6

Analysis of Potable Water Savings Using Behavioural Models

Marcelo Marcel Cordova and Enedir Ghisi
Federal University of Santa Catarina, Department of Civil Engineering, Laboratory of Energy Efficiency in Buildings, Florianópolis – SC
Brazil

1. Introduction

The availability of drinking water in reasonable amounts is currently considered the most critical natural resource of the planet (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2003). Studies show that systems of rainwater harvesting have been implemented in different regions such as Australia (Fewkes, 1999a; Marks et al., 2006), Brazil (Ghisi et al., 2009), China (Li & Gong, 2002; Yuan et al., 2003), Greece (Sazakli et al., 2007), India (Goel & Kumar, 2005; Pandey et al., 2006), Indonesia (Song et al., 2009), Iran (Fooladman & Sepaskhah, 2004), Ireland (Li et al., 2010), Jordan (Abdulla & Al-Shareef, 2009), Namibia (Sturm et al., 2009), Singapore (Appan, 1999), South Africa (Kahinda et al., 2007), Spain (Domènech & Saurí, 2011), Sweden (Villareal & Dixon, 2005), UK (Fewkes, 1999a), USA (Jones & Hunt, 2010), Taiwan (Chiu et al., 2009) and Zambia (Handia et al., 2003).

One of the most important steps in planning a system for rainwater harvesting is a method for determining the optimal capacity of the rainwater tank. It should be neither too large (due to high costs of construction and maintenance) nor too small (due to risk of rainwater demand not being met). This capacity can be chosen from economic analysis for different scenarios (Chiu et al., 2009) or from the potential savings of potable water for different tank sizes (Ghisi et al., 2009).

Several methodologies for the simulation of a system for rainwater harvesting have been proposed. The approaches commonly used are behavioural (Palla et al., 2011; Fewkes, 1999b; Imteaz et al., 2011; Ward et al., 2011; Zhou et al., 2010; Mitchell, 2007) and probabilistic (Basinger et al., 2010; Chang et al., 2011; Cowden et al., 2008; Su et al., 2009; Tsubo et al., 2005).

One advantage of the behavioural methods is that they can measure several variables of the system over time, such as volumes of consumed and overflowed rainwater, percentage of days in which rainwater demand is met (Ghisi et al., 2009), etc. The main disadvantage of these methods is that as the simulation is based on a mass balance equation, there is no guarantee of similar results when using different rainfall data from the same region (Basinger et al., 2010). This problem can be avoided, in part, with the use of long-term rainfall time series.

Probabilistic methods have the advantage of their robustness, for example, by using stochastic precipitation generators. A disadvantage of these methods is their portability. Several models adequately describe the rainfall process in one location but may not be satisfactory in another (Basinger et al., 2010).

A way of comparing different models for rainwater harvesting systems is by assessing their potential for potable water savings and optimal tank capacities.
The objective of this study is to compare the potential for potable water savings using three behavioural models for rainwater harvesting in buildings. The analysis is performed by varying rainwater demand, potable water demand, upper and lower tank capacities, catchment area and rainfall data.
Studies which consider behavioural models generally use either Yield After Spillage (YAS) or Yield Before Spillage (YBS) (Jenkins et al., 1978). This study aims to compare them with a software named Neptune (Ghisi et al., 2011). A method for determining the optimal tank capacity will also be presented based on the potential for potable water savings.

2. Methodology

Behavioural methods are based on mass balance equations. A simplified model is given by Eq. (1).

$$V(t) = Q(t) + V(t-1) - Y(t) - O(t) \tag{1}$$

where V is the stored volume (litres), Q is the inflow (litres), Y is the rainwater supply (litres), and O is the overflow (litres).
The software named Neptune was used to perform the simulations. YAS and YBS methods were implemented only for simulations in this research, but they are not available to users.
Neptune requires the following data for simulation: daily rainfall time series (mm); catchment area (m^2); number of residents; daily potable water demand (litres per capita/day); percentage of potable water that can replaced with rainwater; runoff coefficient; lower tank capacity; and upper tank capacity (if any).
For each day of the rainfall time series, Neptune estimates: the volume of rainwater that flows on the catchment surface area, the stored volume in the lower tank (at the beginning and end of the day), the overflow volume and the volume of rainwater consumed. If an upper tank is used, the volume stored in the upper tank and the volume of rainwater pumped from the lower to the upper tank are also estimated.
The volume of rainwater that flows on the catchment surface is estimated by using Eq. (2).

$$V_{catch}(t) = P(t) \cdot S \cdot C \tag{2}$$

where V_{catch} is the volume of rainwater that flows on the catchment surface (litres); P is the precipitation in day t (mm); S is the catchment surface area (m^2); C is the runoff coefficient (non-dimensional, $0 < C \leq 1$).
The methods Neptune, YAS and YBS differ in the way stored volumes are calculated and pumped. Details about them are shown as follows.

2.1 Neptune

The volume of rainwater stored in the lower tank at the beginning of a given day is calculated using Eq. (3).

$$V_{in\,low}(t) = min\begin{cases} V_{low\,tank} \\ V_{catch}(t) + V_{end\,low}(t-1) \end{cases} \tag{3}$$

where $V_{in\ low}(t)$ is the volume of rainwater stored in the lower tank at the beginning of day t (litres); $V_{low\ tank}$ is the capacity of the lower tank (litres); $V_{catch}(t)$ is the volume of rainwater that flows on the catchment surface on day t (litres); $V_{end\ low}(t)$ is the volume of rainwater available in the lower tank at the end of the day (litres).

Next, the volume of rainwater that can be pumped to the upper tank is calculated by using Eq. (4).

$$V_{pump}(t) = min\begin{cases} V_{in\ low}(t) \\ V_{up\ tank} - V_{end\ up}(t-1) \end{cases} \tag{4}$$

where $V_{pump}(t)$ is the volume of rainwater pumped on day t (litres); $V_{in\ low}(t)$ is the volume of rainwater stored in the lower tank at the beginning of day t (litres); $V_{up\ tank}$ is the capacity of the upper tank (litres); $V_{end\ up}(t-1)$ is the volume of rainwater available in the upper tank at the end of the previous day (litres).

The volume of rainwater available in the lower tank at the end of a day is defined as the difference between the volume of rainwater in the beginning of the day and the volume that was pumped (Eq. (5)(4)).

$$V_{end\ low}(t) = V_{in\ low}(t) - V_{pump}(t) \tag{5}$$

where $V_{end\ low}(t)$ is the volume of rainwater available in the lower tank at the end of day t (litres); $V_{in\ low}(t)$ is the volume of rainwater stored in the lower tank at the beginning of day t (litres); $V_{pump}(t)$ is the volume of rainwater pumped on day t (litres).

The volume of rainwater available in the upper tank at the beginning of a given day (after pumping) is given by Eq. (6).

$$V_{in\ up}(t) = V_{end\ up}(t-1) + V_{pump}(t) \tag{6}$$

where $V_{in\ up}(t)$ is the volume of rainwater available in the upper tank at the beginning of day t (litres); $V_{end\ up}(t-1)$ is the volume of rainwater available in the upper tank at the end of the previous day (litres); $V_{pump}(t)$ is the volume of rainwater pumped on day t (litres).

