Climate change impacts on potential water savings through household rainwater tanks in Adelaide (Australia)

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Abstract. This paper presents impacts of climate change on future water savings through rainwater tanks for the city of Adelaide in South Australia. Four rainfall stations within Adelaide metropolitan were selected for the current study. The projected rainfall data was generated by the Australian government applying Statistical Downscaling Modelling (SDSM) technique using observed data for the period of 1986-2005. Projected data was downloaded from the Australian government’s climate portal for three future years (2040, 2065 and 2090) and for two climate change scenarios. Projected daily rainfall data was applied to an earlier developed daily water balance model, eTank, which was widely used for the analysis of rainwater tank outcomes. Analyses were conducted for a single demand of rainwater (300 L/day) for two roof sizes (150 m$^2$ and 300 m$^2$) and two tank volumes (5 kL and 10 kL). It is found that potential future water savings for all the selected future years for the three selected stations are expected to reduce; considering all the variables, ranges of potential reductions for “Adelaide Airport” is 1%~53%, for “Kent Town” is 4%~29% and for “Happy Valley Reservoir” is 1%~27%. For the fourth station, Edinburgh Royal Australian Air Force (RAAF), water savings are expected to increase under all the scenarios with a roof size of 150 m$^2$. Whereas, with a roof size of 300 m$^2$, for the same station water savings are expected to decrease under all the scenarios. The maximum potential increase in water savings is expected to be 16% (with a roof of 150 m$^2$), while the maximum potential decrease in water savings is expected to be 23% (with a roof of 300 m$^2$).

Keywords: climate change, SDSM, water savings.

1. Introduction

It is anticipated that due to climate change some part of the world will receive higher amount of rainfall than average, whereas other parts will receive lower amount of rainfall. These altered weather conditions will certainly affect the reliability of traditional water supply system. Haque et al. [1] reported that climate change is also a dominating factor for the reduction of catchment yield. Ever increasing population is causing farther adversity, as with the increasing population demand of potable water also increasing. Regions which depend on groundwater, due to over-extraction this valuable resource is under threat. Groundwater resources are rapidly depleting and as a result groundwater table is continuously dropping, which eventually causing groundwater extraction more difficult and expensive.
To overcome these emerging issues and to tackle the future water stress many concerned authorities are adopting different sustainable technologies and practices. Among different technologies, rainwater system is found to be beneficial, especially in the regions where moderate to decent rainfalls are occurring [2]. Rainwater collected from roof require very little or no treatment for non-potable uses and helps to reduce the cost of mains water supply. There were several studies on rainwater tank efficiency, reliability and investment feasibility in different parts of the world. As for example, in Australia Imteaz and Moniruzzaman [3], Moniruzzaman and Imteaz [4], Rahman et al. [5] and Khaustagir and Jayasuriya [6]; in Brazil Ghisi and Schondermark [7]; in Portugal Matos et al. [8]; in South Korea Mun and Han [9] and in USA Sample and Liu [10].

It was demonstrated that for accurate analysis of rainwater tank outcomes a daily-scale model must be preferred over a longer-scale model [11]. Rahman et al. [5] and Ghisi [12] used daily-scale model and applied historical rainfall data (i.e. daily data for all the available years) to calculate potential outcomes from rainwater tank and calculated rainwater savings (and other outcomes) for many years and eventually averaged the outcomes calculated for many years. Such average outcomes provide an overall insight of expected outcomes, however unable to provide exact information on potential rainwater harvesting for a particular scenario (i.e. dry or wet period) or expected inter-annual variations of particular outcomes (i.e. water savings, reliability, saving efficiency). To demonstrate inter-annual climatic variability, Moniruzzaman & Imteaz [4] and Imteaz et al. [13] presented rainwater tank outcomes for three distinct weather conditions (dry, average and wet). Another issue is that most of the regional studies presented single outcome for a particular city for a particular condition. However, Rahman et al. [5] and Imteaz et al. [13] have shown that significant variations of rainwater tank outcomes are likely to occur even within a city, especially for large cities.

