The development of a generalised equation for the annual water savings through rainwater tanks under different climatic conditions for southwest Brisbane (Australia)

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Abstract. Optimisation of rainwater tank outcomes has been a challenge for the users, as the water savings and reliability depend on many factors such as rainfall amount, rainfall distribution, tank size, roof area and rainwater demand. Among the analysis methods, daily water balance modelling is the most reasonable and acceptable approach. However, general end-users can hardly interpret/grasp the outcomes of such analyses. To overcome this hurdle, this paper presents the development of a generalised equation for calculating expected water savings through rainwater tanks with major contributing factors like rainfall, rainwater demand, tank size and roof area for southwest Brisbane (Australia). Daily rainfall data was collected for the station, Oxley which is in southwest Brisbane from the Australian Bureau of Meteorology website. The expected annual water savings for different combinations of rainfall, tank size, roof area and demand are presented in the form of charts that were converted to a generalized equation having independent variables of rainfall, tank size, roof area and demand. Results from the developed equation were seen matching with the model (eTank) simulated results. Such an equation can be easily incorporated into mobile apps or computer programs to help quick calculations for expected water savings.

Keywords: Rainwater tank, Daily water balance, Water savings and Climatic conditions

1. Introduction

Water is a precious resource available on earth. Many countries around the world face an acute shortage of water. The situation in Australia is also alarming. It experiences mean annual rainfall less than 600mm for more than 80 per cent of its area [1]. On top of that, the pressure of constantly increasing population in conjunction with global warming and climate change has led to an increase in water consumption. This has posed great stress on water authorities which are struggling to fulfil the water demand of the people. The water demand is of two types, potable water demand such as water required for drinking, cooking, bathing, etc and non-potable water demand such as water required for toilet flushing, laundry, gardening, car washing, etc. As the non-potable water demand does not require water to be of high quality, therefore, the non-potable water demand can be easily met by adopting water-saving techniques like greywater recycling, wastewater recycling and stormwater harvesting. Since the rainwater is relatively clean and clear from impurities, it is preferred more than all other alternatives. Although, a communal rainwater tank was used in southeast Queensland to meet the potable demand of a small urban
development, but the energy used for treating the water was four times higher than the energy used in a centralised system [2].

A rainwater harvesting system (RWHS) not only saves the potable water supplied by the water authorities but also reduces the volume of surface runoff into the sewer networks and solves the problem of traffic congestion during rainfall. A set of dimensionless curves were developed to determine the required storage capacity of the rainwater tank based on the desired level of performance [3]. It was showed that the peak flow in a sewer system can be reduced if properly designed rainwater tanks are installed at a vast scale [4]. A researcher suggested that the unit cost of rainwater can be reduced by increasing the consumption rate [5]. In Brazil, rainwater captured from the roof of the fuel station was utilised to wash the vehicles at the fuel station and it managed to save 32 per cent potable water [6]. It was found that a rainwater tank of 40 m³ can provide water savings ranging from 30 to 60 per cent depending on the water demand [7]. Some studies related to financial benefits and payback period were also carried out for shopping centre [8, 9], office building [10] and residential buildings [11, 12, 13, 14, 15].

Rainfall does not happen uniformly at every location. Some locations receive a high amount of rainfall whereas other nearby locations receive it in low amount. Moreover, it also varies from year to year at the same location. Hence, an average rainfall value adopted for designing a rainwater harvesting system may not give realistic results. To illustrate this, Imteaz et al., [16] investigated the spatial and climatic variation in annual water savings in Melbourne and concluded that difference in water savings is significant except for low demand and large roof area scenarios. A similar study was also carried out for Adelaide [17], Sydney [18] and Kathmandu [19]. It was also found that the size of the storage tank is overestimated if mean monthly rainfall data is used instead of daily rainfall data [20].

The initial investment required to adopt a rainwater harvesting system in a house is a matter of concern for many people. Therefore, to encourage its acceptance, the government provides incentives and rebates to homeowners for its installation. An investigation was carried out for 10 different locations in greater Sydney and it was found that a high rainfall is strongly correlated with high water savings [21]. It was also concluded that the existing rebate provided by the government is unable to make the benefit-cost ratio greater than or equal to unity for the homeowners [21]. On the other hand, a variable rebate scheme was proposed depending on the annual water savings at different locations within the Sydney metropolitan area [22]. It is certainly an attractive scheme for homeowners and probably an optimisation of the government’s spending on subsidies for promoting RWHS installation.

