20th International Congress on Modelling and Simulation, Adelaide, Australia, 1–6 December 2013
www.mssanz.org.au/modsim2013

Regionalisation of water savings from rainwater harvesting system in Greater Sydney

Lubna Sharmeen, Ataur Rahman and Upeka Kuruppu

School of Computing, Engineering and Mathematics
University of Western Sydney, Australia
Email: u.kuruppu@uws.edu.au

Abstract: Rainwater harvesting is becoming popular in Australian cities. Often, a standard tank size is recommended by local authorities; for example in Sydney, a 3kL tank is recommended for detached houses by NSW Government as per BASIX regulation. This paper investigates the performance of a rainwater harvesting system in saving water using data from 162 different locations in Greater Sydney region. A combination of toilet, laundry and irrigation use is considered for three different tank sizes of 2kL, 3kL and 5kL. It has been found that the water savings in Greater Sydney region ranges from 38 kL to 47 kL for a 2kL tank size, 46 kL to 57 kL for a 3kL tank size and 55 kL to 77 kL for a 5kL tank size. It has also been found that a 5 kL tank is preferable to 2 kL and 3 kL as this can offer 20% to 64% more water savings. It has also been found that water savings vary notably at different locations across the Greater Sydney region, and hence a blanket recommended tank size may not be appropriate for the whole of Greater Sydney.

***Keywords**:* *Water balance model, rainwater harvesting, rainwater tanks, tank reliability, water recycling*

1. INTRODUCTION

Australia is one of the driest continents on earth, and is characterized by a highly variable rainfall with long period of dry spells affecting a large part of the continent. Due to frequent droughts and an increasing population in the urban areas, water supply has become a major concern in Australia (Ryan et al., 2009). Due to long-lasting draughts and increasing water demand, water authorities have been imposing mandatory water restrictions and various conservation strategies in most of the metropolitan areas. Rainwater tank is an alternative water supply method that has become popular over the recent years in Australia similar to many other countries (Imteaz et al., 2011 a, 2011b, 2013). A survey from the Australian Bureau of Statistics (ABS) demonstrated that in Sydney the installation of rainwater tank increased from 10% (in 2007) to 16.3% (in 2010) (ABS, 2011). Growth in population is putting pressure on water supplies; therefore, rainwater tank has become a popular alternative method in an urban setting where water is becoming quite expensive with time. Rainwater tank is an important component of water sensitive urban design as this intends to save mains water and offers many other environmental benefits (IEAust, 2006). Rainwater tank reduces the dependency on mains water and can significantly benefit social, economic and environmental outcomes as rainwater tank tend to encourage water conservation and reuse. Government authorities in Australia often encourage the community to install the rainwater tank by providing cash subsidy (Rainwater Harvesting, 2010).

In urban areas, rainwater harvesting system is used to supplement the mains water whereas many rural and peri-urban communities completely rely on this, where water conservation measure has been used throughout the history and where other water resources are scarce. It is important that rainwater harvesting system is designed according to the household needs where water reliability should meet the required demand when it is used for sole supply. It is also preferable to design a tank based on some key factors such as local rainfall, roof area, site characteristics and usage of water by the occupants. It is expected different locations will require a different rainwater tank size as rainfall often show a greater spatial variability over a large city; however, most of the local authorities recommend a single size for all the households e.g. BASIX in NSW has recommended a 3 kL rainwater tank for all the new households in Sydney.

Due to rising of water demand in recent years, there have been increased interest on rainwater tank and hence there have been many research on this issue (e.g. Coombes et al., 1999; Coombes and Kuczera, 2003; Chanan and woods, 2006; Marks et al., 2006; Khastagir and Jayasuriya, 2010; Tam et al., 2010 and Rahman et al., 2011). Coombes and Kuczera (2003) investigated the performance of 1KL to 10KL rainwater tank with mains water tickle top-up used to supplement mains water supply for domestic, laundry, hot water and outdoor usage in Australian capital cities. It has been found that mains water savings increased with tank volume, number of occupants in dwellings and roof areas. Their results showed that mains water savings for individual dwellings in Western Sydney ranged from 6% to 33% and 10% to 58% for dwellings with 100m^2 and 200m^2 roof areas.