One of the major impediments of wide-scale implementation of rainwater tank is that users are not convinced about their potential return of their investments on rainwater tank. Impacts of climate change have added further uncertainty to the end users. It is obvious that potential rainwater tank outcomes calculated using historical rainfall data are not likely to be same under future climate change scenario. Zhang et al. [14] studied the effects of climate change on water saving efficiency and reliability of rainwater tank system for three different cities (Beijing, Chengdu and Urumqi) in China. They have reported that rainwater tanks in Beijing and Chengdu are likely to be less efficient, while reliability and efficiency of rainwater harvesting system in Urumqi are likely to be improving. Haque et al. [1] presented impacts of the climate change on rainwater tank efficiency for the city of Sydney (Australia). They have used projected rainfall data for the future years and utilising a daily water balance model calculated the potential rainwater savings under the future climate change scenario. They have revealed potential water savings reductions of 0.8%-19.7% (depending on location) for a tank size of 3kL considering combined (i.e. indoor and outdoor) water demand. Also, as per their findings for a bigger tank size the variations of water savings reductions are expected to be wider. These studies necessitate consideration of the impact of climate change in the future water savings calculations. Nonetheless, impacts of climate change on rainfall cannot be generalised, as for some locations future rainfalls are expected to be increased, while for other locations the rainfalls are expected to be decreased. Moreover, frequencies and intensities of the rainfalls are also expected to be changed. As such, separate studies warranted for different cities or regions. This paper presents the impact of climate change on future water savings through rainwater tank for the city of Adelaide (Australia). The outcomes of this research will provide insights about the performance of rainwater tank under future climate change scenarios.

2. Study Area and Data
The study area is Adelaide, the capital city of South Australia having Mediterranean climate, which is usually consist of hot dry summers and cold winters. Adelaide city is one of the driest cities in Australia and receives approximately 585 mm of average annual rainfall. Four locations from four different directions of the Adelaide were selected for the current analysis. Rainfall stations were selected considering the availability of continuous daily rainfall data for a longer period. Map of the region and
selected stations are shown in the Figure 1. Detailed features of the selected stations are provided in Table 1.

3. Methodology

3.1. Extraction of Daily Rainfall Data

In general, emergent General Circulation Models (GCM) are capable of globally predicting potential responses of climate to anthropogenic greenhouse gas (GHG) emissions. However, the outputs from GCM simulations at local scale are often unrealistic due to uncertainties of regional projections inherited from its coarse resolution, which limits its ability to resolve reduced-scale climate features. To overcome this, Wilby et al. [15] proposed a technique to spatially acquire regional climate data at a finer scale named as Statistical Downscale Modelling (SDSM). Over the years, SDSM has become a common tool for numerous studies [16, 17, 18, 19] involving climate projections. To standardize such studies, Australian government through its Commonwealth Scientific and Industrial Research Organisation (CSIRO), commissioned several such studies to selected consultants to prepare and store future projected climate data for different regions/states of Australia. The selected city in this study is belongs to South Australia, and Goyder Institute for Water Research was commissioned to prepare future projected climate data for different regions of South Australia. Applied SDSM was calibrated and validated using observed data from 1986 to 2005. Different climatic variables including daily rainfall data were projected until the year 2100, which are stored in a CSIRO Data Portal [20], available for public use. For the current study daily rainfall data for the future years for all the selected stations were collected from the mentioned data portal. Intergovernmental Panel on Climate Change (IPCC) assessed future CO$_2$ concentrations based on different Representative Concentration Pathways (RCP) as outlined in [21]. For this study, two future CO$_2$ concentrations are considered; i) RCP 4.5: moderate concentration of reaching 538 ppm by the year 2100 and ii) RCP 8.5: very high concentration of reaching 936 ppm by the year 2100.

