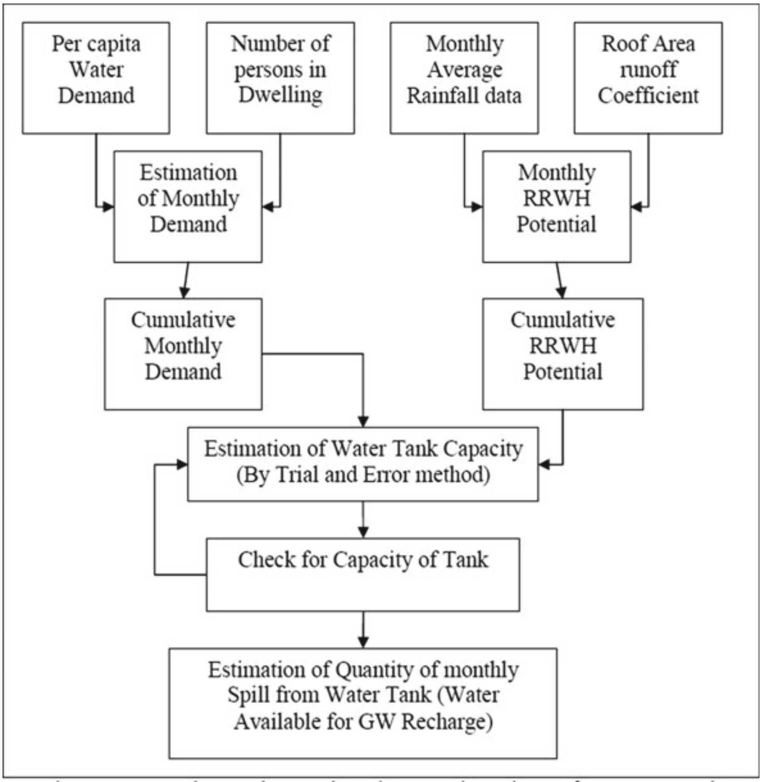

Fig. 27.2 Methodological flow chart (Dwivedi and Bhadauria 2009; Panhalkar 2011)

27.2.3 Roof-Top Rainwater Harvesting System Design and Planning

In a single household RRHW system, rainwater which falls from the roof-top of the building is conveyed to a storage tank suitably located on or under the ground, through a system of semi-circular channels of PVC or galvanized iron; so that it can be used during the period of water scarcity for domestic purpose. Usually this system is designed for drinking and cooking needs of an individual household level.

Slope of the roof tells how fast water runoff during a rain event will. Either it will shed runoff slowly or quickly depending on the pitch angle of a given particular roof. When angle of pitch increases, it causes water to move fast and reduces the risk of contamination to remain on the catchment surface area (Manyama 2006; Gupta and Khare 2016).

Calculation of roof catchment area is also referred to as the action of sizing a catchment area, whereby the “footprint” of the roof in an individual household is the base of calculating catchment size by finding the sum of built up area and its roof overhang. Therefore, the roof area as catchment will determine the probable amount of rainwater that can be harvested (Dwivedi and Bhadauria 2009; Pande and Telang 2014; Texas Water Development Board 2006). The catchment size ranges from 25 to 150 m^2, due to varying of the actual building surface area among family to family, house to house and their living standards dominated on the study area. Average household size is 4.0 based on 2012 census (National Bureau of Statistics 2013). This value is used to establish domestic water demand for a single household per day per month and per year.

27.2.4 Storage Capacity

The aspect of rainwater harvesting system design is very important to estimate minimum volume of storage for proper functioning of system (Gupta and Khare 2016; Pande and Telang 2014). It involves sizing of the rainwater tank required to store enough water to satisfy the appropriate household user’s demand. The minimum required volume of storage tank is a function of many variables like catchment surface area, rainfall distribution and coefficient of runoff fixed in the rainwater supply with regard to demand pattern.

27.2.5 Potential of Roof-Top Rainwater Harvesting

The roof-top potential rainwater is the quantity of rainwater harvested from all the rainy days to a particular roof within a period of one year. In general, potential RRWH is normally known as the annual roof-top yield of which it is referred to as the mathematical relationship between mean annual rainfall and size of the roof by considering to the runoff loss factor of less than 20% (Hatibu and Mahoo 2000; Manyama 2006).