Some studies related to the optimum size of the tank were also carried out in different parts of the world. A set of dimensionless curves were developed that were useful in finding the optimum size of a rainwater tank for the Greater Melbourne area [23]. A mathematical model based on a linear programming approach was used to evaluate the optimum size of the tank in Northern Cyprus [24]. A simple spreadsheet-based daily water balance model was developed to design the size of a rainwater tank connected to a large roof [25]. A user-friendly regional regressive model was developed to estimate the water savings from RWHS in the region [26]. In one study, different detailed methods were analysed to size a rainwater tank and found that the 80% Efficiency criteria provide the best benefit-cost ratio [27]. The potential for potable water savings was investigated for 195 cities in southeastern Brazil which were observed to range from 12% to 79% per year [28]. It was suggested that a proper design and evaluation method is needed to amplify the performance of the RWHS [29].

Imteaz et al., [30] found that a 100% reliability is unachievable in a dry year for a relatively small roof (100m²) connected to a very large tank (10,000L). The performance of RWHS in 3 cities of Iran was evaluated and it was concluded that the annual water savings are directly proportional to the amount of annual rainfall [31]. The water-saving potential of RWHS was investigated for multi-unit buildings in 3 Australian cities and reported that a large tank can provide significant water savings even in dry years [32]. Although the installation of RWHS makes sure that some water is saved by the end of the day but a reasonable payback period is also desired. The potential of RWHS for high rise buildings in 4 Australian cities was studied and found Sydney to have the shortest payback period [33].
As usual, like other systems, RWHS also requires periodic inspection and maintenance for its efficient working and long life [34]. Most of the studies that were carried out to calculate the potential water savings involved mathematical/probabilistic/statistical analyses which are difficult to understand or interpret by a general end-user. Although, some equations were developed to calculate the expected water savings through rainwater tanks, however, these equations were only valid for a particular climatic condition [35, 36]. As such, it becomes complicated for a general end-user to use different equations for different climatic conditions for one particular region. Contrary to it, a more versatile and user-friendly equation is required to make it easier and a better option for a general end-user.

Although Brisbane is the third most populous city in Australia, such equation has never been developed for this city. This paper presents the development of a generalised equation to calculate the expected annual water savings through rainwater tanks under five different climatic conditions with major contributing factors as rainfall, tank size, demand and roof area for southwest Brisbane. The expected annual water savings for different rainfall, tank size, demand and roof area are presented in the form of charts that were converted to a generalized equation having independent variables of rainfall, tank size, demand and roof area. Results from the developed equation were seen matching with the model (eTank) simulated results. Such an equation can be used by a general end-user who would like to calculate the expected annual water savings through rainwater tanks by merely using a calculator or a spreadsheet. This equation can also be incorporated into mobile apps or computer programs to help quick calculations for expected annual water savings.

2. Methodology
An earlier developed daily water balance model, eTank [37] was used for the evaluation of rainwater tank outcomes. The model considers the daily rainfall, tank size, rainwater demand (indoor and outdoor), roof area and the losses that occur while the rainwater goes into the rainwater tank. For this study, a 15% loss was considered which included spillage, evaporation, first flush and leakage [38]. This model can calculate the annual water savings, town water use, overflow, reliability and the outdoor use of water. However, the development of a generalised equation for annual water savings was the objective of this study. Hence, other outcomes like town water use, overflow, reliability and the outdoor use of water are not taken into consideration.

For each climatic condition (dry, mild dry, average, mild wet and wet), expected annual water savings were calculated for different combinations of input conditions like tank size (2500L, 5000L, 7500L and 10,000L), rainwater demand (200L/day, 300L/day, 400L/day and 500L/day) and roof area (150m², 200m², 250m² and 300m²). It should be noted that these are the standard tank sizes used in Australia and the typical values of rainwater demand and roof area for an Australian household. Following this, for each tank size, a set of curves were produced between annual water savings and roof area for different demand scenario. From these curves, a generalised equation was developed for each climatic condition using the best fit technique. Ultimately, from these equations, a single equation was developed for the station under consideration. The process of the development of a generalised equation is described as follows:

After drawing the curves between annual water savings and roof area for different demand scenarios, it was observed that each curve follows a logarithmic pattern and hence it can be represented as follows:-

\[
AWS = x_1 \cdot \ln(RA) \pm y_1
\]  

(1)

Where AWS denotes the annual water savings, RA is the roof area, \( x_1 \) and \( y_1 \) is the coefficient and intercept respectively. As four rainwater demands were considered, therefore, four such equations were derived using the best fit technique yielding four different values for \( x_1 \) and \( y_1 \).

