Potential for Domestic Rooftop Rainwater Harvesting In the District of Colombo, Sri Lanka

S. Sendanayake
Department of Civil Engineering, South Asian Institute of Technology and Medicine, Malabe, Sri Lanka

Abstract: With the increase of urban and suburban population and the rising living standards, the domestic per capita consumption and hence the demand on the centralized reticulated water supply is on the rise in the district of Colombo where both the administrative and commercial capitals of Sri Lanka are located. Even though the district is receiving relatively high annual average rainfall in a bimodal pattern through the year, temporal variations cause occasional dropping of water levels at the main intake sources; the 'Kelani' river and 'Labugama-Kalatuwawa' reservoirs compelling restriction of supply. In addition, frequent disruptions to water supply due to repairs needed on a centuries old distribution system, poorly coordinated public constructions and rising cost in water treatment and distribution requires a serious approach into the widespread use of Rooftop Rain Water Harvesting (RRWH) at domestic level, not only increasing the domestic water security but allowing the householders to manage both supply and demand of water they use. This study focuses on the potential for RRWH at domestic level in Colombo district, based on the socio-economic indicators such as the current supply situation, cost and benefits that can be anticipated.

Key words: Reticulated, rooftop, rainwater harvesting, Colombo, bimodal, temporal

1. Introduction

Colombo, with a land extent of 699 km² is the smallest among the 25 districts of the tropical island country of Sri Lanka (Fig. 1). The district is bordering the Indian Ocean to the west with low topological variations in the landscape experiencing an annual average rainfall of 2500 mm in a bimodal pattern corresponding to South-West and North-East monsoons during June-August and December-February respectively. In addition, two inter-monsoonal periods from September-October and April-May bring in convective showers resulting in well spread year round rainfall. Due to the location of both the administrative and commercial capitals, Colombo is the most populous district in Sri Lanka with a population of 2.3 million or 11.4% of the total population of the country at a population density of 3300 people per km². Of the total, 78% of the population in the district can be considered as urban dwellers while the rest are in the suburbs [3].

Figure 1a: Colombo District

Figure 1b: Boundaries of Colombo district (Google maps)

In the district, 84% of all housing units are single storey detached type in diffuse settings and 14% are of two or more storey. Of all housing units in the district 82.9% are owned by the householder and 97.7% of the houses are provided with electricity [3]. Roofing materials used are mainly of asbestos-cement concrete at 64.6%, clay tiles 21% while concrete and GI sheeting make up the rest. Of all the housing units in Colombo district over 90% are fitted with water seal toilets while the rest are having common sanitation facilities.

The number of occupants per housing unit is found to be 3.9 with a possible downward trend in the
future due to low population growth at 0.35%. It is important to note that in Sri Lanka, legislation has been introduced in 2007, as an act, amending the Urban Development Authority (UDA) law to formulate a scheme for RWH to be included in the building development plan in keeping with the national rainwater policy and strategies. This paper outlines the current water supply issues in Colombo district, the factors that could influence the widespread acceptance and use of domestic Roof top Rain Water Harvesting (RRWH) systems and the models currently available which would suit the requirements.

2. Demand and supply of water for domestic dwellings in Colombo district

The district has seen an increase of population from 1.7 million to 2.3 million people, an increase of 600,000 people in absolute terms but the annual population growth rate has been steadily dropping from 1.43% during 1981-2001 to 1.05% during the period 2001-2012. The average number of people per household has dropped from 5.3 to 3.9 during the 30 year period from 1981-2012 [3].

2.1 Domestic demand on water

With the increase of sanitation facilities, better awareness of personal hygiene and the use of modern amenities and equipment such as washing machines etc, the per capita consumption of water has seen a marked increase from 65 liters in 1991 to current 100 liters. The usage has increased by as much as 35% and it is likely that the additional requirement has gone to car washing and garden watering, activities not requiring treated water. However, it appears that the decrease in the average number of occupants to 3.9 has helped maintain the daily water demand per household to approximately 400 liters. The breakdown of daily water consumption in a typical household in Colombo district is shown in Figure 2 indicating that 65% of the demand is for non potable uses [12].

2.2 Water supply in Colombo district

By 2012, 93.6% of all houses in the district have been supplied with pipe borne water by the National Water Supply and Drainage Board (NWSDB) and related government authorities using surface water abstracted from ‘Kelani’ river 10 km upstream of sea and freshwater reservoirs inland. The leakage in distribution, where some sections of the network centuries old is reported to be high, but the actual figures are unavailable. It is reported that the cost of operation and maintenance of the water supply distribution network in 2015 to be of SLR 21.4 billion [1].

Frequent disturbance to supply also occurs due to maintenance works, construction of public road/highways and when laying of telecommunication lines. Climate change and deforestation in catchment areas have affected the water levels in the main sources of water to the district in recent times resulting in restrictions in the supply occasionally. In addition, sand mining which affects the yield in downstream intake points, soil erosion and intrusion of saline water into intake points as a result of lowering of river water level remains concerns.