Table 1. Details of selected rainfall stations

| Rainfall Station         | Station number | Elevation (m) | Annual average rainfall (mm) | Location  |
|--------------------------|----------------|---------------|-------------------------------|-----------|
| Edinburgh RAAF           | 23083          | 17            | 430.1                         | Northern  |
| Adelaide Airport         | 23034          | 2             | 442.0                         | Western   |
| Kent Town                | 23090          | 48            | 547.9                         | Central   |
| Happy Valley Reservoir   | 23721          | 174           | 634.0                         | Southern  |
3.2. Evaluations of Annual Water Savings

Extracted daily rainfall data for the concentration pathways (RCP4.5 and RCP8.5) from the above-mentioned data portal were used to calculate the future annual water saving by using a daily water balance model, “eTank” [22]. Details on logical sequences, formulations and comparison with other prevailing tools are provided in Imteaz et al. [22]. For the current study, annual water savings were calculated for the three representative years; 2040 (for 2030-2050), 2065 (for 2055-2075) and 2090 (for 2080-2100). Water savings were calculated for the selected daily rainfall data for different combinations of roof areas (150 m² and 300 m²) and tank sizes (5 kL and 10 kL) considering a daily rainwater demand of 300 L. Calculated annual water savings were compared with the calculated water savings for average years in the selected regions. For the current average years’ calculation, five average years (1995, 2004, 1988, 2011 & 1998) were selected from the historical rainfall data.

For the analyses of calculated potential water savings, an established index named ‘seasonality index (SI)’ has been used. Earlier studies [23, 24] have used SI values and correlated rainwater savings potentials with the SI values for the corresponding cities. Mathematically, SI is expressed by the following equation:

\[
SI = \frac{1}{R} \sum_{j=1}^{12} \left| X_j - \frac{R}{12} \right|
\]  

(1)

Where, \( SI \) is the Seasonality Index, \( R \) is the mean annual rainfall and \( X_j \) is the mean monthly rainfall for month ‘\( j \)’.

4. Results and Discussions

Table 2 shows the calculated water savings for all the stations under the selected two climate projection scenarios along with average water savings under current condition. The results are shown for two combinations of roof areas (150 m² and 300 m²) and tank sizes (5 kL and 10 kL). From the table it is clear that the outcomes vary not only with the locations, but also with the future years and projection scenarios. For all the stations except “Kent Town”, under RCP 8.5 scenario, potential water savings are...
expected to increase in the years 2040 and 2065. However, the same are expected to decrease in the year 2090. Under RCP 4.5 scenario, for the same stations (Adelaide airport, Edinburgh RAAF and Happy Valley Reservoir) the potential water savings are expected to decrease in the near future (i.e. 2040), then increase in the year 2065 and then again decrease in the far future (i.e. 2090). For “Kent Town”, the potential water savings are expected to decrease under all the scenarios for all the projected years, except under RCP 4.5 in the year 2065. Considering all the variables, in the cases when potential water savings are expected to decrease, the ranges of reductions are: 6%~20% for “Adelaide Airport”, 1%~21% for “Kent Town”, 3%~27% for Edinburgh RAAF and 2%~14% for “Happy Valley Reservoir”. Again, for the cases when the potential water savings are expected to increase, the ranges of increases are: 4%~28% for “Adelaide Airport”, 6%~15% for “Kent Town”, 5%~38% for Edinburgh RAAF and 10%~26% for “Happy Valley Reservoir”. This finding is in line with the findings of Imteaz and Moniruzzaman [25] who assessed potential changes in water savings under climate change scenarios for several locations of Sydney and reported a mix of increase and decrease in potential water savings. Among the cases when water savings are expected to increase, Edinburgh RAAF is expected to experience highest magnitude in increase (38%). Interestingly, among the cases when water savings are expected to decrease, the same location (Edinburgh RAAF) is expected to experience highest magnitude in decrease (27%).

To analyse the calculated water savings potentials, details on projected rainfalls are required. Figure 2 show the projected annual rainfalls under both the projection scenarios along with average annual rainfall (under current condition) for all the stations. It is found that for “Adelaide Airport” projected annual rainfalls under RCP 8.5 is higher for the years 2040 and 2065. However, under RCP 4.5 only the projected annual rainfall for 2065 is higher than the current average annual rainfall. Similar trend is observed in regard to potential water savings, i.e. higher the annual rainfall amounts higher the water savings, except in the case of RCP 4.5 (in the year 2065) for bigger roof area (300 m²). To analyse such anomaly (annual rainfall increased, whereas water savings decreased) Table 3 presents the calculated projected annual rainfalls along with current average annual rainfall and corresponding ‘seasonality index (SI)’ value for each rainfall pattern. It is found that for the cases when projected annual rainfall increased, SI values for those years are also higher than the SI value under current average condition for the respective station. Such high SI values mean occurrences of more sporadic rainfall events, which several climate scientists also predicted, i.e. with the impacts of climate change future rainfall magnitudes are expected to be higher in parts of the world. Sporadic rainfalls of higher magnitudes will cause rainwater tank to be filled quickly and occurrences of immediate overflows. With such rainfall bursts, even though annual total rainfall amount is found to be higher, however in regards to water savings these rainfalls may not contribute much due to losses through overflows. With a bigger roof area such bursts of higher magnitudes even magnify, causing excessive losses and consequently less water savings, as it happened in this particular case with a roof area of 300 m².