It was observed that the four different values for \( x_1 \) and \( y_1 \) can be represented as follows:

\[
x_1 = x_2 \cdot \ln(D) \pm y_2
\]

(2)

\[
y_1 = x_3 \cdot \ln(D) \pm y_3
\]

(3)

Where D denotes the rainwater demand, \( x_2 \), \( x_3 \) and \( y_2 \), \( y_3 \) are the coefficients and intercepts respectively. Again, as four different tank sizes were considered, therefore, four such equations were derived using the same technique yielding four different values for \( x_2 \), \( x_3 \), \( y_2 \) and \( y_3 \). It was found that \( x_2 \), \( y_2 \), \( x_3 \), and \( y_3 \) were almost constant for each tank size.

\[
1 \leq D \leq 3000
\]  

(4)

Such an equation can be used by a general end-user who would like to calculate the expected annual water savings through rainwater tanks by merely using a calculator or a spreadsheet. This equation can also be incorporated into mobile apps or computer programs to help quick calculations for expected annual water savings.
$x_1, y_2$ and $y_3$ are dependent on tank size and hence four values for $x_2, x_3, y_2$ and $y_3$ can be represented as follows:

\begin{align*}
  x_2 &= x_4 \times \ln (T) \pm y_4 \\
  x_3 &= x_5 \times \ln (T) \pm y_5 \\
  y_2 &= x_6 \times \ln (T) \pm y_6 \\
  y_3 &= x_7 \times \ln (T) \pm y_7
\end{align*}

Where $T$ denotes the tank size, $x_4, x_5, x_6, x_7$ and $y_4, y_5, y_6, y_7$ are the coefficients and intercepts respectively. These coefficients and intercepts were found to be constant for a particular climatic condition. Lastly, as five different climatic conditions were considered, therefore, five such equations were derived which yielded five different values for $x_4, x_5, x_6, x_7$ and $y_4, y_5, y_6, y_7$.

It was observed that five different values for $x_4, x_5, x_6, x_7$ and $y_4, y_5, y_6, y_7$ are dependent on annual rainfall but contrary to the previous logarithmic pattern this time they are correlated in a linear pattern and hence can be represented as follows:

\begin{align*}
  x_4 &= x_8 \times R \pm y_8 \\
  x_5 &= x_9 \times R \pm y_9 \\
  x_6 &= x_{10} \times R \pm y_{10} \\
  x_7 &= x_{11} \times R \pm y_{11} \\
  y_4 &= x_{12} \times R \pm y_{12} \\
  y_5 &= x_{13} \times R \pm y_{13} \\
  y_6 &= x_{14} \times R \pm y_{14} \\
  y_7 &= x_{15} \times R \pm y_{15}
\end{align*}

Where $R$ denotes the annual rainfall, $x_8, x_9, \ldots, x_{15}$ and $y_8, y_9, \ldots, y_{15}$ are the coefficients and intercepts respectively. They were found to be constant for a particular region. Now, substituting Eqs. (8), (9), (12) & (13) into Eqs. (4) & (5) and Eqs. (10), (11), (14) & (15) into Eqs. (6) & (7) and then substituting Eqs. (4), (5), (6) & (7) into Eqs. (2) & (3) and finally substituting Eqs. (2) & (3) into Eq. (1), a generalised equation that is capable to calculate the expected water savings for five different climatic conditions is obtained as follows:

$$AWS = \left(\left( x_8 \times R \pm y_8 \right) \times \ln(T) \pm \left( x_{12} \times R \pm y_{12} \right) \right) \times \ln(\Delta) \pm \left( \left( x_{10} \times R \pm y_{10} \right) \times \ln(T) \pm \left( x_{11} \times R \pm y_{11} \right) \right) \times \ln(\Delta) \pm \left( \left( x_9 \times R \pm y_9 \right) \times \ln(T) \pm \left( x_{13} \times R \pm y_{13} \right) \right) \times \ln(\Delta) \pm \left( \left( x_{14} \times R \pm y_{14} \right) \times \ln(T) \pm \left( x_{15} \times R \pm y_{15} \right) \right) \right)$$

The derivation of the final equations is presented in the results section.