Highly subsidized, the cost of water in Colombo district is low, as shown in Table 1. One unit is 1 m³. Currency conversion rate; US$ 1 = SLR 145.

<table>
<thead>
<tr>
<th>Tariff block (units)</th>
<th>Price per unit (SLR)</th>
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<tr>
<td>0-5</td>
<td>8.00</td>
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<tr>
<td>6-10</td>
<td>11.00</td>
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<td>11-15</td>
<td>20.00</td>
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<td>16-20</td>
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<td>21-25</td>
<td>58.00</td>
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<tr>
<td>26-30</td>
<td>88.00</td>
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<td>31-40</td>
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<td>41-50</td>
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<tr>
<td>51-75</td>
<td>130.00</td>
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<td>Above 75</td>
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A few small-scale private water schemes are also in existence in the district, particularly catering to housing schemes in the suburbs drawing water mostly from deep wells. Water quality is seen as the main concern in these schemes where the poorly treated or untreated supplies at risk from pollution. In the suburban areas of the district, wells dug in the past are still in existence despite the availability of centralized reticulated supply. However, the wells are fast contaminating, if not already contaminated and therefore mostly in disuse.

3. Factors influencing the use of domestic RRWH systems in Colombo district

The key influencing factors can be identified as demand exceeding supply as a result of depletion of surface water, the current use of treated water for non-potable purposes and the escalating treatment and distribution cost.
3.1 Increase of demand

With the end of decades long civil war and rising income levels, the construction of new housing units is on the increase, particularly in Colombo district, requiring new water connections hence expansion of the existing network. In addition, the expansion of a robust commercial construction and manufacturing industry could increase the demand well above current supply levels, particularly in the face of the depletion of available surface water sources.

3.2 Use of treated water for non-potable purposes

From Fig. 2, it can be seen that at domestic level more than 65% of the total consumption is for non-potable use such as toilet flushing, laundry, car washing etc, for which high quality treated water is not necessary.

4. Domestic RRWH systems

It has been long proposed that introduction of RRWH systems at domestic level to help households reduce the dependency on the centralized supply to maintain water security while reducing the cost on water. RRWH systems typically consist of a catchment area to capture precipitation, a conveyance system to direct the runoff to the storage and a tank to store rainwater to be used during dry spells. Roofs are the ideal catchment and with 85.6% of the houses in the district having asbestos cement concrete sheeting and clay tiles for which the collection efficiency is reported to be of 80-85% [15], no additional cost is incurred for the catchment. Further, with guttering and downspouts in place in majority of the houses, the conveyance system can be considered as already in place. Generally, semi-circular gutters have been recognized as the most efficient at conveying water with a minimum 1 cm² gutter cross sectional area for every 1 m² of roof area [5]. In the face of frequent high intensity rainfall experienced by the district, installing of flash guards is recommended to minimize spillage from gutters.

4.1 Sizing the storage tank

It is the storage tank that has to be constructed at site or retrofitted, costing the most, hence needing optimization of size and prudent selection of cost effective materials having the least impact on the environment. The storage tank should be able to provide uninterrupted supply of water even during dry weather spells hence requiring optimum sizing depending on rainwater supply and demand. Many methods have been developed to size the tank and the graphs developed for Sri Lanka using system performance simulation [13] can be used to determine the most effective combination of roof catchment area and storage capacity for a desired Water Saving efficiency (WSE) level. WSE value indicates the supply reliability of the system as a percentage of demand and the graph corresponding to annual average rainfall depth of 2500 mm suits the system sizing in Colombo district [13]. For example, a house with 100 m² of roof area would be requiring 6 m³ capacity storage tank to supply a daily requirement of 400 liters of water at 95% reliability. For different daily demand values the corresponding effective combinations of roof area and tank capacity can be found by varying the area and capacity by the same percentage change that of the demand [13]. For sub-surface positioning, cylindrical shaped RCC tanks are recommended over rectangular shaped ones for better withstand of soil pressure. As for the tank material, though low cost High Density Poly Ethylene (HDPE) tanks are commercially available at lower prices, recent studies have indicated that cast-in-place Reinforced Cement Concrete (RCC) tanks having lower Life Cycle Energy (LCE) and Life Cycle Cost (LCC) values, thus having a lower impact on the environment [11]. In accordance with the limited availability of space in Colombo district where the population density is the highest in Sri Lanka, the tanks can be preferably positioned sub-surface, thus preventing physical and aesthetic disturbance to the building envelop. In such cases, RCC is cheaper as HDPE tanks require an enclosure with retaining
walls to prevent wet soil pressure collapsing its thin walls [10].

An optimized RRWH system can provide as much as 95% of the daily demand of water [12] and for the draw-off a centrifugal or positive displacement pump can be used as 97% of the housing units are supplied with grid power. As the pumping requirement is low, pumps of low power ratings can be used to lift the collected rainwater to a header tank for the water to be supplied to service points through gravity. Currently, as a precautionary measure against frequent disruptions and poor supply pressure in the public water supply, most of the houses are fitted with an overhead tank of either RCC, HDPE or brick masonry which can be utilized as the header tank in RRWH systems without incurring an additional cost.