The volume of rainwater consumed daily depends on rainwater demand and volume stored in the upper tank; it is calculated by using Eq. (7).

$$V_c(t) = min\begin{cases} D(t) \\ V_{in\ up}(t) \end{cases} \tag{7}$$

where $V_c(t)$ is the volume of rainwater consumed in day t (litres); $D(t)$ is the rainwater demand in day t (litres per capita/day); $V_{in\ up}(t)$ is the volume of rainwater available in the upper tank at the beginning of day t (litres).

The volume of rainwater available in the upper tank at the end of a given day is obtained by using Eq. (8).

$$V_{end\ up}(t) = V_{in\ up}(t) - V_c(t) \tag{8}$$

where $V_{end\ up}(t)$ is the volume of rainwater available in the upper tank at the end of day t (litres); $V_{in\ up}(t)$ is the volume of rainwater available in the upper tank at the beginning of day t (litres); $V_c(t)$ is the volume of rainwater consumed on day t (litres).

The potential for potable water savings results from the relationship between the total volume of rainwater consumed and the potable water demand over the period considered in the analysis, according to Eq. (9).

$$E_{pot} = 100 \cdot \sum_{t=1}^{T} \frac{V_c(t)}{D(t) \cdot N} \tag{9}$$

where E_{pot} is the potential for potable water savings (%); $V_c(t)$ is the volume of rainwater consumed on day t (litres); $D(t)$ is the rainwater demand on day t (litres per capita/day); N is the number of inhabitants; T is the period considered in the analysis (the same as the duration of the rainfall time series).

2.2 YAS

In the YAS method, the volume of rainwater collected will be consumed only in the next day. Thus, in systems where there is an upper and a lower tank, rainwater will be pumped at the beginning of the next day (Chiu & Liaw, 2008).

When considering the use of an upper tank, the difference between YAS and Neptune resides only in calculating the volume of rainwater pumped. It can be seen, in Eq. (10), that YAS method considers the volume stored in the tank at the previous day.

$$V_{pump}(t) = min \begin{cases} V_{in\,low}(t-1) \\ V_{up\,tank} - V_{end\,up}(t-1) \end{cases} \tag{10}$$

where $V_{pump}(t)$ is the volume of rainwater pumped on day t (litres); $V_{in\,low}(t-1)$ is the volume of rainwater stored in the lower tank at the beginning of the previous day (litres); $V_{up\,tank}$ is the capacity of the upper tank (litres); $V_{end\,up}(t-1)$ is the volume available in the upper tank at the end of the previous day (litres).

The other equations are identical to those presented for Neptune.

2.3 YBS

In Neptune and YAS methods, the available volume of rainwater at the end of a given day is estimated by using Eq. (8). Thus, it is possible to notice that the tank is never full at the end of the day, no matter the amount of rainwater available.

The main feature of the YBS method is the possibility that this gap does not exist. When using both upper and lower tanks, a way to fill the upper tank is pumping rainwater two times a day; the first time before or during consumption and the second one after consumption (usually at night).

For YBS method, the volume of rainwater stored in the lower tank at the beginning of day t is the same as that for Neptune and YAS, given by Eq. (3).

Thus, according to YBS method, the first volume of rainwater to be pumped is calculated by using Eq. (11).

$$V_{pump}(t) = min \begin{cases} V_{in\,low}(t) \\ V_{up\,tank} - V_{end\,up}(t-1) \end{cases} \tag{11}$$

where $V_{pump}(t)$ is the volume of rainwater pumped on day t (litres); $V_{in\,low}(t)$ is the volume of rainwater stored in the lower tank at the beginning of day t (litres); $V_{up\,tank}$ is the volume

of the upper tank (litres); $V_{end\,up}(t-1)$ is the volume of rainwater available in the upper tank at the end of the previous day (litres).
The volume of rainwater available in the lower tank after the first pumping is given by Eq. (12).

$$V_{low\,aft\,pump}(t) = min\begin{cases} V_{low\,tank} \\ V_{end\,low}(t-1) + V_{catch}(t) - V_{pump}(t) \end{cases} \tag{12}$$

where $V_{low\,aft\,pump}(t)$ is the volume of rainwater available in the lower tank after the first pumping (litres); $V_{low\,tank}$ is the capacity of the lower tank (litres); $V_{end\,low}(t-1)$ is the volume of rainwater available in the lower tank at the end of the previous day (litres); $V_{catch}(t)$ is the volume of rainwater that flows on the catchment surface (litres); $V_{pump}(t)$ is the volume of rainwater pumped on day t (litres).
The volume of rainwater available in the upper tank after the first pumping is given by Eq. (13).

$$V_{in\,up}(t) = V_{end\,up}(t-1) + V_{pump}(t) \tag{13}$$

where $V_{in\,up}(t)$ is the volume of rainwater available in the upper tank after the first pumping (litres); $V_{end\,up}(t-1)$ is the volume of rainwater available in the upper tank at the end of the previous day (litres); $V_{pump}(t)$ is the volume of rainwater pumped on day t (litres).
The volume of rainwater consumed in a given day is calculated by using Eq. (14).

$$V_c(t) = min\begin{cases} D(t) \\ V_{in\,up}(t) \end{cases} \tag{14}$$

where $V_c(t)$ is the volume of rainwater consumed on day t (litres); $D(t)$ is the rainwater demand on day t (litres per capita/day); $V_{in\,up}(t)$ is the volume of rainwater available in the upper tank at the beginning of day t (litres).
After that consumption, the volume of rainwater available in the upper tank is calculated by using Eq. (15).

$$V_{up\,aft\,cons}(t) = V_{in\,up}(t) - V_c(t) \tag{15}$$

where $V_{up\,aft\,cons}(t)$ is the volume of rainwater available in the upper tank after consumption (litres); $V_{in\,up}(t)$ is the volume of rainwater available in the upper tank at the beginning of day t (litres); $V_c(t)$ is the volume of rainwater consumed on day t (litres).
The volume of rainwater available for the second pumping is given by Eq. (16).

$$V_{pump\,2}(t) = min\begin{cases} V_{low\,aft\,pump}(t) \\ V_{up\,tank} - V_{up\,aft\,cons}(t) \end{cases} \tag{16}$$

where $V_{pump\,2}(t)$ is the volume of rainwater available for the second pumping (litres); $V_{low\,aft\,pump}(t)$ is the volume of rainwater available in the lower tank after the first pumping (litres); $V_{up\,tank}$ is the capacity of the upper tank (litres); $V_{up\,aft\,cons}(t)$ is the volume of rainwater available in the upper tank after consumption (litres).
The volume of rainwater available in the upper and lower tanks at the end of a given day are given by Eqs. (17) and (18), respectively.

$$V_{end\ up}(t) = min\begin{cases} V_{up\ tank} \\ V_{up\ aft\ cons}(t) + V_{pump\ 2}(t) \end{cases} \quad (17)$$

where $V_{end\ up}(t)$ is the volume of rainwater available in the upper tank at the end of day t (litres); $V_{up\ tank}$ is the capacity of the upper tank (litres); $V_{up\ aft\ cons}(t)$ is the volume of rainwater available in the upper tank after consumption (litres); $V_{pump\ 2}(t)$ is the volume of rainwater available for the second pumping (litres).

$$V_{end\ low}(t) = V_{low\ aft\ pump}(t) - V_{pump\ 2}(t) \quad (18)$$

where $V_{end\ low}(t)$ is the volume of rainwater available in the lower tank at the end of the day (litres); $V_{low\ aft\ pump}(t)$ is the volume of rainwater available in the lower tank after the first pumping (litres); $V_{pump\ 2}(t)$ is the volume of rainwater available for the second pumping (litres).