### 3. Data

This study was carried out for southwest Brisbane. Based on the direction from the Central business district and the availability of data, a station was selected. The details regarding the station and the climatic years are described in Table 1. The good quality rainfall data is available at the bureau of meteorology website (http://reg.bom.gov.au/climate/data/) and was downloaded for the selected station. Five different climatic conditions namely dry, mild dry, average, mild wet and wet years were adopted after doing the statistical analysis of the rainfall data. These climatic years were categorised based on the percentile value of the annual rainfall [30]. For instance, a year having annual rainfall value closer to 10 percentile value denotes a dry year. Similarly, a year having annual rainfall value closer to 25 percentile value denotes a mild dry year, a year having annual rainfall value closer to mean value denotes an average year, a year having annual rainfall value closer to 75 percentile value denotes a mild wet year and lastly, a year having annual rainfall value closer to 90 percentile value denotes a wet year. A single year may represent an unrealistic rainfall pattern (i.e., sporadic bursts and/or longer dry periods). Therefore, 4 additional years were selected for each climatic condition. They were selected such that 2 years have a rainfall value immediately higher and 2 years have a rainfall value immediately lower than the rainfall value of the year that is taken into consideration.

### 4. Results
The daily rainfall data of different climatic years were inserted in the model (eTank). Expected annual water savings were then calculated for different combinations of tank size, rainwater demand and roof area.

4.1. Development of the generalised equation

Annual water savings were calculated using the model (eTank) for a dry year and tank size of 2500L for different combinations of rainwater demand and roof area. Figure 1 shows the relationship between annual water savings and roof area for different demand scenario. Each curve in figure 1 follows a logarithmic pattern and hence can be expressed as a single logarithmic equation using the best fit technique.

The equations for all the demand scenarios are as follows:

For 200L/day demand, \( AWS = 5.64 \times \ln(RA) - 14.16 \)  

(17)

For 300L/day demand, \( AWS = 11.37 \times \ln(RA) - 7.72 \)  

(18)

| Station number | Climatic year | Years | Annual Rainfall(mm) |
|----------------|---------------|-------|----------------------|
| 040463         | Dry           | 1993  | 556.8                |
|                |               | 1977  | 560                  |
|                |               | 2007  | 676                  |
|                |               | 1994  | 715.2                |
|                |               | 1997  | 735.6                |
|                | Mild dry      | 1986  | 756                  |
|                |               | 2014  | 804.5                |
|                |               | 1991  | 805.8                |
|                |               | 2016  | 822.5                |
|                |               | 1987  | 846.6                |
|                | Average       | 1978  | 1009.7               |
|                |               | 1982  | 1024.6               |
|                |               | 1984  | 1031.8               |
|                |               | 1995  | 1060.2               |
|                |               | 1992  | 1112                 |
|                | Mild wet      | 2011  | 1184.9               |
|                |               | 1973  | 1197                 |
|                |               | 2015  | 1207.8               |
|                |               | 1976  | 1219.7               |
|                |               | 1990  | 1273.6               |
|                | Wet           | 1999  | 1340.4               |
|                |               | 1988  | 1346.5               |
|                |               | 1983  | 1386.8               |
|                |               | 1981  | 1470.5               |
|                |               | 1996  | 1488.2               |

For 400L/day demand, \( AWS = 16.6 \times \ln(RA) - 30.72 \)  

(19)

For 500L/day demand, \( AWS = 20.27 \times \ln(RA) - 47.31 \)  

(20)
Where ‘AWS’ represents the expected annual water savings in kL and ‘RA’ represents the roof area in m². In the above equations, the coefficients (5.64, 11.37, 16.6 and 20.27) and the intercepts (-14.16, 7.72, 30.72 and 47.31) are correlated with the demand. Therefore, using the best fit technique, the above-mentioned coefficients and the intercepts are expressed as equation (21) and equation (22) respectively.

\[
\text{Coefficients} = 16.08 \times \ln(D) - 79.82 \quad (21)
\]

\[
\text{Intercepts} = 67.55 \times \ln(D) - 374.01 \quad (22)
\]

Where ‘D’ represents the rainwater demand in litres. The coefficients and intercepts of equations (17)-(20) can be replaced with equation (21) and equation (22) respectively. As such, a single equation is obtained as follows having independent variables of roof area and rainwater demand:

\[
AWS = (16.08 \times \ln(D) - 79.8) \times \ln(RA) - (67.55 \times \ln(D) - 374) \quad (23)
\]

![Figure 1](image_url)

**Figure 1.** Annual water savings calculated using the model (eTank) for a 2500L tank in a dry year.

Similarly, three more equations were derived for other tank sizes such as 5000L, 7500L and 10,000L.

