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SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

Selecting an appropriate size for domestic rainwater tanks in Colombo*Guna Hewa, David Pezzaniti, Simon Beecham and Kapil Gupta*

Both India and Sri Lanka have experienced rapid population growth and migration to the major cities in the past decade. This rapid urbanisation has resulted in overstressing of existing water supply systems, with a loss of recharge areas and an increased depletion of groundwater. These effects have further aggravated the urban water crisis. During the monsoons, the existing drainage systems are overloaded and overflow thereby resulting in flooding causing severe damage to property. Sewage overflows often lead to the outbreak of epidemics and occasionally to the loss of life. Rainwater harvesting systems serve the dual purpose of water storage to reduce urban runoff peak flows as well as augmentation of the existing water supply systems. To achieve minimum costs while optimising the security of supply, rainwater tanks need to be sized taking the local rainfall conditions into consideration. This paper presents a methodology to determine the optimal size of rooftop storage based on historical rainfall data. Annual savings of in-house demand as well as the security of rainwater supply are discussed. The methodology is applied to Colombo in Sri Lanka. A case study is based on 150lpd household demand with 25m² of roof area in Colombo. The appropriate rainwater tank is determined to be 2000 L in capacity. The resulting water saving is 54% of annual in-house demand and more importantly, zero supply from the tank happens during only one third of the year.

Introduction

The countries located in the Indian subcontinent and South East Asia is characterized by rapid population growth and migration to the nearby cities. This is essentially a socio-economic phenomenon caused by the agrarian nature of the economies and their dependence on the monsoon rainfall. These migrations have resulted in overstressing of existing housing infrastructure as well as water supply and wastewater disposal systems in the cities. Also, the construction of housing estates and commercial areas with associated roads has resulted in loss of recharge areas and consequent depletion of groundwater levels. This has necessitated the transfer of water through large diameter pipelines over large distances from the available water sources. Sri Lanka and the southern state of Tamil Nadu in India receive almost 60 % of their rainfall from the North East Monsoon during October to February and the existing drainage systems are overloaded and overflow. This results in flooding causing severe damage to property. Consequently, sewer overflows also often lead to outbreaks of epidemics and occasionally loss of life.

Rainwater harvesting systems have been suggested as a solution to the urban water crisis. Most rainwater harvesting systems have been suggested as groundwater recharge systems and are most appropriate for publicly owned buildings where ownership is not an issue. However, there is very little incentive for the individual house owner to opt for a

rainwater harvesting system which recharges the groundwater as they are often not the direct beneficiary.

Rooftop rainwater systems have been proposed in this paper as they offer a direct benefit to the property owner as compared to groundwater systems where the benefits accrue elsewhere. Theoretically, if all the rainwater falling over built-up areas is collected, then the rainwater harvesting structures in these areas can serve the dual purpose of water retention to reduce connected impervious areas as well as storing harvested rainwater to supplement the existing water supply systems. However, it is not practical to capture all the rainwater, particularly at concentrated rainfalls events. Therefore, domestic rainwater harvesting is more for demand management purposes than flood mitigation.

Some of the traditional Sri Lanka stormwater harvesting systems are little more than a pot situated under a piece of cloth or plastic sheet tied at its corners to four poles. More sophisticated systems are available overseas. For example in Australia water recycling through Water Sensitive Urban Design (WSUD) is commonly in place. In such systems the water storage tank usually represents the biggest capital investment element of domestic rainwater harvesting (RWH) system. The Intermediate Technology Group (<http://www.itdg.org>) has published three methods of sizing RWH storages; all of them being based on a percentage mean annual rainfall volume. Procedures based on time increments longer than one day are generally less suitable for yield analyses

and time periods of less than one day are complex and more suitable for flood studies (Argue, 2005).

Another important factor is that rainfall is highly variable even within cities. For example, two rain gauges within a distance of 20 km of each other in Mumbai have a variation of 500 mm in the average annual rainfall. The percentage rainfall that contributes to storage tank inflow varies with roofing material, weather conditions such as sun exposure, wind, leakages etc. For the majority of cases rainwater tanks are covered and therefore evaporation losses are not significant. The National Health Forum (Cunliffe, 1998) recommends 80 to 85% while Argue et al. (2005) recommends 80 to 90% of total runoff as contributing to storage. The water demand patterns of individual households may vary depending on the lifestyles of the residents and these too have to be factored into the design methodology. Therefore, the gross 80% rule applied to mean annual rainfall in many countries, for instance Sri Lanka may result in an inappropriately under or oversized tank. A design methodology which could incorporate the above factors is necessary to achieve the best results in domestic stormwater harvesting.