Tam et al. (2010) aimed to assess the cost effectiveness of the use of rainwater tank in Australian residential houses and found that among the seven cities they examined, Brisbane, the Gold Coast and Sydney where mean annual rainfall is relatively higher, can present a great deal of financial benefit as compared to Melbourne where rainfall is relatively smaller. A study conducted by Rahman et al. (2010) based on multi-storey buildings in Sydney found that under some favourable conditions there may be a possibility to achieve a “pay-back” for installing rainwater tanks. They found that the benefit-cost ratio for rainwater tank increases as the number of users increase.

Eroksuz and Rahman (2010) evaluated the water savings potential of rainwater tanks fitted in multi-unit residential buildings in three cities in New South Wales Australia: Sydney, Newcastle and Wollongong. It was found that even during dry years, rainwater tank can provide significant water savings and that a larger tank size is more suitable for maximising water savings within multi-unit buildings. In addition, a prediction equation was developed which may be used to estimate average annual water savings based on the mean annual rainfall data. Imteaz et al. (2011) conducted a research in Swinburne University of Technology Melbourne, Australia, based on a daily water balance model. They found that a larger rainwater tank is preferable when it is connected to large roof areas. It was also found that the total cost of RWT can be recovered within 15 to 21 years depending on the tank size, climatic conditions and future water price increase rate. Rahman et al (2012) examined the water savings potential of rainwater tank fitted to detached houses and assessed the financial viability to provide guidance to water authorities at ten different locations across Greater Sydney. A water balance simulation model on daily time scale was developed and water savings, reliability and financial viability were examined for tank sizes of 2kL, 3kL and 5kL. The result showed that the average annual water savings from rainwater tank were strongly associated with the average annual rainfall and without the government rebate the benefit-cost ratio was smaller than 1.00.

Khastagir and Jayasuriya (2011) examined the financial viability of rainwater tank in Melbourne. It was found that the payback period varied considerably with the tank size and local rainfall characteristics within Melbourne. They noted that a single tank size is not appropriate for the entire Melbourne, as it has a significant rainfall gradient. As far as we know, no such study has been undertaken in Sydney. Tis paper aims to identify how rainwater tank size might vary over Greater Sydney, which might help selecting the most optimum tank size for a given location in Greater Sydney.

2. STUDY AREA AND DATA

For this study 162 different locations across Greater Sydney were selected (Figure 1). These locations are situated between the approximate boundaries of the peri-urban regions of Greater Sydney which are roughly defined by cities such as Manly, Cronulla, Liverpool, Penrith, Richmond, Brooklyn and Kuring-Gai Chase. The daily rainfall data from a selected station daily rain gauge for each of the locations was obtained from the Australian Bureau of Metrology. The record length of the daily data ranges from 20-152 years between the years of 1859-2010, with an average record length of 57 years as shown in Table 1. The distribution of the record lengths is shown in Figure 2. The Greater Sydney shows a wide variability in mean annual rainfall ranging from 616 mm to 1367 mm (a variation by about 200%). The median and mean rainfall values over the 162 stations are 957 mm and 958 mm, respectively. The mean annual rainfall is generally higher in the Northern Sydney and smaller in the west and south-west.

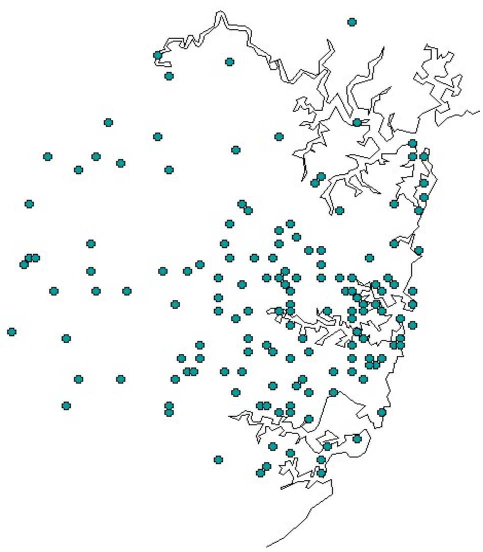

Figure 1. Locations of the daily rainfall stations in the Greater Sydney region used in this study

A combination of toilet, laundry and irrigation uses (combined use) was considered in this study area with three different tank sizes of 2kL, 3kL and 5kL. At each of the different locations a hypothesized new development was considered with a single household having 4 occupants. A total site area of 450m^2 was considered with a roof, lawn and impervious areas of 200m^2, 150m^2 and 100m^2, respectively. The rainwater tanks are is considered to be located above ground. In addition a mains top up system is considered for each tank when the volume of water drops below 20% of the tank capacity.