2.4 Computer simulations

In order to compare Neptune, YAS and YBS, computer simulations were carried out for different cases. Table 1 shows the parameters considered for the simulations.

Parameter	Case 1 – Low rainwater demand	Case 2 – Medium rainwater demand	Case 3 – High rainwater demand
Catchment surface area (m^2)	100	200	300
Potable water demand (litres per capita/day)	100	200	300
Number of inhabitants per house	3	4	5
Percentage of potable water that can be replaced with rainwater (%)	30	40	50
Total rainwater demand (litres/day per house)	90	320	750
Capacity of the upper tank (litres)	90	320	750

Table 1. Simulation parameters for low, medium and high rainwater demand for Santana do Ipanema, Florianópolis and Santos.

In all three cases a runoff coefficient of 0.8 was taken into account, i.e., 20% of rainwater is discarded due to dirt on the roof, gutters, etc. The capacity of the upper tank is given by the daily rainwater demand. It is calculated by using Eq. (19).

$$V_{up\ tank} = D_{pot} \cdot N_{inh} \cdot P_{subst} \quad (19)$$

where $V_{up\ tank}$ is the capacity of the upper tank (litres); D_{pot} is the potable water demand (litres); N_{inh} is the number of inhabitants; P_{subst} is the percentage of potable water that can be replaced with rainwater.

Three cities with different rainfall patterns were considered in the simulations: Santana do Ipanema, Florianópolis and Santos. The monthly average rainfall for the three cities are shown in Figure 1, Figure 2 and Figure 3, respectively.

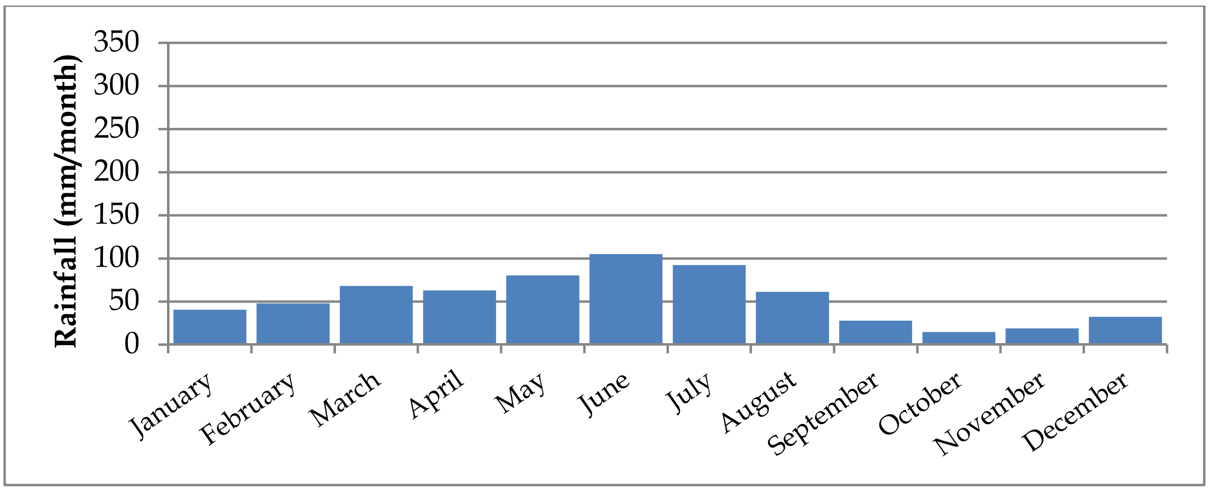


Fig. 1. Monthly average rainfall in Santana do Ipanema over 1979-2010.

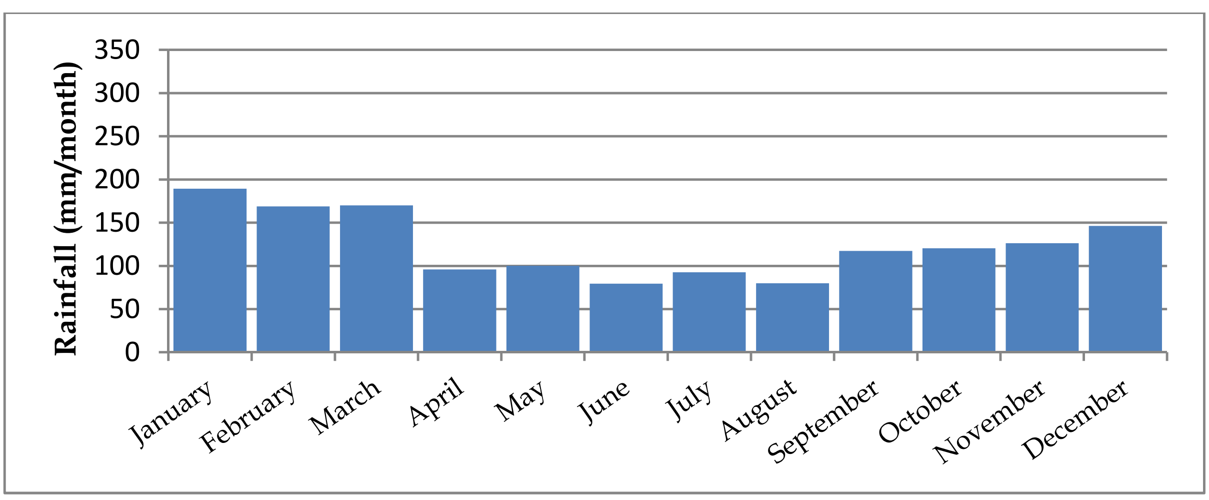


Fig. 2. Monthly average rainfall in Florianópolis over 1949-1998.

