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Climatic and spatial variability of potential rainwater savings for a large coastal city

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ABSTRACT

Majority of the investigations on rainwater harvesting focused on sizing and potential water savings including studies proposing different methods of estimating rainwater tank outcomes. Several studies used monthly rainfall data to estimate rainwater tank outcomes. However, quantification using daily rainfall data will be much more accurate compared to using monthly rainfall data. A vast majority of works using daily rainfall data used daily water balance model for analysis. Again most of the studies using daily water balance model used historical rainfall data, calculated water savings for many years and then presented an average of all the calculated years' total outcome(s). 'Raintank Analyser' is a tool, which uses the same methodology and widely used; used by the South Australian policy makers for producing relevant design charts. In contrast, eTank, a daily water balance model was developed to produce potential rainwater savings, augmented townwater supply, tank overflow, reliability and payback period for three distinct climate conditions (dry, average and wet years). This paper presents comparison of eTank calculated potential water savings with those calculated by 'Raintank Analyser' under similar conditions for a rainfall station in central Adelaide. In general, 'Raintank Analyser' produced water savings are very close to the eTank calculated water savings in average year. However, through the eTank produced potential water savings in dry and wet years, it is found that significant climatic variations exist. Magnitudes of climatic variations under different scenario are presented. Again, to assess spatial variability, three more rainfall stations from different regions of Adelaide metropolitan were selected. eTank was used to calculated potential water savings in three climatic conditions (dry, average and wet years) for various combinations of roof and tank sizes. Again it is found that depending input variable conditions (tank size, roof area and climate) significant spatial variations exist within some of the regions. Also, it is found that potential water savings not only depends on total rainfall amount of a particular area, but also on other input conditions; i.e. under similar conditions an area with lower annual rainfall may provide higher water savings due to rainfall pattern.

1. Introduction

With the ever-increasing population and adverse impacts of climate change, water authorities in many cities of the world are struggling to maintain water supply to a satisfactory level. To avoid scarcity rich nations having sufficient coast-line resorting to sea water extraction through desalination, which is very expensive and uses unsustainable energy source. On the other hand, developing nations are over-extracting surface water and/or groundwater, which causing alarming water quality issues as well as dropping down of groundwater table to a very low level. To avoid these adverse impacts, it is necessary to implement some innovative sustainable practice. With this view many water authorities around the world are considering different measures including promoting water efficient devices, rainwater collection, greywater recycling, sewer mining and aquifer recharge. Among all the sustainable water alternatives for the countries having fair rainfall amounts, onsite rainwater collection and use is most widely used due to its easy collection, low cost, low treatment and maintenance requirements. There have been several studies in other parts of the world quantifying potential rainwater collection and potable water savings (Matos et al., 2014; Ghisi et al., 2007, 2009). Some researchers (Matos et al., 2014; Aladenola and Adeboye, 2010) conducted analysis on monthly time scale i.e. monthly water balance method using

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monthly rainfall and demand. However, Imteaz et al. (2012) conducted a case study using south-west Nigerian daily rainfall data applying water balance model of daily time step. Comparing with the findings of Aladenola and Adeboye (2010) they have shown that analysis using monthly water balance method overestimates the required tank size, in comparison with a daily water balance method, which is supposed to be more accurate. Some researchers (Imteaz et al., 2011; Santos and Taveira-Pinto, 2013 and Matos et al., 2014) conducted analyses on potential water savings for commercial buildings (i.e. large roof) and produced design charts. Cook et al. (2014) has presented a detailed monitoring study for a commercial rainwater tank installed in an office building in a major Australian city (Brisbane) and highlighted operational complexity and malfunctioning of the tank mainly due to lack of commitments and incapability of the person in charge.

Some researchers (Cook et al., 2013; Gurung and Sharma, 2014) broadened the use of rainwater tanks from a single household scale to a communal scale and analysed performance of such communal rainwater tanks for residential suburbs. Among those Cook et al. (2013) conducted detailed monitoring and modelling study for a communal rainwater tank system built for a retirement village near Brisbane. They also investigated the cost implications due to energy uses for pumping. Berwanger and Ghisi (2014) conducted feasibility analysis for a city in Brazil and commented that rainwater tank will be feasible for only selective cases depending on water demand and roof area. Jung et al. (2014) conducted economic feasibility of rainwater tanks for seven major cities of South Korea considering continuous supply of rainwater demand and concluded that to be able to achieve continuous supply the required rainwater tank size is not economically feasible. Due to this fact often a smaller tank is used which requires augmented supply from townwater supply or other sources.