4.2 Multi tank models

The cost of pumping can be further reduced if the storage capacity can be distributed at two or more levels in cascading multi tank arrangements [7]. In this method, the roof collection is to first enter a smaller capacity (1 m³) upper tank located at the eave level and the overflow of which to cascade down to a sub-surface larger capacity parent tank. The supply to service points is from the upper tank with pumping from the sub-surface parent tank to make up the deficit as and when needed. The activation of the pump can be through a floater switch arrangement monitoring the water level of the upper tank. Since most of the houses are of single or two storey type, the cascading two tank model [8] can be used effectively cutting down the power consumption by as much as 60% [9].

4.3 Quality of rainwater

Rainwater typically is of low pH value of 5.9 but in certain instances could drop to as low as 5.6 depending on the air quality. It is possible for the pH value of rainwater in Colombo district to be in the range of 5.6 to 5.9 due to its high population density and industrial zones. However, if stored in RCC tanks, the acidity would be neutralized due to Calcium leaching from cement. In this scenario, the CaCO₃ content increases, referred to as carbonate alkalinity, induced by carbon dioxide dissolved in water reacting with calcium hydroxide in the hydrated cement paste in the RCC tanks. Still dust, contaminants from vehicle exhaust fumes and bird droppings on the catchment surface could introduce pathogens and coli form bacteria posing a health risk to the user thus preventing widespread use of rainwater for potable use.

The quality of harvested rainwater depends on the cleanliness of the catchment and local air quality. High volume of vehicles in the district cause considerable air pollution with increased emissions. Introduction of a First Flush (FF) device, which can be used to prevent the initial collection of rainwater after a dry spell entering the storage tank, however, can reduce the risk considerably. It is reported that a FF device removing the first 1 mm of rain could reduce contaminants by as much as 90% [2]. A FF device can be of a simple design with the downspout feeding the tank extended to accommodate the initial roof runoff (Fig. 3).

Figure 3: Schematic drawing of a First Flush device

Roof runoff stored in an air tight tank is reported to maintain reasonable quality up to 4 months if the tank can avoid both light and organic matter causing gradual die-off of bacterial pathogens. Harvested rainwater can be treated by Chlorination improving its microbiological quality. Chlorination is cheap and can be used to deactivate most micro organisms but should be applied after the harvested rainwater has been removed from the storage tank to prevent forming of undesirable by-products reacting with organic matter [14]. The effective level of Chlorine is reported to be 0.4 – 0.5 mg/l of free chlorine which can be applied as tablets or solutions [14]. Slow sand filtering can be used to remove most of the nutrients from collected rainwater improving its bacteriological quality. However, this method, though cheaper in operation would not make rainwater fit to drink. It is reported that this technique is of limited use when the concentration of suspended solids is more than 10 mg/l [14]. Coupling of a membrane filtration and a disinfection system can also be used and in some cases collected rainwater can be sent through a series of sand and carbon filters followed by a UV sterilizer to minimize the health risk. However, in such cases, supply pressure of collected rainwater has to be increased as the filters require higher operating pressure.
4.4 Cost of domestic RRWH systems

Since the existing roofs as catchments and guttering as conveyance system can be used effectively, the cost of these components can be excluded from the overall system cost. Therefore, the cost of the storage tank and the pump are the components that should be under consideration. At current prices, 5 m³ capacity commercially available HDPE tank capable of catering to a daily demand of 400 liters at 95% WSE is the cheapest while similar capacity sub-surface RCC tank cast-in-place could cost SLR 125,000 – 150,000. However, HDPE tank if placed sub-surface enclosed in retaining walls costing a similar amount. Since the amount of daily pumping required and Total Dynamic Heads (TDH) are very low, pumps of low power rating and delivery rates can be used which are low in price.

5. Conclusions

Colombo district, the most populous in Sri Lanka, is experiencing growing supply stress in service water as a result of increase in demand and depletion of surface water levels due to climate change. With the majority of houses are of detached types in diffuse settings owned by the householders, there is a high potential for domestic RRWH that could result in increased water security for the residents. In addition, the roofs of most houses are ideal as catchment areas using materials with high runoff coefficients and the existence of necessary infrastructure such as sumps, header tanks, guttering and downspouts readily supporting implementation of RRWH. Energy efficient RRWH systems such as the multi-tank model could cut down the operational cost by as much as 60% and simple and cost effective safeguards for contaminants such as FF devices and disinfection methods such as Chlorination can be used to minimize health risks. However, harvested rainwater, without intensive treatment is not recommended for potable uses but could be used for non-potable uses estimated to be 65% of the daily usage, reducing the burden on reticulated supply and minimizing the household cost on water. Though the payback periods could be high due to current subsidized price of water, the durability and the marginal operational costs of RRWH systems encourage widespread use. Importantly, the opportunity for the owner to manage the water requirements in a decentralized setting could help consideration of water as a valuable resource that could reflect well in long term sustainability.

References