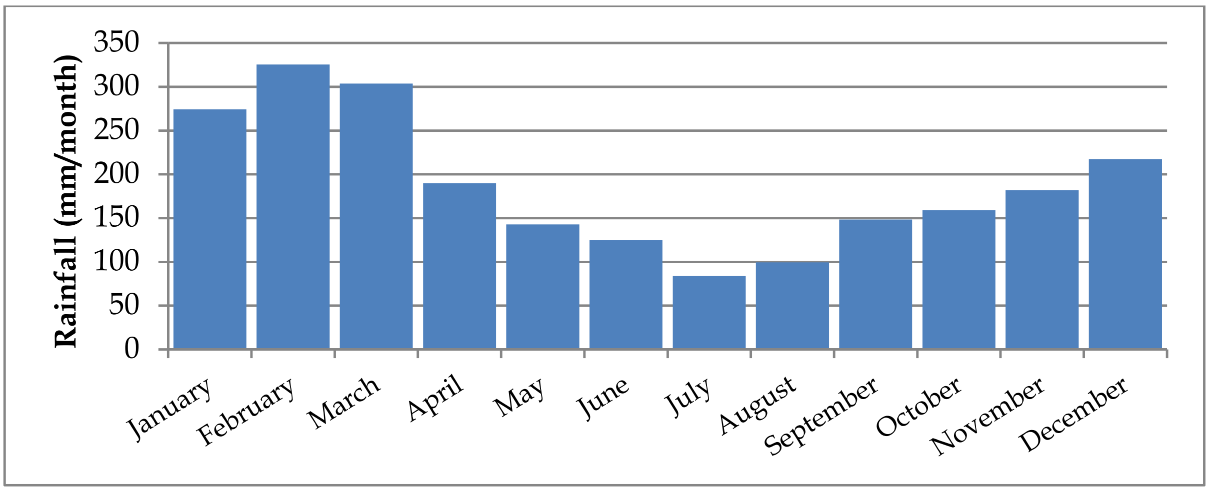


Fig. 3. Monthly average rainfall in Santos over 1910-1996.

The annual average rainfall for the three cities are: Santana do Ipanema – 652 mm; Florianópolis – 1486 mm; Santos – 2252 mm.
For the simulations, the last 10 years of daily rainfall data were used for each city. Data from 2001-2010 were used for Santanan do Ipanema; from 1989-1998 for Florianópolis , and from 1987-1996 for Santos.

2.5 Optimal capacity for the lower tank

To calculate the ideal capacity for the lower tank, simulations were performed for tank capacities ranging from 0 to 10,000 litres, at interval of 250 litres. Then graphs of potential for potable water savings as a function of tank capacities were drawn. For each two points in the graph, the difference between potable water savings was estimated by using Eq. (20).

$$\Delta_i = \frac{E_{pot}(i) - E_{pot}(i-1)}{V_{low\ tank}(i) - V_{low\ tank}(i-1)} \quad (20)$$

where Δ_i is difference between potable water savings (%/m³); E_{pot} is the potential for potable water savings (%); $V_{low\ tank}$ is the lower tank capacity (m³).
Eq. (20) represents the resulting increase in E_{pot} for a given increase in V_{inf}. As "%/litre" usually results in very small values, the tank capacities are expressed in m³.
The tank capacity chosen as optimal is the one in which $\Delta_i \leq 1\%/m^3$. This means that, for that interval, an increase of 1 m³ in the capacity of the lower tank results in an increase less or equal to 1% in the potential for potable water savings.
This ensures that the tank capacity will not be too small (such that the rainwater demand will not be met) or too large (such that the tank will not be filled for most of the time).

3. Results

In this section, results for the three cases and three cities are shown. The optimal capacities for the lower tank are determined for YAS, YBS and Neptune.
It will be seen that the potential for potable water savings, in %, obtained with Neptune is always greater than YBS and smaller than YAS. Thus, to compare results for a given capacity, the reference will be that estimated by Neptune.

3.1 Low rainwater demand

The simulation for Santana do Ipanema gives the results shown in Figure 4.

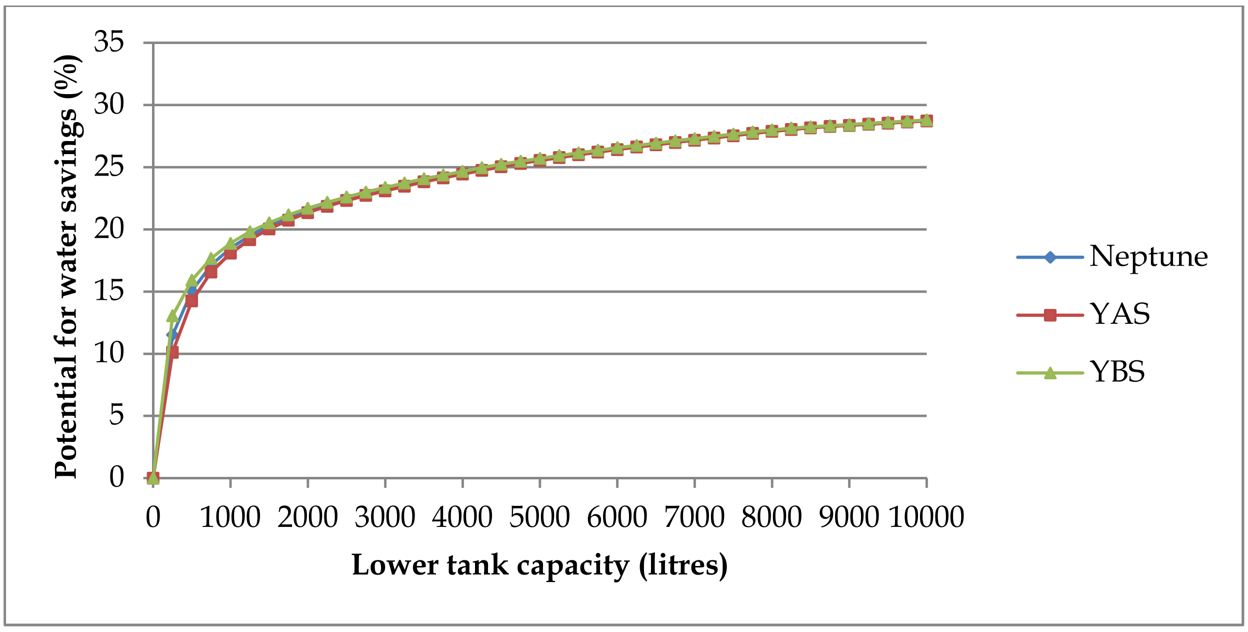


Fig. 4. Potential for potable water savings for Santana do Ipanema, with low rainwater demand.

Due to low rainfall, even with a low rainwater demand (90 litres/day), it can be seen that the maximum percentage of rainwater demand, 30%, is not reached within the range of tank capacities simulated.

The ideal capacities for the lower tanks are: Neptune – 4500 litres; YAS – 4750 litres; YBS – 4500 litres. The potential for potable water savings are, respectively, 25.15%, 25.31% and 25.24%.

Considering a tank capacity of 4500 litres, additional results are obtained (Table 2).