| Table 2. Current and future water savings under different scenarios |
| --- |
| **Station** | **Roof Area (m²)** | **Tank Size (kL)** | **Current Average Condition** | **Year 2040** | **Year 2065** | **Year 2090** |
| Adelaide airport | 150 | 5 | 55.68 | 52.01 | **68.70** | 61.86 | **62.41** | 49.62 | 44.66 |
| | 300 | 5 | 73.0 | 67.63 | **76.04** | 68.57 | **86.86** | 60.51 | 64.49 |
| | 150 | 10 | 58.94 | 52.01 | **75.39** | 61.86 | **62.41** | 49.62 | 44.66 |
For "Kent Town", out of six cases, only in one case (RCP 4.5 in the year 2065), projected annual rainfall is higher than the current average annual rainfall. The same trend is reflected in the future potential water savings; only in the case of RCP 4.5 (year 2065), water savings are expected to be higher than the current average water savings. For both “Edinburgh RAAF” and “Happy Valley Reservoir” stations in three cases (RCP 8.5 in the year 2040, RCP 4.5 in the year 2065 and RCP 8.5 in the year 2065) projected annual rainfalls are higher than the current average annual rainfall of the corresponding station. The same trend is reflected in the future potential water savings; i.e. potential future (for the three cases) water savings are expected to be higher than the current average water savings. In these cases, although the projected annual rainfalls are expected to have higher SI values, still the influence of higher sporadicty is not dominant compared to the higher rainfall amounts.

|                | 300 | 10  | 82.80 | 77.28 | 88.84 | 77.31 | 96.32 | 67.35 | 73.14 |
|----------------|-----|-----|-------|-------|-------|-------|-------|-------|-------|
| Kent Town      | 150 | 5   | 62.76 | 61.09 | 60.07 | 71.13 | 60.44 | 62.15 | 53.35 |
|                | 300 | 5   | 75.06 | 61.54 | 72.68 | 83.71 | 62.43 | 65.26 | 66.38 |
|                | 150 | 10  | 69.53 | 64.38 | 67.86 | 79.92 | 65.28 | 62.15 | 56.04 |
|                | 300 | 10  | 85.29 | 70.62 | 81.79 | 90.83 | 69.60 | 67.55 | 77.16 |
| Edinburgh RAAF | 150 | 5   | 50.23 | 48.66 | 69.53 | 60.08 | 59.29 | 46.98 | 40.06 |
|                | 300 | 5   | 68.07 | 72.05 | 78.80 | 73.30 | 85.42 | 64.97 | 66.92 |
|                | 150 | 10  | 55.10 | 48.66 | 70.60 | 60.08 | 59.29 | 46.98 | 40.06 |
|                | 300 | 10  | 80.29 | 79.97 | 90.37 | 84.38 | 93.10 | 72.99 | 76.09 |
| Happy Valley Reservoir | 150 | 5   | 60.79 | 55.25 | 69.04 | 68.79 | 69.61 | 58.15 | 57.70 |
|                | 300 | 5   | 62.41 | 56.53 | 72.37 | 78.46 | 76.78 | 61.05 | 58.97 |
|                | 150 | 10  | 70.55 | 60.64 | 77.33 | 79.61 | 77.68 | 66.31 | 66.38 |
|                | 300 | 10  | 72.27 | 63.91 | 79.89 | 84.93 | 80.15 | 68.07 | 65.50 |

Note: Bold numbers are increase in water savings.