Quantification of RRWH potential depends upon the total amount of rainfall, type of roofing materials and roof area (Dwivedi and Bhadauria 2009; Lizárraga-Mendiola et al. 2015; Panhalkar 2011). It is simply the product of annual rainfall and roof area, and it can easily be calculated by adopting the following empirical relationship; $\{= R * A * \text{Cr}\}$ (Dwivedi and Bhadauria 2009; Panhalkar 2011), whereby $S =$ rainwater harvesting potential (m^3), $R =$ mean annual rainfall (mm), $A =$ catchment area (m^2) and $\text{Cr} =$ runoff coefficient.

27.2.6 Estimation of Water Tank Capacity and Groundwater Recharge

An estimation sample of rainwater tank capacity with respect to dominated rooftop area to fulfil a single household drinking and cooking water demands has been calculated, by adopting the method proposed by Dwivedi and Bhadauria (2009) and Panhalkar (2011), as it is shown in Fig. 27.2. The quantity of rainwater obtained that exceeds the actual tank capacity is known as the overflow and used for recharging aquifer (Of et al. 2015; Hatibu and Mahoo 2000).

27.3 Results and Discussion

27.3.1 Land Use

Land use practices receive considerable attention across the whole world including Arusha region in Tanzania. Water Development Division defines land use concerns, the benefits attained from land activities, its management and natural environmental modifications done by human being into built environment like commercial and residential land fields for recreation, passage, pastures, etc. Currently, about 67.7% of the study area is considered arable farmland, with 2.9% in bare land, 5.1% forests and woodland and 23.9% settlement areas (Fig. 27.1).

27.3.2 Rainfall Pattern

The meteorological data from five rainfall stations have been averaged for 40 years (1970–2009) to identify rainfall patterns. The results show that the region exhibits two main seasons of rainfall, with long rains commencing from January to May and

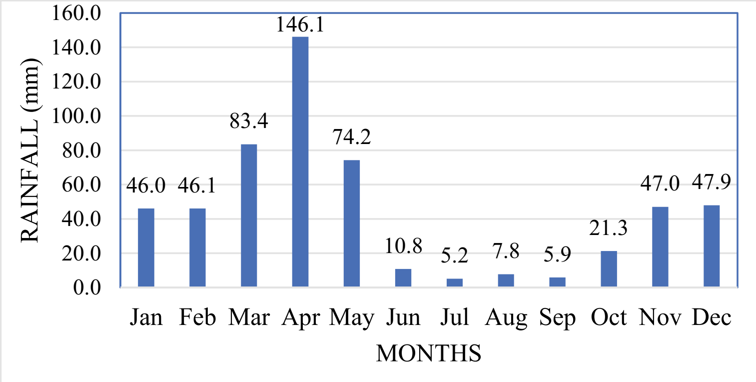

Fig. 27.3 Mean monthly rainfalls for five stations of the study area

the short rain from October to December. The amount of rainfall during the long rain months was observed to be higher than that of the short rain months for all the five stations. The wettest month for all the five stations was April followed by March and May for the long rain (*masika*) season (Fig. 27.3). There is very little rainfall during dry season commencing from June to October of which water becomes scarce. Mean rainfall amount during March, April and May has been found to be 83.4 mm, 146.1 mm and 74.2 mm, respectively, for long rain season as per Fig. 27.3. Similarly, for short rain season, mean rainfall amount during October, November and December has been observed to be 21.3 mm, 47 mm and 47.9 mm, respectively. The observations on Fig. 27.3 show that the study area experiences bimodal rainfall season, also revealed by other studies done. Hence, potential rainwater can be harvested during these two seasons.

27.3.3 Roof-Top Rainwater Harvesting System Design and Planning

Figure 27.4 recommends basic components of roof-top rainwater harvesting system which consists of a collection area (roof catchments), filter unit, cistern or storage facility and a conveyance system having gutters, down pipes and first flush diverter to prevent the entry of first monsoon shower in the storage tank which may contain roof contaminants.