Parameter	Neptune	YAS	YBS
Volume of rainwater overflowed (litres)	26,826	26,943	26,727
Daily average of volume overflowed (litres/day)	7.4	7.4	7.3
Volume of rainwater consumed (litres)	275,554	274,384	276,570
Daily average of volume consumed (litres/day)	75.9	75.2	75.8
Percentage of days that rainwater demand is completely met	83.19	82.83	83.54
Percentage of days that rainwater demand is partially met	1.23	1.23	1.15
Percentage of days that rainwater demand is not met	15.58	15.94	15.31

Table 2. Results for Santana do Ipanema for low rainwater demand and a lower tank capacity of 4500 litres.

The difference between average rainwater consumption for Neptune and YAS is 0.32 litres/day, which is equivalent to 0.36% of daily rainwater demand. Similarly, the difference between YBS and Neptune is 0.28 litres/day, which corresponds to 0.31% of daily rainwater demand.
For Florianópolis, the potential for potable water savings as a function of the volume of lower tank is presented in Figure 5.

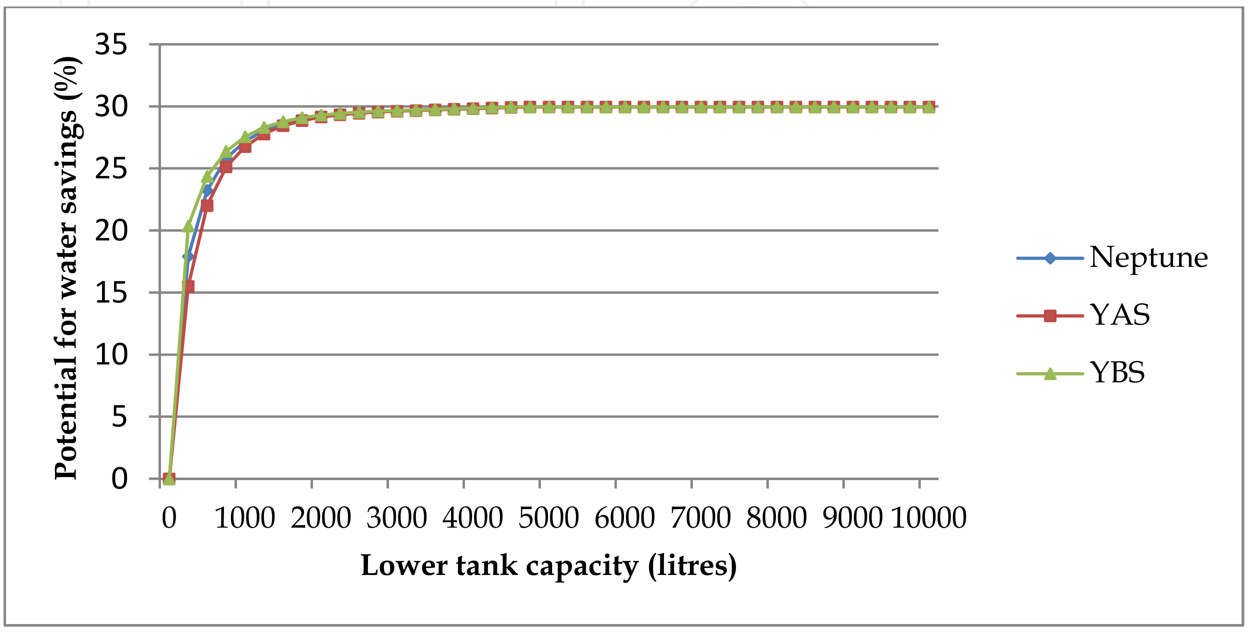


Fig. 5. Potential for potable water savings for Florianópolis, with low rainwater demand.

For Florianópolis, which has greater rainfall than Santana do Ipanema, one sees that, with tank capacity around 3000 litres the maximum potential for water savings is reached.
The ideal capacities for the lower tanks are: Neptune – 2000 litres; YAS – 2000 litres; YBS – 1750 litres. The potential for potable water savings are, respectively, 29.24%, 29.15% and 29.08%.
Table 3 presents additional results for the three methods using a lower tank of 2000 litres.

Parameter	Neptune	YAS	YBS
Volume of rainwater overflowed (litres)	103,548	103,649	103,473
Daily average of volume overflowed (litres/day)	31.2	31.3	31.2
Volume of rainwater consumed (litres)	290,840	289,924	291,432
Daily average of volume consumed (litres/day)	87.7	87.5	87.9
Percentage of days that rainwater demand is completely met	97.20	96.83	97.44
Percentage of days that rainwater demand is partially met	0.51	0.57	0.36
Percentage of days that rainwater demand is not met	2.29	2.60	2.20

Table 3. Results for Florianópolis for low rainwater demand and a lower tank of 2000 litres.

The difference between average rainwater consumption for Neptune and YAS is 0.28 litres/day, which is equivalent to 0.31% of daily rainwater demand. Similarly, the difference between YBS and Neptune is 0.18 litres/day, which corresponds to 0.20% of daily rainwater demand.
The potential for potable water savings for Santos is presented in Figure 6.

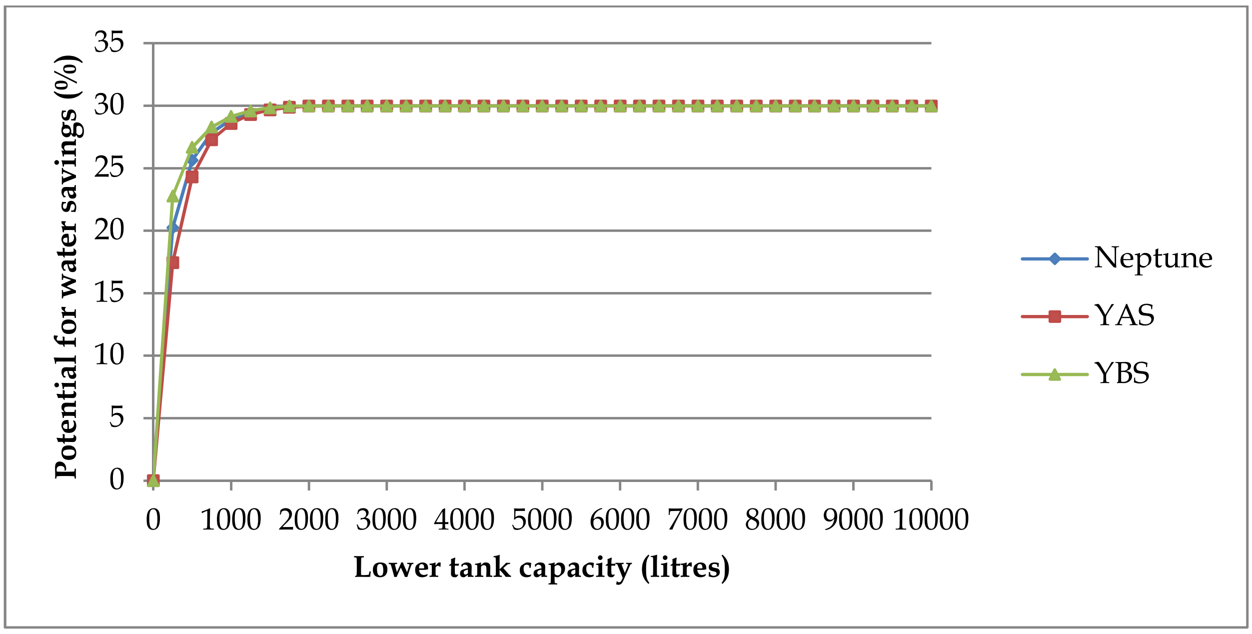


Fig. 6. Potential for potable water savings for Santos, with low demand of rainwater.