Methodology

A daily time step water balance procedure which calculates daily inflows, outflows and changes in the volume of water in storage devices over a period of years is the basis of estimating the average annual harvest potential (yield) of a RoofRunoffHarvesting System (RRHS) (Argue, 2005). The simple model used to undertake the analysis incorporated several components that allowed for both constant (in-house) and variable (ex-house) demands.

Input requirements

Several input parameters are required to account for processes associated with the collection of roof runoff and water consumption (demand).

Daily rainfall

Depending on the type of analysis and output requirements, the minimum record length of the local historical daily rainfall data needed for yield analysis is 10 years.

Connected roof area

The roof area connected to a RRHS is the catchment area contributing to storage. In order to increase capture, the connected area should be as large as possible. However, it is not always feasible to connect the entire roof to single rainwater storage. Other components of the drainage area to be included are roofs to; verandahs, garages, carports and sheds.

Initial and first flush loss

The percentage rainfall that contributes to storage tank inflow varies with roofing material, weather conditions such as sun exposure, wind, leakages etc. Initial loss is defined as the amount of initial rainfall depth that is retained by the roof and conveyance system. It accounts for wetting

and absorption by the roof material and dead storage in the gutters and piping system. The magnitude of initial loss can be influenced by the evaporation characteristics between rainfall events. Therefore, in this model, an initial loss of 0.5mm, 1.0mm and 1.5mm is allocated for Iron, Terracotta and concrete roofing respectively.

Generally, the first portion of roof runoff is considered to have a relatively high proportion of suspended solids and associated pollutants, particularly after long dry spells or in environments where pollution buildup on the roof is rapid. It is a good practice to avoid collection of the initial runoff with a first flush device that typically has a volume of approximately 20 to 60 L (Australian Capital Territory, 2005)

Constant and variable demands

Constant demand, associated with in-house usage, is generally proportional to the number of people living in the dwelling. There are many in-house uses, however boiled rainwater is recommended for drinking water in Sri Lanka (Rainwater Harvesting Forum, <http://www.webasia.com/rainwaterharvesting>). Demand for showers, washing (clothes), cleaning (vehicles) is commonly managed by harvested domestic rainwater. However, in order to provide sufficient pressure to for showers, toilets etc, a pump is required which can switch between tank supply and mains when appropriate depending on water levels in the tank. Alternatively, mains water can be connected to the tank to maintain a minimum level.

Variable demand, associated with irrigation is closely linked to the climatic condition and the type and area of vegetated being irrigated. Average monthly irrigation values and vegetation areas are required to account for irrigation demand. In this design methodology, user can define the level of irrigation water requirements. However, the model only applies irrigation demand if there has been a specified period of 'no rain', typically two to three days.

Selection of appropriate rainwater tank size

Selecting an appropriate rainwater tank size can sometimes be difficult. However if the objectives for selecting a rainwater tank size are clearly defined, the task is simplified. In most instances there can be other sources (e.g. borehole water, reticulated community supply, etc) of water supply to the household. Where there is an additional source(s) the main objective is usually to achieve a suitable yield per unit storage. In cases where rainwater is the primary source, security of supply is generally the primary objective. Another objective not explored in this paper is minimizing the cost per unit supply. In this study, analysis has been undertaken to assess the selection of tank sizes based on yield performance and security of supply.

With yield analysis there is generally no optimum solution for the selection of tank size. It can be seen in Figure 1 that the yield/storage curve is not linear and does not exhibit a minimum or maximum point. However, for the range of tank sizes being assessed a linear yield/storage relationship

can be derived between the minimum and maximum tank sizes or by determining the average yield/unit storage increments. At some point along the yield/storage curve the slope (yield/unit storage) will be equal to the linear relationship. At this point a smaller tank size will result in increasing benefit and a larger tank will result in a decreasing benefit with respect to the linear relationship. In this study, benefit is measured in terms of average annual yield. This approach offers a method for selecting an appropriate size tank if yield per unit storage is the primary objective.