In Australia several studies focused on potential rainwater tank benefits from different roof/building types (Cook et al., 2014; Rahman et al., 2013; Muthukumaran et al., 2011; Khastagir and Jayasuriya, 2010). Users should be careful to adopt outcomes of studies, where a single output(s) is presented for a city (especially for large city), as Imteaz et al. (2013) has presented significant variations of rainwater tank outcomes for large city. Most of the Australian studies were conducted for the major Australian cities i.e. Sydney, Melbourne and Brisbane. Adelaide, being the fifth largest city of Australia has got very limited attention in this regard. Coombes and Kuczera (2003) using PURRS (Probabilistic Urban Rainwater and wastewater Reuse Simulator) model for Adelaide have quantified potential ranges of annual rainwater savings from 17.5 kL to 39 kL for 1 kL tank and 24.5 kL to 66 kL for 10 kL tank depending on roof size and demand.

Among the mathematical modelling techniques used for rainwater tank analysis, daily water balance model is the most accurate. South Australian government used 'Raintank Analyser' to develop several design charts for the optimum sizing of rainwater tanks (DPLG, 2010). 'Raintank Analyser' is a daily water balance tool developed by the University of South Australia (UniSA, 2004) using spreadsheet and daily rainfall data. Major input variables for the tool are daily rainfall, roof area, in-house water demand, monthly irrigation demand and first flush loss. The tool produces expected average annual yields with respect to a range to tank sizes including suggested tank size. However, most of the studies including 'Raintank Analyser' who applied daily water balance modelling, used the model for continuous simulations of historical daily data for a long period (depending on data availability) and eventually calculating an average water savings after calculations of cumulative water savings for many years (historical time series) and dividing it by the number of years used. In general for most of the end-users (who are unlikely to have deeper statistical knowledge) this sort of averaged expected annual water saving is misleading, especially in Australia where inter-annual climatic variations are often quite high. Scientists predict that with the adverse impacts of climate change, such type of climatic variations will be more prominent. To overcome this issue, Imteaz et al. (2015) developed a daily water balance model (eTank) for the analysis of rainwater tank outcomes under three different climatic conditions (i.e. dry, average and wet). eTank has been used for rainwater tanks' outcomes analyses for Melbourne, Sydney and Canberra (Imteaz et al., 2014). This paper presents a comparison of outcomes (i.e. expected water savings) produced by 'Raintank Analyser' and 'eTank' for a rainfall station in Adelaide. As eTank produces outcomes for three climatic conditions, expected water savings calculated by 'Raintank Analyser' were compared with the expected water savings under three climatic conditions calculated by eTank under different conditions. Further analysis was conducted with three additional rainfall stations in different regions within Adelaide to show the spatial variability in regards to expected water savings.

2. Methodology

'Raintank Analyser' downloaded from the University of South Australia website, comes with historical daily rainfall data for some pre-selected cities including Adelaide. In the tool rainfall data from 'Adelaide airport' station is already provided. As such for the comparison with eTank, 'Adelaide airport' station was selected. Daily rainfall data from 1956 to 2012 for the selected station is used for the analysis. eTank uses representative dry, average and wet years' rainfall data. For a particular climatic condition, a single year may exhibit an unusual pattern; as such for each climatic condition 5 years' data were used. Through percentile analysis of historical annual rainfall data series, following years were selected for the mentioned climatic conditions:

1965—dry year,
1988—average year, and
1963—wet year.

For the selection of 5 years' data, for each of the conditions four additional years were selected in a way that out of these four years, two years are having annual rainfalls immediately higher and the other two years are having annual rainfalls immediately lower than the rainfall amount of above selected years. Five selected years and annual rainfall amount in each of the selected years are shown in Table 1. Calculations were performed using eTank for all these selected years for different options having two tank sizes (5 kL and 10 kL), two roof sizes (100 m^2 and 200 m^2) and two demands (200 L

Table 1
Selected rainfalls and corresponding years for the dry, average and wet years.

Climate	Year	Annual rainfall (mm)
Dry	2008	292
	2002	323
	1965	326.2
	1994	326.6
	1961	328.5
Average	1995	420.4
	2004	426.3
	1988	441.6
	2011	444.2
	1998	450.6
Wet	1960	538.7
	1968	570.7
	1963	573.3
	1983	576.2
	1974	586.3