In this case, the maximum potential for potable water savings is reached for a lower tank capacity of about 2000 litres.
The ideal capacities for the lower tanks are: Neptune – 1500 litres; YAS – 1500 litres; YBS – 1500 litres. The potential for potable water savings are, respectively, 29.76%, 29.67% and 29.84%.
Table 4 presents additional results for the three methods using a lower tank of 1500 litres.

Parameter	Neptune	YAS	YBS
Volume of rainwater overflowed (litres)	250,974	251,075	250,924
Daily average of volume overflowed (litres/day)	68.8	68.8	67.8
Volume of rainwater consumed (litres)	321460	320460	322228
Daily average of volume consumed (litres/day)	88.1	87.8	88.3
Percentage of days that rainwater demand is completely met	99.06	98.72	99.33
Percentage of days that rainwater demand is partially met	0.25	0.31	0.20
Percentage of days that rainwater demand is not met	0.69	0.97	0.47

Table 4. Results for Santos for low rainwater demand and a lower tank of 1500 litres.

The difference between average rainwater consumption for Neptune and YAS is 0.27 litres/day, which is equivalent to 0.27% of daily rainwater demand. Similarly, the difference between YBS and Neptune is 0.21 litres/day, which corresponds to 0.23% of daily rainwater demand.

3.2 Medium rainwater demand

Considering a daily rainwater demand of 320 litres and a catchment surface of 200 m², the shape of the curves on the graphs remain the same, with an asymptotic tendency.
For Santana do Ipanema, the maximum potential for potable water savings (40%) cannot be reached due to small amounts of rainfall. The ideal capacity for the lower tank with method Neptune is 5000 litres. YAS estimated a capacity 250 litres bigger, while YBS estimated a capacity 250 litres smaller. The potential for potable water savings are, respectively, 23.29%, 23.26% and 23.36%. With a lower tank with capacity of 5000 litres, the difference between average rainwater consumption for Neptune and YAS is equivalent to 0.78% of daily rainwater demand. Similarly, the difference between YBS and Neptune corresponds to 0.73% of daily rainwater demand.
The ideal capacities for the lower tank using Neptune and YAS were the same as those estimated for Santana do Ipanema. YBS had an optimal capacity of 4500 litres. However, due to higher rainfall the potential for potable water savings are, respectively, 36.34%, 36.27% and 36.17%. With a lower tank capacity of 5000 litres, the difference between average rainwater consumption for Neptune and YAS corresponds to 0.82% of daily rainwater demand. Similarly, the difference between YBS and Neptune is equivalent to 0.71% of daily rainwater demand.
As an example, Figure 7 shows the potential for potable water savings as a function of the lower tank capacity for Santos.

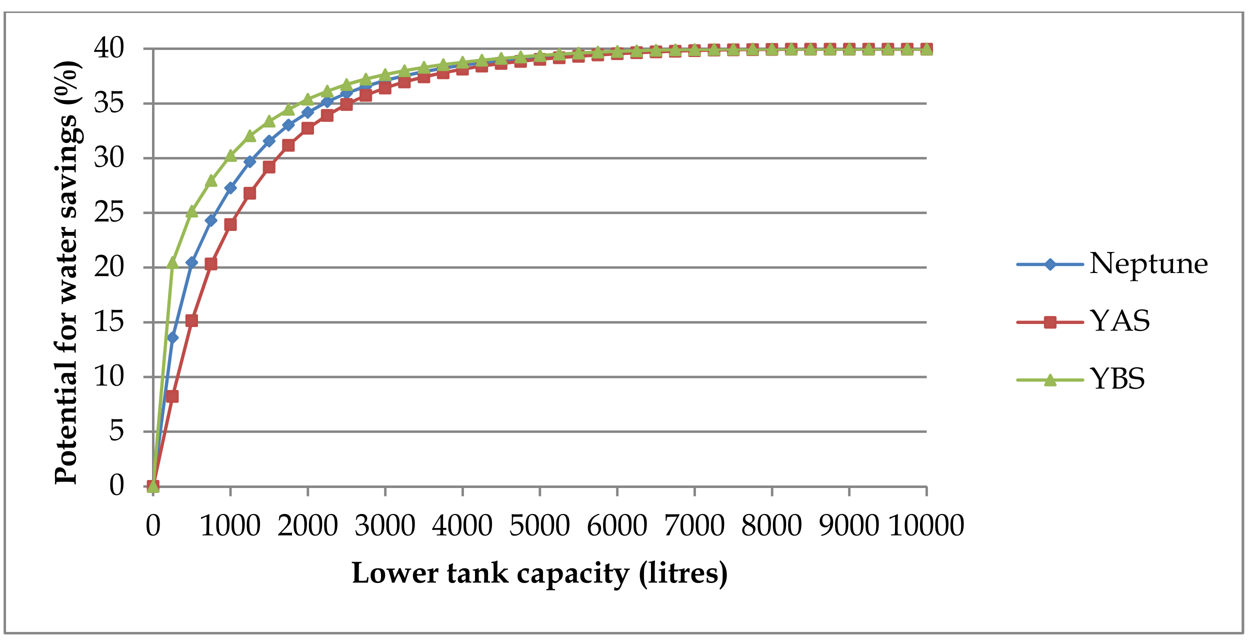


Fig. 7. Potential for potable water savings for Santos, with medium rainwater demand.

Santos, which has higher rainfall than Santana do Ipanema and Florianópolis, can reach the maximum potential for potable water savings, with a tank capacity of about 7000 litres. The ideal capacities, however, are considerably smaller. The estimated capacities for Neptune, YAS and YBS were, respectively, 4000 litres, 4250 litres and 3750 litres. For these lower tanks, the potential for potable water savings are 38.49%, 38.42% and 38.56%. With a lower tank capacity of 4000 litres, the difference between average rainwater consumption for Neptune and YAS is equivalent to 0.89% of daily rainwater demand. Likewise, the difference between YBS and Neptune corresponds to 0.68% of daily rainwater demand.

3.3 High rainwater demand

The third case considers a higher rainwater demand, i.e., 750 litres/day. The catchment surface is also larger, i.e., 300 m².

For Santana do Ipanema, which has the lowest rainfall, the simulation gives the results shown in Figure 8.