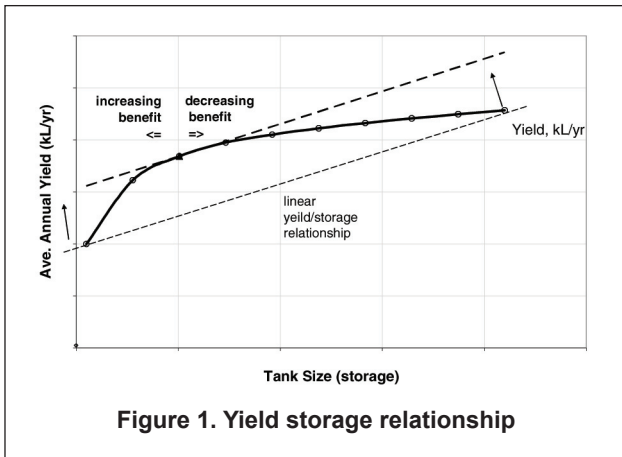


Figure 1. Yield storage relationship

Study area and data

Colombo, the commercial and administrative capital of Sri Lanka, is considered as a case study to demonstrate the methodology. Colombo is located on the west coast of the country and experiences an average annual rainfall of over 2000mm.

While the high annual rainfall data was the primary reason for selecting Colombo as a case study, there were a number of other reasons as well. Despite its continuous population growth and the associated commercial developments, a significant proportion of Colombo’s population does not have access to mains water.

Characteristics of the Colombo daily rainfall data

A total of 15 years of daily rainfall data for the period from 1991 to 2005 was used in this study. There were no significant gaps in the rainfall data. Summary statistics of daily, monthly and annual rainfall data for Colombo are presented in Table 1 and the seasonal variation of monthly data is presented in Figure 2.

Although mean annual daily rainfall is as low as 6.3mm, events as high as 285 mm of rainfall per day, which is equivalent to a 1 in 30 year annual maximum rainfall have also occurred within the last 15 years. As previously noted, for this reason, during Monsoon periods in Sri Lanka the existing drainage systems are overloaded well beyond their capacity, resulting in extreme flooding. These floods often cause severe damage to property and can lead to the outbreak of disease epidemics.

Table 1. Summary statistics of Colombo rainfall

	Daily	Monthly	Annual
Mean (mm)	6.3	199	2300
Standard deviation (mm)	15.7	164	316
Minimum (mm)	0	0	1921
Maximum (mm)	285	769	2888
Coefficient of Variation	2.5	0.82	0.14
Coefficient of Skewness	5.3	1.30	0.60

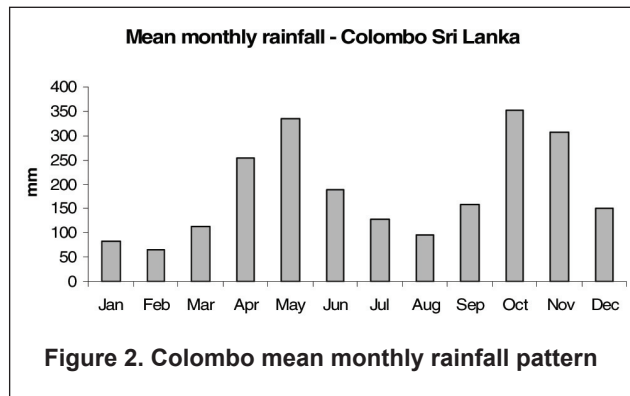


Figure 2. Colombo mean monthly rainfall pattern

From Figure 2, the periods from April to June as well as October to November bring greater percentages of total rainfall resulting in two peaks per year. Although both August and February bring relatively low rainfall, from the available 15 years of records it was found that August was the driest month of the year.