For 5000L tank,

\[
AWS = (31.8 \times \ln(D) - 161.3) \times \ln(RA) - (142.28 \times \ln(D) - 770.25) \quad (24)
\]

For 7500L tank,

\[
AWS = (40.25 \times \ln(D) - 204.8) \times \ln(RA) - (184.13 \times \ln(D) - 991.4) \quad (25)
\]

For 10,000L tank,

\[
AWS = (48.05 \times \ln(D) - 245.5) \times \ln(RA) - (224.76 \times \ln(D) - 1208.6) \quad (26)
\]

In equation (23)-(26), the coefficients of the first term (16.08, 31.8, 40.25 and 48.05) and the intercepts of the first term (79.8, 161.3, 204.8 and 245.5) are correlated with the tank size and can be expressed as equation (27) and equation (28) respectively.

\[
\text{Coefficients} = 22.76 \times \ln(T) - 162.1 \quad (27)
\]

\[
\text{Intercepts} = 117.88 \times \ln(T) - 843.1 \quad (28)
\]

\[\text{Annual Water Savings (kL)}\]

\[\text{Roof Area (m²)}\]
Where ‘T’ represents the tank size in litres. Similarly, in equations (23)-(26), the coefficients of the second term (67.55, 142.28, 184.13 and 224.76) and the intercepts of the second term (374, 770.2, 991.4 and 1208.6) are correlated with the tank size and can be expressed as equation (29) and equation (30) respectively.

\[
\text{Coefficients} = 111.52 \ast \ln(T) − 806.5
\]  \hspace{1cm} (29)

\[
\text{Intercepts} = 591.67 \ast \ln(T) − 4263.3
\]  \hspace{1cm} (30)

The coefficients and the intercepts of the first term in equations (23)-(26) can be replaced with equation (27) and equation (28) respectively. Again, the coefficients and the intercepts of the second term in equations (23)-(26) can be replaced with equation (29) and equation(30) respectively. As such, a single equation is obtained as follows to calculate the expected annual water savings for the dry year that contains independent variables like roof area, rainfall demand and tank size:

\[
AWS = \left[(22.76 \ast \ln(T) − 162.1) \ast \ln(D) − (117.88 \ast \ln(T) − 843.1)\right] \ast \ln(RA) − \left[(111.52 \ast \ln(T) − 806.5) \ast \ln(D) − (591.67 \ast \ln(T) − 4263.3)\right]
\]  \hspace{1cm} (31)

Similarly, four more equations were developed for four remaining climatic years i.e., mild dry, average, mild wet and wet year.

For the mild dry year, the equation to calculate the expected annual water savings is as follows:

\[
AWS = \left[(23.5 \ast \ln(T) − 165.1) \ast \ln(D) − (126.83 \ast \ln(T) − 900.2)\right] \ast \ln(RA) − \left[(111.96 \ast \ln(T) − 794.6) \ast \ln(D) − (621.58 \ast \ln(T) − 4423.7)\right]
\]  \hspace{1cm} (32)

For the average year, the equation to calculate the expected annual water savings is as follows:

\[
AWS = \left[(22.55 \ast \ln(T) − 159.4) \ast \ln(D) − (122.78 \ast \ln(T) − 876.4)\right] \ast \ln(RA) − \left[(101.84 \ast \ln(T) − 726.6) \ast \ln(D) − (571.41 \ast \ln(T) − 4082.9)\right]
\]  \hspace{1cm} (33)

For the mild wet year, the equation to calculate the expected annual water savings is as follows:

\[
AWS = \left[(13.86 \ast \ln(T) − 90.9) \ast \ln(D) − (75.66 \ast \ln(T) − 502.93)\right] \ast \ln(RA) − \left[(54.25 \ast \ln(T) − 358.7) \ast \ln(D) − (311.38 \ast \ln(T) − 2058.5)\right]
\]  \hspace{1cm} (34)