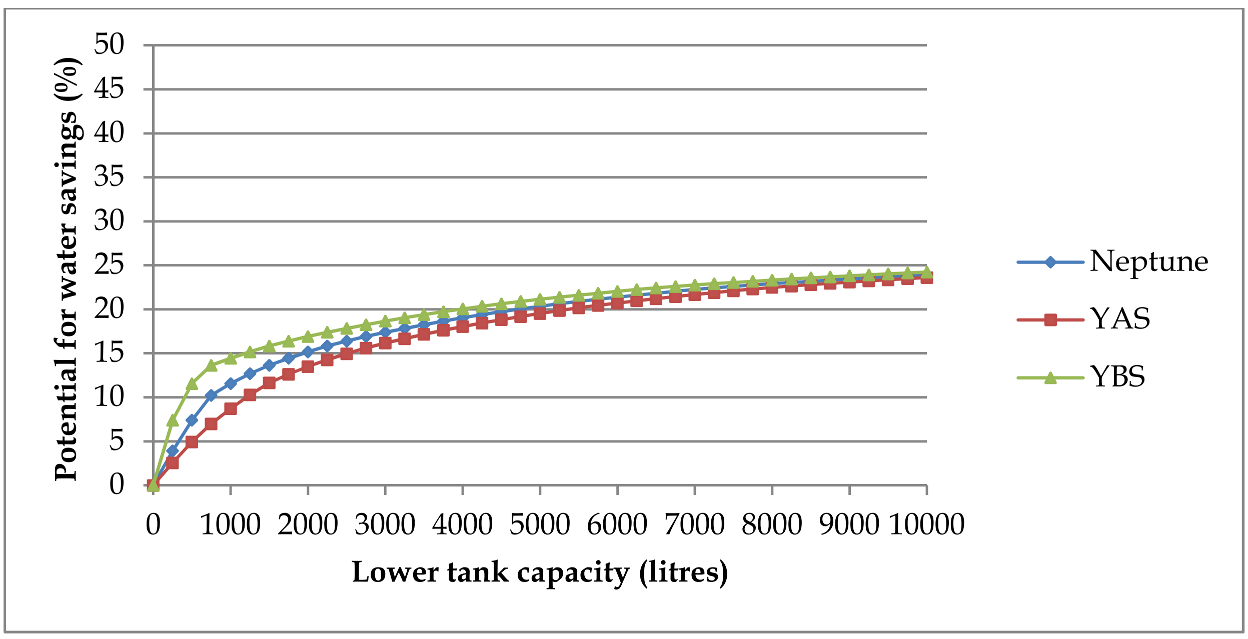


Fig. 8. Potential for potable water savings for Santana do Ipanema, with high rainwater demand.

Due to low rainfall in Santana do Ipanema, and the high rainwater demand, the highest potential for potable water savings obtained in the interval 0-10000 litres is less than 25%. Differences in the lower tank capacity are greater than the ones obtained in the previous sections. The ideal capacities for Neptune, YAS and YBS are 5500 litres, 6250 litres and 4750 litres, respectively. The potential for potable water savings, on the other hand, are very similar: respectively 20.90%, 20.97% and 20.90%. Considering a lower tank capacity of 5500 litres, the difference between average rainwater consumption for Neptune and YAS corresponds to 1.46% of daily rainwater demand. Similarly, the difference between YBS and Neptune is equivalent to 1.43% of daily rainwater demand.

For Florianópolis, a potential for potable water savings of 40% is the most that can be obtained in the interval 0-10000 litres, due to the high rainwater demand. The ideal capacities for the lower tanks are: Neptune – 8250 litres; YAS – 9000 litres; YBS – 7500 litres. The potential for potable water savings, however, are almost equal: 39.63%, 39.65% and

39.63%, respectively. The biggest difference in the average rainwater consumption occurs between Neptune and YAS, and is equivalent to 1.50% of daily rainwater demand.

Because of higher amounts of rainfall, lower tank capacities estimated for Santos are smaller than those obtained for Florianópolis. For Neptune, it is 7750 litres. YAS and YBS estimated volumes of 8500 litres and 7000 litres, respectively. The potential for potable water savings are, respectively, 46.10%, 46.11% and 46.79%. With a lower tank capacity of 7750 litres, the difference between average rainwater consumption for Neptune and YAS is equivalent to 1.65% of daily rainwater demand. Similarly, the difference between YBS and Neptune corresponds to 1.35% of daily rainwater demand.

As noted in the previous sections, the differences between methods are very small compared to the daily rainwater demand.

4. Conclusions

Three behavioural models for rainwater harvesting analysis were investigated. Two rainwater tanks were considered, i.e., a lower and an upper one, so that the water is pumped from the lower to the upper tank.

A methodology for determining the optimum lower tank capacity was presented, based on variations in the potential for potable water savings as a function of the tank capacity. Results showed that the method estimates a capacity for the lower tank that is not too small so as to allow for a great amount of rainwater to be wasted; and neither too large so as to allow for the increase in construction and maintaining costs to surpass the increase in potential for potable water savings.

Simulations were performed for three rainwater demands and three cities. Results showed that, due to the modelling, the YAS method always estimates the smallest potential for potable water savings, followed by Neptune and YBS, respectively. It was also found that the differences between the methods increase as increases the rainwater demand.

Despite the potential for potable water savings obtained with YBS being slightly higher than the other two methods, one should take into account that two pumpings per day can occur; and this causes an increase in system maintenance and energy costs.

The greatest difference of daily average rainwater consumed obtained between Neptune and YAS was 1.65%. Similarly, the greatest difference between Neptune and YBS was 1.35%. Thus, it can be concluded that, for practical purposes, the methods are equivalent.

5. References

Abdulla, F. A. & Al-Shareef, A. W. (2009). Roof rainwater harvesting systems for household water supply in Jordan. *Desalination*, n. 243, p. 195-207.

Appan, A. (1999). A dual-mode system for harnessing roofwater for non-potable uses. *Urban Water*, n. 1, p. 317-321.

Basinger, M.; Montalto, F. & Lall, U. (2010). A rainwater harvesting system reliability model based on nonparametric stochastic rainfall generator. *Journal of Hydrology*, n. 392, p. 105-118.

Chang, N.; Rivera, B. J. & Wanielista, M. P. (2011). Optimal design for water conservation and energy savings using green roofs in a green building under mixed uncertainties. *Journal of Cleaner Production*, n. 19, p. 1180-1188.

Chiu, Y. & Liaw, C. (2008). Designing rainwater harvesting systems for large-scale potable water saving using spatial information system. *Lecture Notes in Computer Science*, v. 5236, p. 653-66.

Chiu, Y.; Liaw, C. & Chen, L. (2009). Optimizing rainwater harvesting systems as an innovative approach to saving energy in hilly communities. *Renewable Energy*, n. 34, p. 492-498.

Cowden, J. R.; Watkins Jr., D. W. & Mihelcic, J. R. (2008). Stochastic rainfall modeling in West Africa: Parsimonious approaches for domestic rainwater harvesting assessment. *Journal of Hydrology*, n. 361, p. 64-77.

Domènech, L &; Saurí, D. (2011). A comparative appraisal of the use of rainwater harvesting in single and multi-family buildings of the Metropolitan Area of Barcelona (Spain): social experience, drinking water savings and economic costs. *Journal of Cleaner Production*, n. 19, p. 598-608.