A daily water demand data for toilet, laundry and irrigation use for residential properties was obtained from Sydney Water. In the study, the toilet was assumed to be a 6-litre AAA (where, the higher the A's the more water efficient the device is) which rated dual flush toilet, and a frequency of toilet use of three times per person per day was assumed (equivalent to 0.018kL per person per day). The washing machine considered in this study was rated 4A and was assumed that the washing machine would have a volume of 50-litre, and would be used 3 times per week (equivalent to 0.0215kL per day of water use). The irrigation demand per square metre of lawn area was assumed to be 10 mm per day.

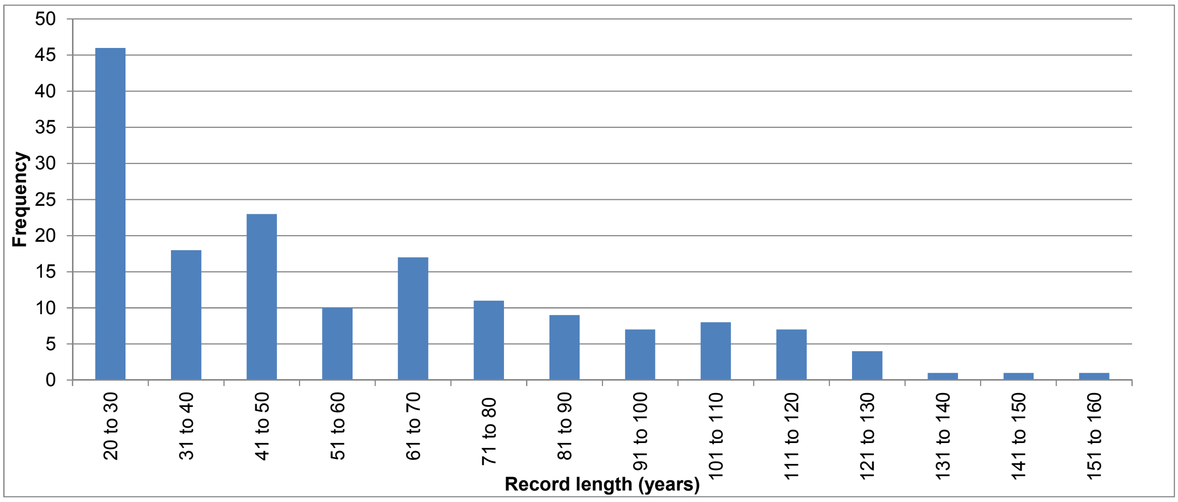

Figure 2. Distribution of record lengths of 162 daily rainfall stations in the Greater Sydney region

3. METHOD

A water balance simulation model (WBSM) on daily time scale in excel was built for the investigation of rainwater tank water savings. This considered factors associated with tank size, daily rainfall, losses, daily water demand, mains top up and tank spillage.
In this model, rainfall was used as inflow and possible spill and release as outflow which was very similar to the approach of Su et al. (2009) and Rahman et al. (2012). The release was estimated based on the following equations:

$$R_t = D_t \quad \text{if } I_t + S_{t-1} \geq D_t \tag{1}$$
$$R_t = I_t + S_{t-1} \quad \text{if } I_t + S_{t-1} < D_t \tag{2}$$

Where D_t is the daily demand (m^3) on day t, S_{t-1} is the tank storage at the end of the previous day (m^3), R_t is release from rainwater tank (m^3) and I_t is inflow (m^3). Spill (SP_t) (m^3) was calculated from the following equations:

$$SP_t = I_t + S_{t-1} - D_t - S_{MAX} \quad \text{if } I_t + S_{t-1} - D_t > S_{MAX} \tag{3}$$
$$SP_t = 0 \quad \text{if } I_t + S_{t-1} - D_t \leq S_{MAX} \tag{4}$$

Where, S_{MAX} is the design storage capacity (m^3). The tank storage S_t at the end of day t was calculated using the following equations:

$$S_t = \mathrm{S_{MAX}} \quad \text{if } SP_t > 0 \tag{5}$$
$$S_t = S_{t-1} + I_t - R_t \quad \text{if } SP_t \leq 0 \tag{6}$$

The reliability of the rainwater tank was calculated as the ratio of the number of days when intended demand was met fully by the available rainwater and the total number of simulated days.