For “Kent Town”, out of six cases, only in one case (RCP 4.5 in the year 2065), projected annual rainfall is higher than the current average annual rainfall. The same trend is reflected in the future potential water savings; only in the case of RCP 4.5 (year 2065), water savings are expected to be higher than the current average water savings. For both “Edinburgh RAAF” and “Happy Valley Reservoir” stations in three cases (RCP 8.5 in the year 2040, RCP 4.5 in the year 2065 and RCP 8.5 in the year 2065) projected annual rainfalls are higher than the current average annual rainfall of the corresponding station. The same trend is reflected in the future potential water savings; i.e. potential future (for the three cases) water savings are expected to be higher than the current average water savings. In these cases, although the projected annual rainfalls are expected to have higher SI values, still the influence of higher sporadicty is not dominant compared to the higher rainfall amounts.
Table 3. Current and future projected rainfalls and seasonality index* values under different scenarios

| Station               | Average 2040 | Year 2040 | Year 2065 | Year 2090 |
|-----------------------|--------------|-----------|-----------|-----------|
|                       |              | RCP 4.5   | RCP 8.5   | RCP 4.5   | RCP 8.5   | RCP 4.5 | RCP 8.5 |
| Adelaide airport      | 436.6 (0.39) | 385.26 (0.49) | 558.47 (0.55) | 458.25 (0.52) | 462.29 (0.57) | 367.58 (0.29) | 330.85 (0.63) |
| Kent Town             | 542.80 (0.43) | 476.87 (0.50) | 520.78 (0.51) | 591.97 (0.54) | 507.87 (0.48) | 460.39 (0.33) | 520.25 (0.47) |
| Edinburgh RAAF        | 428.30 (0.33) | 360.48 (0.49) | 522.95 (0.53) | 445.04 (0.48) | 439.21 (0.54) | 348.02 (0.29) | 296.73 (0.59) |
| Happy Valley Reservoir| 631.80 (0.41) | 608.92 (0.55) | 814.36 (0.54) | 696.17 (0.55) | 707.40 (0.59) | 575.38 (0.31) | 529.46 (0.58) |

Note: Bold numbers are increase in annual rainfall, numbers within parenthesis are the SI values*
*Seasonality index (SI) defined by Eqn. 1

5. Conclusion

One of the major impediments on wide-scale implementations of rainwater tank is the uncertainty on potential water savings. With the impacts of climate change, concern on such uncertainty even becoming more dominant. Statistical downscaling is an emerging technique widely used for evaluating and projecting future weather parameters such as rainfall and temperature. For the current study, projected daily rainfall data for four different regions within Adelaide metropolitan were extracted from statistically downscaled data performed and stored by the Australian government authority, CSIRO. For the purpose of comparisons three future years (2040, 2065 and 2090) were selected under two different climate projection scenarios (RCP 4.5 and RCP 8.5). Generated daily rainfall data for each region was used to calculate potential water savings in the selected future years with a constant rainwater demand (300 L/day) for two roof areas (150 m² and 300 m²) and two tank sizes (5 kL and 10 kL) using an earlier developed daily water balance model, eTank, which has been widely used for such analyses for many cities around the world.
From the eTank simulations it is found that out of six cases in three cases (RCP 8.5 in the year 2040, RCP 4.5 in the year 2065 and RCP 8.5 in the year 2065) for “Edinburgh RAAF” and “Happy Valley Reservoir” stations potential water savings are expected to increase, as in these cases for the same stations projected annual rainfalls are expected to be higher than the current average annual rainfalls. For the remaining three cases water savings are expected to decrease, which are in line with the projected annual rainfalls for the same cases in the same regions. For “Adelaide Airport” similar outcomes are expected under the same three cases, except for the case of bigger roof (300 m²) water savings are expected decrease even though annual rainfall amount is expected to increase. Reason for this discrepancy is increase in SI value for the projected rainfalls, which are expected to occur with more sporadic rainfall bursts. These higher rainfall bursts are magnified with the support of bigger roof causing excessive runoff and subsequent overflow losses from the rainwater tank. For “Kent Town”, only in one case (RCP 4.5 in the year 2065) projected annual rainfall is higher than the current average annual rainfall and the same trend is expected to happen in regards to annual water savings, i.e. water savings are also expected to increase for the same scenario. In summary, a mix of increase and decrease of water savings are expected depending on the scenario and roof size.

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