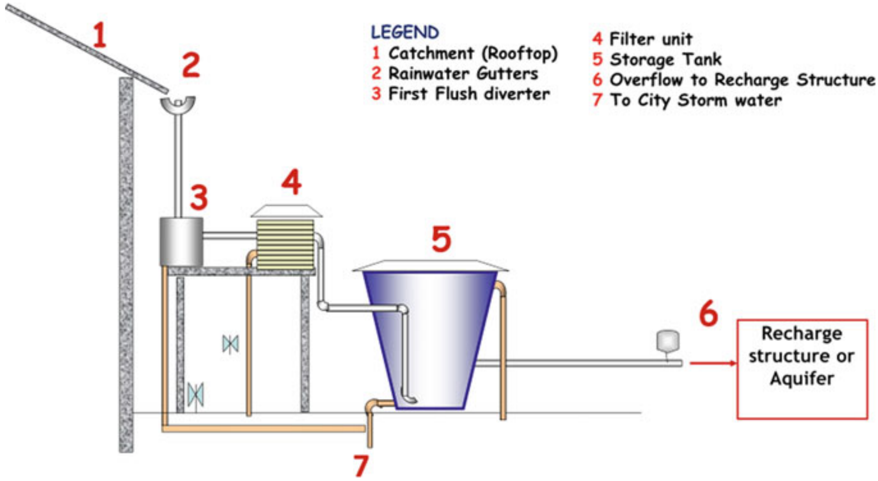

Fig. 27.4 Proposed schematic roof-top RWH system design flow diagram

27.3.4 Roofing Material

According to Tanzania Housing Board (THB) (NBS 2014; Takwimu 2010), 73.7% of houses were roofed with corrugated iron sheets, 17.4% of houses were roofed with dried grass/leaves, 7.8% of houses were roofed with mud and leaves, 0.5% of houses were roofed with tiles, 0.2% of houses were roofed with plastic material and same 0.2% of houses were roofed with asbestos, whereas concrete and box tent are used to roof 0.1% of houses each, as shown in the pie chart below. Roofing materials chart shown in Fig. 27.5 reveals that the most used type is corrugated iron sheets, and therefore, it is the most considered roof catchment material for rainwater harvesting

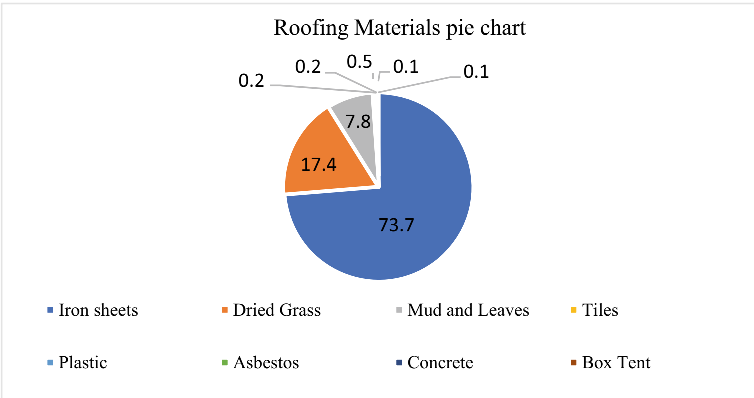

Fig. 27.5 Roofing material percentage distribution over the study area, Arusha region

in the study area. The literature also recommends a metal roof because they easily shed off contaminants within short period of time.

27.3.5 *Estimation of Water Tank Capacity and Groundwater Recharge*

An estimated sample of rainwater tank capacity for 50 m^2 roof-top area is shown in Table 27.1. Drinking and cooking water demand of four persons in a single family at 10 L per capita per day (Chandel and Sharma 2013), for each month, has been calculated. The demand at10 L per capita per day ranges from 1120 up to 1344 L per month as per Table 27.1. The cumulative demand of such family is also calculated in order to find out the total yearly water requirement of which it found to be 14,600 L. Similarly, a domestic water demand to fulfil a single family of four persons at 80 L per capita per day as per United Nations minimum requirement guide, for each month, has also been calculated. The demand has been found to be between 8920 and 9920 L per month. The overall cumulative domestic water requirement at 80 L per capita per day was found to be 116,800 L as total yearly water demand for a single family at 80 L per capita per day. The monthly roof-top rainwater harvesting potential of an individual house is estimated using mean monthly rainfall data of the study region by applying Gould and Nissen equation and presented on Fig. 27.6. The calculation on Table 27.1 shows monthly RRWH potential ranging from lowest 240 L for July to highest 7000 L for April month. The total RRWH potential is 24,960 and only 58.5 per is sufficient to satisfy a single household yearly water requirement at 10 L per capita per day. The graph of cumulative domestic water demand and cumulative potential RRWH for a complete cycle of months are shown in Fig. 27.7 with respect to Table 27.1, and it can be seen that potential RRWH is relatively high as compared to the cumulative domestic water demand.