The average annual water savings at each given location for all laundry, toilet and irrigation in Greater Sydney was estimated from the following equations developed by Rahman et al. (2011):

$$\mathrm{AWS_2} = 33.56 + 0.0067\times\mathrm{AAR},\ r = 0.49 \tag{7}$$
$$\mathrm{AWS_3} = 40.41 + 0.0085\times\mathrm{AAR},\ r = 0.50 \tag{8}$$
$$\mathrm{AWS_5} = 44.95 + 0.0162\times\mathrm{AAR},\ r = 0.63 \tag{9}$$

Where $\mathrm{AWS_2}$, $\mathrm{AWS_3}$ and $\mathrm{AWS_5}$ is average annual water savings (kL) for the use of toilet, laundry and irrigation for a 2 kL, 3 kL and 5 kL rainwater tank, AAR is average annual rainfall value (mm), and r is Pearson correlation coefficient.

4. RESULTS

Figure 3 shows the average annual water savings of a 5kL tank (for toilet, laundary and irrigaton use) across all the 162 locations over the entire period of data (average of 57 years). Figure 4 shows the percentage of water savings that could be gained from a 5 kL tank. It is found that the highest and lowest water savings for all three tank sizes occur at Frenchs Forest (French Forest Rd) and at St Clair (Juba Close), respectively. Interestingly, the highest and the lowest mean annual rainfall values occur at Frenchs Forest and St Clair, respectively, which are 1367 mm and 616 mm.

Table 1 and 2 provides a summary of water savings by using rainwater tank sizes of 2kL, 3kL and 5kL across all the 162 locations. For a combined use of toilet, laundry and irrigation use, the mean annual water savings for 2kL tank range from 38 kL (at St Clair, Juba Close) to 47 kL (Frenchs Forest, French Forest Rd) with an average water savings of 40 kL over all the 162 locations and a standard deviation of 1.31kL as shown on Table 1. For a 3 kL tank, the water savings range from 46 kL (St Clair, Juba Close) to 57 kL (Frenchs Forest, French Forest Rd) with an average water savings of 49 kL and a standard deviation of 1.66 kL. Finally, for the 5kL tank, the water savings range from 55 kL (St Clair, Juba Close) to 77 kL (Frenchs Forest, French Forest Rd) with an average water savings of 61 kL and a standard deviation of 3.17 kL. The confidence limits of the water savings are also shown in Table 1 for the three tank sizes; it is interesting to note that a 5 kL tank has the widest confidence limits, which reflect that there is a greater variability in water savings from location to location for this tank size as compared to 3 kL and 2 kL tanks.

These results show that at St Clair, by increasing a tank size from 2 kL to 3 kL, water savings increase by 21%, and by increasing the tank size from 2 kL to 5 kL, water savings increase by 45%. Similarly, at Frenchs Forest, by increasing a tank size from 2 kL to 3 kL, water savings increase by 21%, and by increasing the tank size from 2 kL to 5 kL, water savings increase by 64%. The differences in water savings between 3 kL and 5 kL tank is 20% (at St Clair) to 35% (at Frenchs Forest). This is an important result as the costs between 2 kL, 3 kL and 5 kL tank are not that different, but water savings that can be provided by a 5 kL tank is much higher. This suggests that a 5 kL tank would be a preferable size as compared to 2 kL and 3 kL for Greater Sydney region.

It should be noted here that the water savings and reliability reported in this paper is based on the long-term daily rainfall data and represents the average values at a given location; the actual value will differ from year to year depending on the rainfall at a given location, e.g. for a wet year, reliability will be higher than a dry year, as found by Imteaz et al., 2011a, b; 2012; 2013).