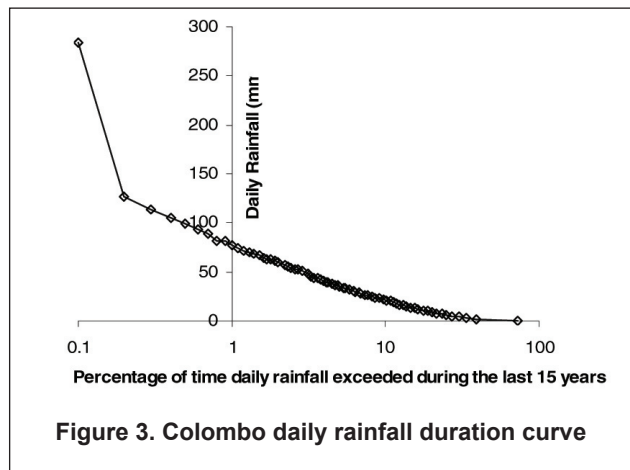


Figure 3. Colombo daily rainfall duration curve

From the rainfall duration curve presented in Figure 3, which was derived from 15 years of daily rainfall data, it was apparent that extreme rainfall events happened infrequently. For instance, in the last 15 years, the percentage of time that 50mm/day, 100mm/day and 150mm/day events occurred were 3, 0.5 and 0.2 respectively.

Daily demand

Daily demand is defined as the rate of water use on a daily basis. These uses may include clothes washing, showers, watering in the dry days and cooking. The demand is directly proportional to the number of household occupants. The Sri Lanka Rainwater Harvesting Forum (<http://www.rainwaterharvesting.com>), states that the per capita daily demand could vary from 25 to 100L with an average of 50L. According to Department of Census and Statistics (2003) the average number of household size is 4.3. More often, at some residences in Colombo, non-registered occupants who come from rural areas to live temporarily in the city area for employment or study purposes add more demand to the above values. Based on the above information, rainwater tank analyses were conducted for a range of total in-house daily demands varying from 100 to 200 litres per day (Lpd).

Roof area

Connected roof areas of typical residential residences may vary from 25m² to 75m² while more established residences could have roof areas as high as 150m² or greater. Roof cover is mainly manufactured from asbestos (49.5%), tiles (27.6%), metal sheets (10.2%) and concrete (8.4%) while the rest counts for unclassified and Cadjan (coconut tree-leaves) roofing (Department of Census and Statistics, 2003).

Applications

The rainwater tank model was applied to a number of roof area-demand combinations. Roof area was varied from 25m² to 100m² while in-house demand varied from 100 to 200 Lpd. As mentioned earlier, per capita daily demand in Colombo has been reported as varying from 25L to 100L with average of 50L (i.e. Average of 50lpcd). Therefore, the in-house demand adopted for the analysis was equivalent to demand of 4 to 8 people with 25lpcd or 2 to 4 people with 50lpcd demand. The results are summarized in the following section.

Results

Table 2. Model output

Variable	Output	Units
Rainfall input data years	15.0	yr
Average annual rainfall	2299	mm/yr
Average annual in-house demand	73	kL/yr
Average annual irrigation demand	0	kL/yr
Suggested tank size is approx.	2000	L
Average annual yield	40	kL/yr
Number of days with zero supply	123	days/yr
% of total demand supplied by tank	54	%

The three curves shown in Figures 4 and 5 represent daily households' demands of 100, 150 and 200L respectively. If the households implement recommended tank sizes based on contributing roof sizes and the demands (Table 3), the amount of rainwater that can be harvested or the amount of mains water that can be saved is provided in Figure 4. Similarly, if a household decided to use a recommended tank size based on roof sizes and the demands characteristics shown in Table 3, the average number of days in year with zero harvesting is shown in Figure 5.

Table 3. Recommended sizes of Roof Runoff Storage tank for a range of demand rates and roof areas for Colombo

Households' Demand (Lpd)	Roof Size (m ²)	Tank Size (L)
100	25	1500
100	50	2600
100	75	4000
100	100	5000
150	25	2000
150	50	2600
150	75	4000
150	100	5000
200	25	2000
200	50	2600
200	75	4000
200	100	5000

Relationships presented in Figure 6 are to demonstrate how far each household can improve the security of water supply by selecting a recommended tank sizes (Table 3). The 'before' case displays how frequently the household experiences consecutive d-days ($1 < d < 30$) with roof runoff below 80% of the households' daily demand. The 'after' case show how frequently the household experiences consecutive d-days ($1 < d < 30$) with tank outflow below 80% of households' daily demand. The dotted line (y-axis in the left-hand side of the Figure) displays the percentage reduction in the number of d-day dry spells.

For a household with a roof area of 25m² and daily demand of 200 L the recommended storage is 2000 L (Table 3). Consequently, average water savings are around 40 kL/year, which is equivalent to 54% of the annual household usage. On average there could be 120 days with no supply from the tank. However, having selected 2000 L capacity storage, the household experiences only ten 10-day dry spells over the

last 15 years as opposed to the twenty experienced without rainwater harvesting systems in place. This represents a 50% improvement in the security of supply.