For the wet year, the equation to calculate the expected annual water savings is as follows:

\[
AWS = \left[(18.83 \ast \ln(T) − 136.9) \ast \ln(D) − (106.59 \ast \ln(T) − 780.9)\right] \ast \ln(RA) − \left[(72.68 \ast \ln(T) − 538.7) \ast \ln(D) − (436.32 \ast \ln(T) − 3217.6)\right]
\]  \hspace{1cm} (35)

All the above mentioned climatic years are categorised according to the percentile value of annual rainfall. The coefficients (22.76, 23.5, 22.55, 13.86 and 18.83) and the intercepts (162.1, 165.1, 159.4, 90.9 and 136.9) of the first term are correlated with the annual rainfall and can be expressed as equation (36) and equation (37) respectively.

\[
\text{Coefficients} = −0.0091 \ast R + 29.6
\]  \hspace{1cm} (36)

\[
\text{Intercepts} = −0.064 \ast R + 208.9
\]  \hspace{1cm} (37)

Where ‘R’ represents the annual rainfall in mm. Similarly, the coefficients (117.88, 126.83, 122.78, 75.66 and 106.59) and the intercepts (843.1, 900.2, 876.4, 502.93 and 780.9) of the second term are correlated with the annual rainfall and can be expressed as equation (38) and equation (39) respectively.

\[
\text{Coefficients} = −0.038 \ast R + 149.2
\]  \hspace{1cm} (38)
8

\textit{Intercepts} = -0.271 \times R + 1058.3 \quad (39)

Once again, the coefficients (111.52, 111.96, 101.84, 54.25 and 72.68) and the intercepts (806.5, 794.6, 726.6, 358.7 and 538.7) of the third term are correlated with the annual rainfall and can be expressed as equation (40) and equation (41) respectively.

\textit{Coefficients} = -0.0702 \times R + 162.4 \quad (40)

\textit{Intercepts} = -0.503 \times R + 1161 \quad (41)

And finally, the coefficients (591.67, 621.58, 571.41, 311.38 and 436.32) and the intercepts (4263.3, 4423.7, 4082.9, 2058.5 and 3217.6) of the fourth term are correlated with the annual rainfall and can be expressed as equation (42) and equation (43) respectively.

\textit{Coefficients} = -0.322 \times R + 837.2 \quad (42)

\textit{Intercepts} = -2.314 \times R + 5982 \quad (43)

Eventually, the coefficients of the first, second, third and fourth term of equations (31)-(35) are replaced by equations (36), (38), (40) and (42) respectively and similarly, the intercepts of the first, second, third and fourth term of equations (31)-(35) are replaced by equations (37), (39), (41) and (43) respectively and a single equation is ultimately developed for Oxley (southwest Brisbane) as follows consisting of independent variables like rainfall, tank size, rainwater demand and roof area:

\[ AWS = \{[(-0.0091 \times R + 29.6) \times \ln(\text{T}) - (-0.064 \times R + 208.9)] \times \ln(D) - [(-0.038 \times R + 149.2) \times \ln(\text{T}) - (-0.271 \times R + 1058.3)] \times \ln(\text{RA}) - \} \times \ln(RA) - [((-0.0702 \times R + 162.4) \times \ln(\text{T}) - (-0.503 \times R + 1161)] \times \ln(D) - [(-0.322 \times R + 837.2) \times \ln(\text{T}) - (-2.314 \times R + 5982)] \] (44)

4.2. Comparison of results

Annual water savings were calculated for five different climatic conditions using the model (eTank) for different combinations of input values like tank size, rainwater demand and roof area. Then, for the same combinations of input values, annual water savings were calculated using the generalised equation. The following figures (2)-(6) shows the equation and model (eTank) simulated results. It can be observed in figures (2)-(6) that the results calculated from the equation closely match the model simulated results. The analysis was done for four tank sizes, however, charts are only shown for 5000L and 10,000L tank size for five distinct climatic years. Although, some deviation is observed in model and equation results for a few cases but only up to a small extent. Moreover, absolutely perfect results cannot be expected from a generalised equation.
Figure 2. Comparison of model and equation results in a dry year for different daily demand scenarios (a) for 5000L tank (b) for 10,000L tank.