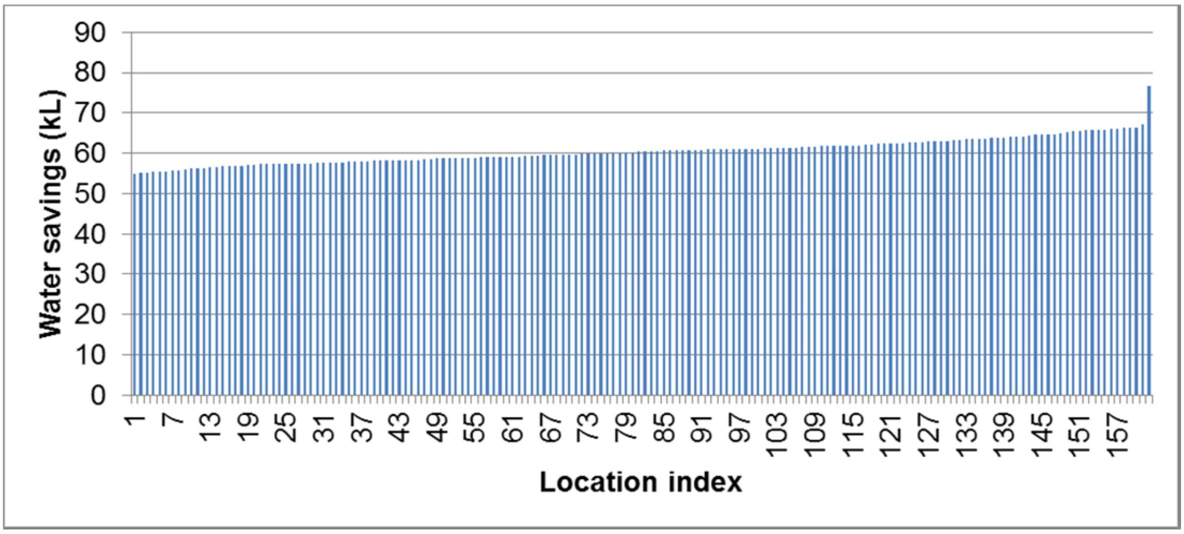

Figure 3. Average annual water savings (kL) for a 5kL tank in the 162 locations in the Greater Sydney (lowest to highest savings plotted)

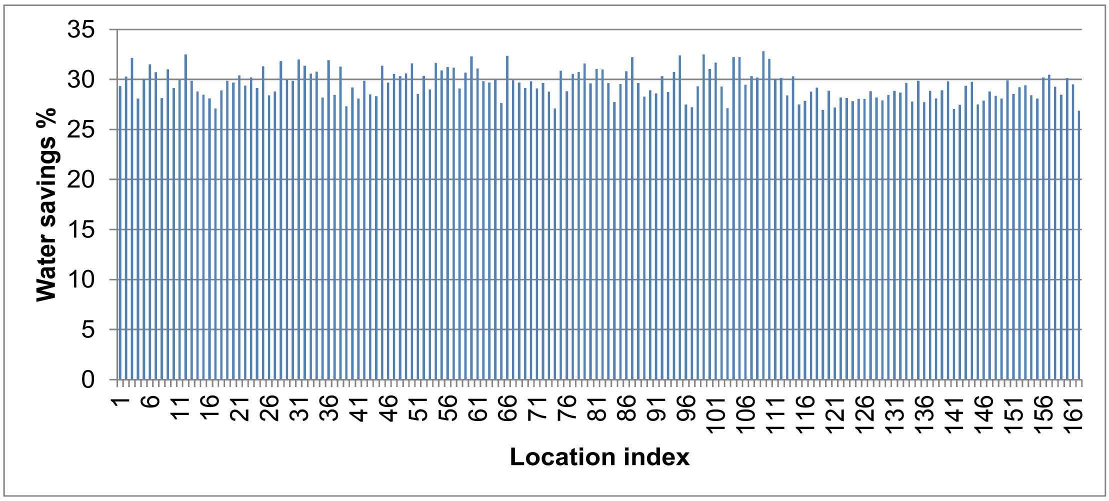

Figure 4. Percentage annual water savings for a 5kL tank in the 162 locations in the Greater Sydney

Table 1. Summary of water savings data for three different tank sizes

Tank Size (kL)	Mean water savings (kL/year)	St Dev water savings (kL)	Water savings confidence limits (CL)	
			5% CL	95% CL
2	40.01	1.31	37.44	42.58
3	48.59	1.66	45.33	51.85
5	60.54	3.17	54.33	66.75

Table 2. Summary of water savings data

Tank Size (kL)	Mean water savings (%)	St Dev water savings (%)	Water savings confidence limits (CL)	
			5% CL	95% CL
2	19.55	0.59	18.39	20.71
3	23.74	0.75	22.27	25.21
5	29.56	1.43	26.76	32.36