Fewkes, A. (1999a). The use of rainwater for WC flushing: the field testing of a collection system. *Building and Environment*, n. 34, p. 765-772.

Fewkes, A. (1999b). Modelling the performance of rainwater collection systems: towards a generalized approach. *Urban Water*, n. 1, p. 323-333.

Fooladman, H. R. & Sepaskhah, A. R. (2004). Economic analysis for the production of four grape cultivars using microcatchment water harvesting systems in Iran. *Journal of Arid Environments*, v. 58, p. 525-533.

Ghisi, E. Tavares, D. F. & Rocha, V. L. (2009). Rainwater harvesting in petrol stations in Brasília: Potential for potable water savings and investment feasibility analysis. *Resources, Conservation and Recycling*, v. 54, p. 79-85.

Ghisi, E.; Cordova. M. M. & Rocha, N. L. (2011). *Neptune 3.0.* Computer programme. Federal University of Santa Catarina, Department of Civil Engineering. Available in: http://www.labeee.ufsc.br.

Goel, A. K. & Kumar, R. (2005). Economic analysis of water harvesting in a mountainous watershed in India. *Agricultural Water Management*, v. 71, p. 257-266.

Handia, L.; Tembo, J. M. & Mwiindwa, C. (2003). Potential of Rainwater harvesting in urban Zambia. *Physics and Chemistry of the Earth*, v. 28, p. 893-896.

Imteaz, M. A.; Shanableh, A.; Rahman, A. & Ahsan, A. (2011). Optimisation of rainwater tank design from large roofs: A case study in Melbourne, Australia. *Resources, Conservation and Recycling*, Article in press.

Jenkins, D.; Pearson, F.; Moore, E.; Sun, J. K. & Valentine, R. (1978). *Feasibility of rainwater collection systems in California*. Californian Water Resources Centre, University of California, USA.

Jones, M. P. & Hunt, W. F. (2010). Performance of rainwater harvesting systems in the south eastern United States. *Resources, Conservation and Recycling*, v. 54, p. 623-629.

Kahinda, J. M.; Taigbenu, A. E. & Boroto, J. R. (2007). Domestic Rainwater harvesting to improve water supply in rural South Africa. *Physics and Chemistry of the Earth*, v. 32, p. 1050-1057.

Li, X. & Gong, J. (2002). Compacted microcatchments with local earth materials for rainwater harvesting in the semiarid region of China. *Journal of Hydrology*, v. 257, p. 134-144.

Li, Z.; Boyle, F. & Reynolds, A. (2010). Rainwater harvesting and greywater treatment systems for domestic application in Ireland. *Desalination*, v. 260, p. 1-8.

Marks, R.; Clark, R.; Rooke, E. & Berzins, A. (2006). Meadows, South Australia: development through integration of local water resources. *Desalination*, v. 188, p. 149-161.

Mitchell, V. G. (2007). How important is the selection of computational analysis method to the accuracy of rainwater tank behaviour modelling. *Hydrological Processes*, v. 21, p. 2850-2861.

Palla, A.; Gnecco, I. & Lanza, L. G. (2011). Non-dimensional design parameters and performance assessment of Rainwater harvesting systems. *Journal of Hydrology*, v. 401, p. 65-76.

Pandey, P. K.; Panda, S. N. & Panigrahi, B. (2006). Sizing on-farm reservoirs for crop-fish integration in rainfed farming systems in Eastern India. Biosystems Engineering, v. 93, p. 475-489.

Sazakli, E.; Alexopoulos, A. & Leotsinidis, M. (2007). Rainwater harvesting, quality assessment and utilization in Kefalonia Island, Greece. *Water Research*, v. 41, p. 2039-2047.

Song, J.; Han, M.; Kim, T. & Song, J. (2009). Rainwater harvesting as a sustainable water supply option in Banda Aceh. *Desalination*, v. 248, p. 233-240.

Sturm, M.; Zimmermann, M.; Schütz, K.; Urban, W. & Hartung, H. (2009). Rainwater harvesting as an alternative water resource in rural sites in central northern Namibia. *Physics and Chemistry of the Earth*, v. 34, p. 776-785.

Su, M.; Lin, C.; Chang, L.; Kang, J. & Lin, Mei. (2009). A probabilistic approach to rainwater harvesting systems design and evaluation. *Resources, Conservation and Recycling*, v. 53, p. 393-399.

Tsubo, M.; Walker, S. & Hensley, M. (2005). Quantifying risk for water harvesting under semi-arid conditions: Part I. Rainfall intensity generation. *Agricultural Water Management*, v. 76, p. 77-93.

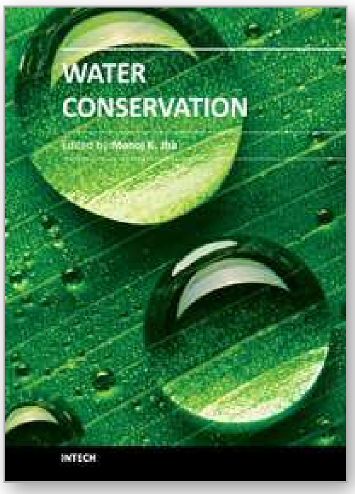
United Nations Educational, Scientific and Cultural Organization (UNESCO). (2003). *The 1st UN World Water Development Report:* Water for People, Water for Life. Available in: <http://www.unesco.org/water/wwap/wwdr/wwdr1/table_contents/index.shtml>.

Villareal, E. L. & Dixon, A. (2005). Analysis of a rainwater collection system for domestic water supply in Ringdansen, Norrköping, Sweden. *Building and Environment*, v. 40, p. 1174-1184.

Ward, S.; Memon, A. & Butler, D. (2011). Rainwater harvesting: model-based design evaluation. *Water Science and Technology*, v. 61, n. 1, p. 85-96.

Yuan, T.; Fengmin, L. & Puhai, L. (2003). Economic analysis of rainwater harvesting and irrigation methods, with an example from China. *Agricultural Water Management*, v. 60, p. 21-226.

Zhou, Y.; Shao, W. & Zhang, T. (2010). Analysis of a Rainwater harvesting system for domestic water supply in Zhoushan, China. *Journal of Zhejian University*, v. 11, n. 5, p. 342-348.



Water Conservation

Edited by Dr. Manoj Jha

ISBN 978-953-307-960-8
Hard cover, 152 pages
Publisher InTech
Published online 09, December, 2011
Published in print edition December, 2011

Water is an essential and basic human need for urban, industrial and agricultural use. While an abundance of fresh water resources is available, its uneven distribution around the globe creates challenges for sustainable use of this resource. Water conservation refers to an efficient and optimal use as well as protection of valuable water resources and this book focuses on some commonly used tools and techniques such as rainwater harvesting, water reuse and recycling, cooling water recycling, irrigation techniques such as drip irrigation, agricultural management practices, groundwater management, and water conservation incentives.