Figure 3. Comparison of model and equation results in a mild dry year for different daily demand scenarios (a) for 5000L tank (b) for 10,000L tank.
Figure 4. Comparison of model and equation results in an average year for different daily demand scenarios (a) for 5000L tank (b) for 10,000L tank.

Figure 5. Comparison of model and equation results in a mild wet year for different daily demand scenarios (a) for 5000L tank (b) for 10,000L tank.
5. Conclusions
Most of the studies related to rainwater harvesting have been carried out using advanced tools or programs. These tools are usually not user friendly and require some level of expertise to handle them. A general end-user may not possess this level of expertise and hence may not be able to work out the amount of annual water savings. To overcome this hurdle, this paper presents the development of a generalised equation for calculating the expected water savings through rainwater tanks with major contributing factors like rainfall, rainwater demand, tank size and roof area for southwest Brisbane (Australia). Results from the developed equation were seen matching with the model (eTank) simulated results in the figures (2)-(6). Such an equation is very useful for a general end-user as it makes it convenient for a person to calculate the annual water savings by merely using a calculator or a spreadsheet. The equation can even be used in making a mobile application to help quick calculations. It should be noted that this equation is only valid for a particular region i.e., south-west Brisbane. The development of similar equation for other regions can be a target of future research.

6. References
[1] ABS 2012 Year Book Australia, Australian Bureau of Statistics, Available from: https://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/1301.0–2012–Main%20Features–Australia’s%20climate–143, accessed on 19 August 2020.
[2] Cook S, Sharma A and Chong M, 2013, “Performance analysis of a communal residential rainwater system for potable supply: a case study in Brisbane, Australia”, Water Resour. Manag. 27 4865-76.
[3] Fewkes A, 1999, “The use of rainwater for WC flushing: the field testing of a collection system”, Build Environ 34 765-72.
[4] Vaes G and Berlamont J, 2001, “The effect of rainwater storage tank size on design storms”, Urban Water J. 3 303-07.
[5] Jenkins G A, 2007, “Use of continuous simulation for the selection of an appropriate rainwater tank”, Australas. J. Water Resour. 11 231–46.
[6] Ghisi E, Tavares D D F and Rocha V L, 2009, “Rainwater harvesting in petrol stations in Brasilia: potential for potable water savings and investment feasibility analysis”, Resour Conserv Recycl 54 79-85.
[7] Villarreal E L and Dixon A, 2005, “Analysis of a rainwater collection system for domestic water supply in ringdansen, Norrkoping, Sweden”, Build Environ 40 1174-84.

[8] Chilton J C, Maidment G G, Marriott D, Francis A and Tobias G, 1999, “Case study of a rainwater recovery system in a commercial building with a large roof”, Urban Water J. 1 345-54.

[9] Matos C, Bentes I, Santos C, Imteaz M and Pereira S, 2015, “Economic analysis of a rainwater harvesting system in a commercial building”, Water Resour. Manag. 29 3971-86.

[10] Ward S, Memon F A and Butler D, 2012, “Performance of a large building rainwater harvesting system”, Water Res. 46 5127-34.

[11] Appan A, 1999, “A dual-mode system for harnessing roofwater for non-potable uses”, Urban Water J. 1 317-21.

[12] Karim M R, Bashar M Z I and Imteaz M A, 2015, “Reliability and economic analysis of urban rainwater harvesting in a megacity in Bangladesh”, Resour Conserv Recycl 104 61-67.

[13] Tam V W Y, Tam L and Zeng S X, 2010, “Cost effectiveness and tradeoff on the use of rainwater tank: an empirical study in Australian residential decision-making”, Resour Conserv Recycl 54 178-86.

[14] Khastagir A and Jayasuriya N, 2011, “Investment evaluation of rainwater tanks”, Water Resour. Manag. 25 3769-84.

[15] Farreny R, Gabarrell X and Rieradevall J, 2011, “Cost-efficiency of rainwater harvesting strategies in dense Mediterranean neighbourhoods”, Resour Conserv Recycl 55 686-94.

[16] Imteaz M A, Sagar K A, Santos C and Ahsan A, 2016, “Climatic and spatial variations of potential rainwater savings for Melbourne (Australia)”, Int. J. Hydrol. Sci. Technol. 6 45-61.

[17] Imteaz M A, Paudel U, Ahsan A and Santos C, 2015, “Climatic and spatial variability of potential rainwater savings for a large coastal city”, Resour Conserv Recycl 105 143-47.