End of each month quantity status of probable harvested rainwater available in the storage water tank is estimated from the difference between month-wise RRWH potential and water demands (Table 27.1). Monthly status of rainwater quantity available in the storage water tank was estimated to be 4000 L capacity for 50 m^2 roof areas as per Table 27.1, as shown in Fig. 27.6.

Dry season is between June to October, whereby rainfall is practically nothing in study area as per Table 27.1; hence, it is not enough to satisfy the total domestic water requirement throughout the year from potential RRWH of which water becomes scarce. Even during wet months, water demand cannot be met from roof having an area less than 75 m^2. Table 27.2 reveals that the gross water demand for wet months can be met from roof having area 75 m^2 and above.

Table 27.1 Estimating water tank capacity to fulfil household drinking and cooking water demand by DRWH and quantity of monthly water available for groundwater recharge from roof-top area 50 m^2

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Months	**Days**	**Averaged Rainfall**	**water demand (cooking & drinking) 10Lcpd @4soul**	**Cumulative water demand 10Lcpd @4soul**	**Overall water demand 80Lcpd**	**Cumulative Overall @80Lcpd demand**	**RWH potential**	**Cumulative RWH Potential**	**Monthly Potential Demand @10Lpcd**	**Surplus Column9 – Column 5**	**COMMENTS**	**End of Month Storage**	**DRWH Available for Ground Water Recharge**	**% of Total Demand Can Met from DRWH**
Jan	31	47	1240	1240	9920	9920	1880	1880	640	640	The drinking & cooking demand can be met from DRWH. The size of the storage tank = 3840~4000 Liters. The surplus water for GW Recharge = 10360 Litres.	640	0	18.95
Feb	28	35	1120	2360	8960	18880	1400	3280	280	920		280	0	15.63
Mar	31	81	1240	3600	9920	28800	3240	6520	2000	2920		2000	0	32.66
Apr	30	175	1200	4800	9600	38400	7000	13520	5800	8720		4000	4720	72.92
May	31	108	1240	6040	9920	48320	4320	17840	3080	11800		4000	3080	43.55
Jun	30	13	1200	7240	9600	57920	520	18360	-680	11120		3320	0	5.42
Jul	31	6	1240	8480	9920	67840	240	18600	-1000	10120		2320	0	2.42
Aug	31	8	1240	9720	9920	77760	320	18920	-920	9200		1400	0	3.23
Sep	30	7	1200	10920	9600	87360	280	19200	-920	8280		480	0	2.92
Oct	31	23	1240	12160	9920	97280	920	20120	-320	7960		160	0	9.27
Nov	30	60	1200	13360	9600	106880	2400	22520	1200	9160		4000	1200	25.00
Dec	31	61	1240	14600	9920	116800	2440	24960	1200	10360		4000	1200	24.60
TOT									**-3840**	**10360**			**10200**	

Note RRWH = Roof-top rainwater harvesting; DRWH = Domestic rainwater harvesting; RWH = Rainwater harvesting