The population of the city of Colombo is expected to be one million by the year 2010 (<http://www.buildsrilanka.com>). The population density is expected to be 268 persons per hectare. Therefore in-house water demand in the City of Colombo will be over 25 million litres per day and 9000 million litres annually. If a rainwater harvesting system deliv-

ers 54% of yield and if 50% of the households install such rainwater harvesting systems by 2010, the demand on mains water can be reduced by over 2400 million litres.

Conclusions

This paper has presented a basic method for rainwater tank sizing for the city of Colombo. The work has shown clearly that rainwater harvesting can provide a viable alternative water supply stream. Even for the relatively small roof areas that are typical in Colombo, quite small tank storages (2 KL) are required because of the high rates rainfall experienced by the region. However rainfall seasonality does have a major influence on tank size selection.

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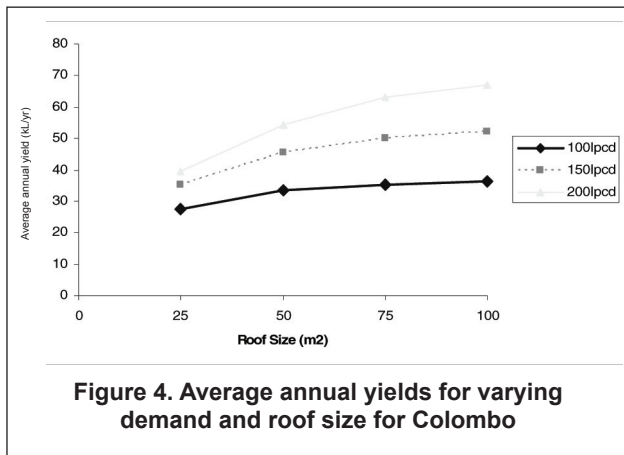


Figure 4. Average annual yields for varying demand and roof size for Colombo

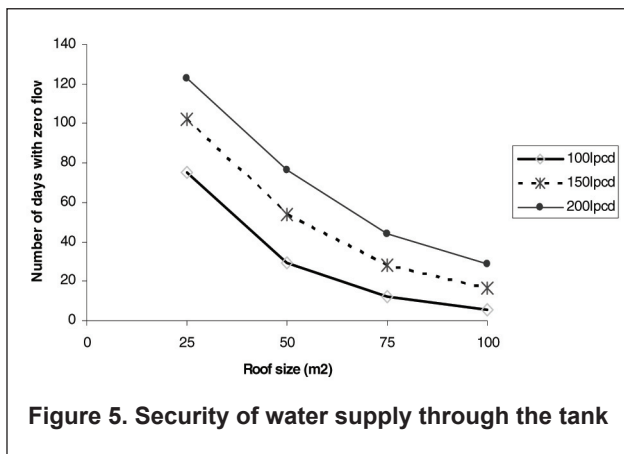


Figure 5. Security of water supply through the tank

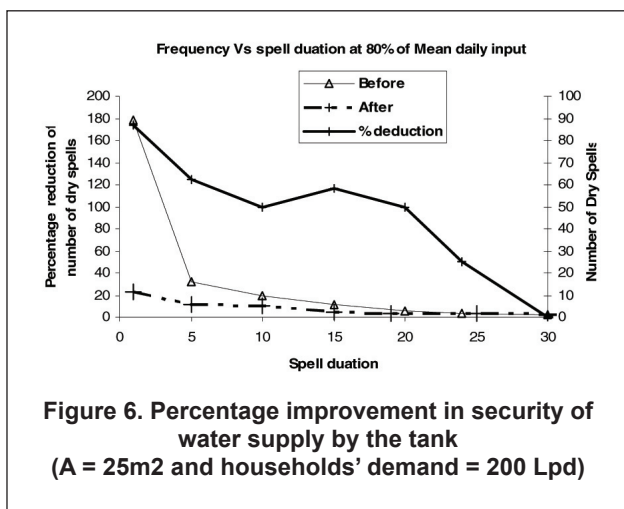


Figure 6. Percentage improvement in security of water supply by the tank (A = 25m2 and households' demand = 200 Lpd)

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