[18] Imteaz M A, Moniruzzaman M and Karim M R, 2017, “Rainwater tank analysis tools, climatic and spatial variability: a case study for Sydney”, Int. J. Water 11 251-65.

[19] Imteaz M A, Kariki R, Hossain I and Karim M R, 2017, “Climatic and spatial variabilities of potential rainwater savings and economic benefits for Kathmandu valley”, Int. J. Hydrol. Sci. Technol 7 213-27.

[20] Imteaz M A, Adeboye O B, Rayburg S and Shanableh A, 2012, “Rainwater harvesting potential for southwest Nigeria using daily water balance model”, Resour Conserv Recycl 62 51-55.

[21] Rahman A, Keane J and Imteaz M A, 2012, “Rainwater harvesting in greater Sydney: water savings, reliability and economic benefits”, Resour Conserv Recycl 61 16-21.

[22] Imteaz M A and Moniruzzaman M, 2018, “Spatial variability of reasonable government rebates for rainwater tank installations: a case study for Sydney”, Resour Conserv Recycl 133 112-19.

[23] Khastagir A and Jayasuriya N, 2010, “Optimal sizing of rain water tanks for domestic water conservation”, J. Hydrol. 381 181-88.

[24] Okoye C O, Solyali O and Akintug B, 2015, “Optimal sizing of storage tanks in domestic rainwater harvesting systems: a linear programming approach”, Resour Conserv Recycl 104 131-40.

[25] Imteaz M A, Shanableh A, Rahman A and Ahsan A, 2011, “Optimisation of rainwater tank design from large roofs: a case study in Melbourne, Australia”, Resour Conserv Recycl 55 1022-29.

[26] Campisano A and Modica C, 2012, “Optimal sizing of storage tanks for domestic rainwater harvesting in Sicily”, Resour Conserv Recycl 63 9-16.

[27] Santos C and Taveira-Pinto F, 2013, “Analysis of different criteria to size rainwater storage tanks using detailed methods”, Resour Conserv Recycl 71 1-6.

[28] Ghisi E, Bressan D L and Martini M, 2007, “Rainwater tank capacity and potential for potable water savings by using rainwater in the residential sector of southeastern Brazil”, Build Environ 42 1654-66.
[29] Mun J S and Han M Y, 2012, “Design and operational parameters of a rooftop rainwater harvesting system: definition, sensitivity and verification”, J. Environ. Manage 93 147-53.

[30] Imteaz M A, Rahman A and Ahsan A, 2012, “Reliability analysis of rainwater tanks: a comparison between south-east and central Melbourne”, Resour Conserv Recycl 66 1-7.

[31] Mehrabadi M H R, Saghafian B and Fashi F H, 2013, “Assessment of residential rainwater harvesting efficiency for meeting non-potable water demands in three climate conditions”, Resour Conserv Recycl 73 86-93.

[32] Eroksuz E and Rahman A, 2010, “Rainwater tanks in multi-unit buildings: a case study for three Australian cities”, Resour Conserv Recycl 54 1449-52.

[33] Zhang Y, Chen D, Chen L and Ashbolt S, 2009, “Potential for rainwater use in high-rise buildings in Australian cities”, J. Environ. Manage 91 222-26.

[34] Moglia M, Tjandraatmadja G and Sharma A K, 2013, “Exploring the need for rainwater tank maintenance: survey, review and simulations”, Water Sci Technol Water Supply 13 191-201.

[35] Imteaz M A, Paudel U, Matos C and Ahsan A, 2016, “Generalised equations for rainwater tank outcomes under different climate conditions: a case study for Adelaide”, Int. J. Water 10 301-14.

[36] Moniruzzaman M and Imteaz M A, 2017, “Generalised equations, climatic and spatial variabilities of potential rainwater savings: a case study for Sydney”, Resour Conserv Recycl 125 139-56.

[37] Imteaz M A, Ahsan A, Naser J and Rahman A, 2011, “Reliability analysis of rainwater tanks in Melbourne using daily water balance model”, Resour Conserv Recycl 56 80-86.

[38] Thomas T H and Martinson D B, 2007, “Roofwater Harvesting: A Handbook for practitioners”, ed McIntyre P (Delft: IRC International Water and Sanitation Centre) p 26.