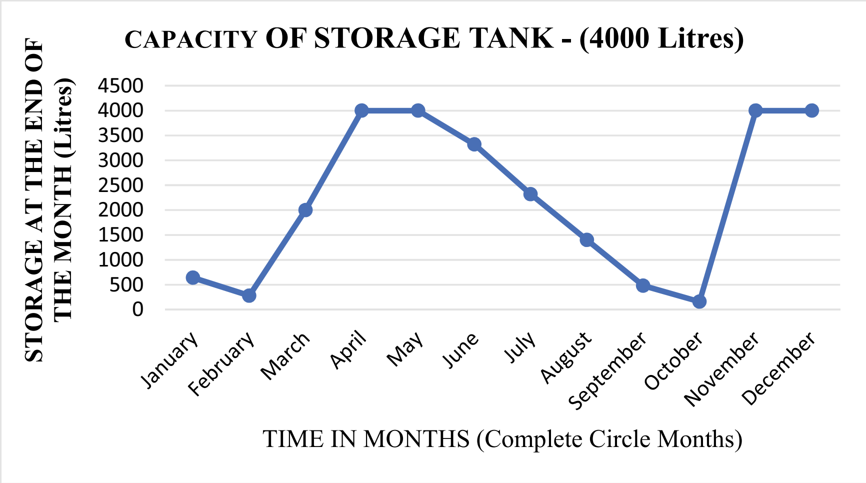

Fig. 27.6 Month-wise rainwater availability in storage tank throughout the year

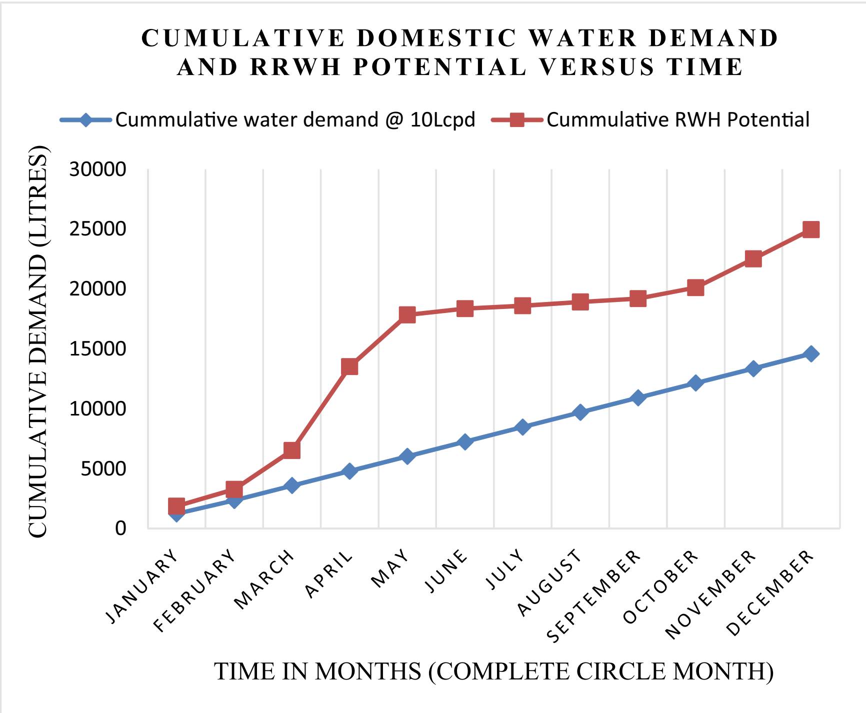

Fig. 27.7 Cumulative domestic water demand and cumulative potential RRWH for complete cycle months

Table 27.2 Water per cent demand fulfilled by domestic rainwater harvesting from different roof sizes

Month	Roof-top area in m^2				
	50	75	100	125	150
January	18.95	28.427	37.9	47.38	56.85
February	15.63	23.438	31.25	39.06	46.88
March	32.66	48.992	65.32	81.65	97.98
April	72.92	109.38	145.83	182.29	218.75
May	43.55	65.323	87.1	108.87	130.65
June	5.42	8.125	10.83	13.54	16.25
July	2.42	3.629	4.84	6.05	7.26
August	3.23	4.8387	6.45	8.06	9.68
September	2.92	4.375	5.83	7.29	8.75
October	9.27	13.911	18.55	23.19	27.82
November	25	37.5	50	62.5	75
December	24.6	36.895	49.19	61.49	73.79

27.4 Conclusion

The sustainability of rainwater supply in an individual household is assured by the size and capacity of the storage tank, while the quality of the harvested rainwater is assured by filter unit. In normal circumstances, filter unit and storage facilities are the critical components with high price in relation to the other components of RWHS, whereby the use of locally available materials diminishes the general cost of the systems.

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