5. CONCLUSION

This paper investigates the performance of a rainwater tank in saving water using data from 162 different locations in Greater Sydney, Australia. A combination of toilet, laundry and irrigation use is considered for three different tank sizes of 2kL, 3kL and 5kL. It has been found that the water savings in Greater Sydney ranges from 38 kL to 47 kL for a 2kL tank size, 46 kL to 57 kL for a 3kL tank size and 55 kL to 77 kL for a 5kL tank size. It has also been found that a 5 kL tank is preferable to 2 kL and 3 kL as this can offer 20% to 64% more water savings. It has also been found that water savings vary notably at different locations across the Greater Sydney, and hence a blanket recommended tank size may not be appropriate for the whole of Greater Sydney.

REFERENCES

Australian Bureau of Statistics (2011). House hold water use and conservation, accessed 10 June 2013, http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/1338.1Main+Features3Dec+2010

Chanan A, Woods P. (2006). Introducing total water cycle management in Sydney: A Kograh Council initiative. *Desalination*, 187, 1-6.

Coombes P. J., Argue J. R. and Kuczera G. (1999). Figtree Place: a case study in water senstitive urban development (WSD). *Urban Water*, 1(4), 335-343.
Coombes P. J., Kuczera G. (2003). Analysis of the performance of rainwater tanks in Australian capital cities. In 28th International hydrology and water resources symposium, Wollongong, NSW.
Coombes P. J., Kuczera G. and Kalma J. D. (2003). Economic water quantity and quality impacts from the use of a rainwater tank in the inner city. *Australian Journal of Water Resources*, 7(2), 25-36.
Eroksuz E., Rahman A. (2010). Rainwater tanks in multi-unit buildings: A case study for three Australian cities. *Resources, Conservation & Recycling*, 54, 1449-1452.
IEAust (2006). Australian runoff quality: A guide to water sensitive urban design. The Institution of Engineers Australia, Canberra.
Imteaz M.A., Shanableh A., Rahman A. and Ahsan A. (2011a). Optimisation of rainwater tank design from large roofs: a case study in Melbourne, Australia. *Resources, Conservation & Recycling*, 55, 1022-1029.
Imteaz M.A., Ahsan A., Naser J. and Rahman A. (2011b). Reliability Analysis of Rainwater Tanks in Melbourne using Daily Water Balance Model. *Resources, Conservation & Recycling*, 56, 80-86.
Imteaz M.A., Rahman A. and Ahsan A. (2012). Reliability analysis of rainwater tanks: A comparison between South East and Central Melbourne. *Resources, Conservation & Recycling*, 66, 1-7.
Imteaz M.A., Ahsan A. and Shanableh A. (2013). Reliability analysis of rainwater tanks using daily water balance model: variations within a large city. *Resources, Conservation & Recycling*, 77, 37-43.
Khastagir A., Jayasuriya N., (2010). Optimal sizing of rain water tanks for domestic water conservation. *Journal of Hydrology*, 381,181-188.
Khastagir A., Jayasuriya N., (2011). Investment evaluation of rainwater tanks, *Water Resources Management,* 25, 3769-3784.
Marks R., Clark., Rooke., Berzins., (2006). Meadows, South Australia: development through integration of local water resources. *Desalination*, 188,149-161.
Rahman A., Dbais J. and Imteaz M. A. (2010). Sustainability of rainwater harvesting system in multistorey residential buildings. *American Journal of Engineering and Applied Sciences*, 3(1), 889-898.
Rahman A., Keane J. and Imteaz M. A. (2012). Rainwater harvesting in greater Sydney: Water savings, reliability and economic benefits. *Resources, Conservation & Recycling*, 61, 16-21.
Rain Harvesting (2010). Reasons for using Rainwater, accessed 10 June 2013, http://www.rainharvesting.com.au/rainwater-knowledge-centre/reasons-for-using-rainwater.
Ryan A., Spash C. L. and Measham T. G. (2009). Household water collection in Canberra. Socio-Economics and the Environment in Discussion: 1834-5638.
Tam V. W. Y., Tam L. and Zeng S. X. (2010). Cost effectiveness and trade off on the use of rainwater tank: an empirical study in Australian residential decision-making. *Resources, Conservation & Recycling*, 54, 178-186.