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Evaluation of Rainwater Harvesting Systems in Three Major cities of New South Wales

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Evaluation of Rainwater Harvesting Systems in Three Major cities of New South Wales

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Abstract. Rainwater harvesting (RWH) systems are becoming more popular to reduce pressure on mains water as well as to serve as a sole freshwater supply system in rural areas. Australia is a large continent with highly variable rainfall and hence performance of a RWH system varies from location to location. This paper presents reliability and water-saving potential of a RWH system in three major cities namely Sydney, Newcastle and Wollongong of New South Wales (NSW) State of Australia. A python-based daily water balance model is built to analyse the performance of a RWH system, which uses rainfall, loss, water demand and roof catchment data. To enable selection of ideal rainwater tank size for the selected locations, three different water uses (toilet and laundry, irrigation, and combined use) and five tank sizes (1, 5, 10, 20 and 30 kL) are considered. It is found that the rainwater tank size is influenced by roof area, number of users, water demand and rainfall characteristics. This study will help in decision-making regarding implementation of a RWH system in these Australian cities. This research also contributes towards achieving water related sustainable development goals (SDG).

1. Introduction

Water is an important resource for our survival. Australia's water supply systems are undergoing significant stress owing to several factors including growing water demand, population growth, urbanisation and frequent drought and bushfire due to climate change and variability. Freshwater scarcity is a major concern in Australia, which is the world's driest inhabited continent [1]. Hence, it is very important to utilise alternate fresh water sources which is capable of meeting the growing future water demand. Rainwater harvesting (RWH) systems are receiving great attention as one of the best alternative freshwater sources because it is relatively cleaner and easy to collect [2,3]. After surface water and groundwater, RWH is Australia's third biggest source of freshwater. RWH is defined as the process to conserve rainwater by collecting, conveying, and storing from impervious surfaces (such as roof and parking lots) for later use [4]. A RWH system has three main components, catchment area, conveyance pipe and storage system. The RWH system performance is measured in terms of water savings, reliability, financial viability, water security and environmental benefits [5]. In RWH system design, optimisation and performance evaluation, several techniques can be used including stochastic approach [6], mass curve analysis [7] and computer-based behavioral analysis [8]. The most accurate way among these is computer based behavioral analysis to optimise the size of a RWH system [9].

In the past there has been many studies, on RWH systems that relate tank size with roof area [10]. For example, Imteaz et al. [11] built an eTank tool using daily water balance modelling approach, which has been adopted in many Australian studies. Ghisi et al. [12] demonstrated water saving potential of RWH systems in Brazil under a variety of rainfall regimes. They observed an average mains water savings of up to 79%, however, depending on rainfall pattern, the potential water savings for several cities were noted as low as 12%. Muthukumaran et al. [13] showed that RWH system within a purpose-built residence in rural Victoria, Australia, could save up to 40% of potable water. Farreny et al. [14] assessed a RWH system in Spain and noted that sloping smooth roofs would accumulate up to 50% more rainfall than flat rough roofs.

The primary goal of this study is to examine the reliability and water-savings potential of a RWH system for three major cities of New South Wales (NSW) in Australia where water demand is quite high. Although numerous research studies on RWH potentials were conducted across the globe, there have been relatively few in-depth studies on RWH potentials in major cities of NSW. As the water demand and supply pattern varies from location to location across NSW, there is a greater need to assess and identify potential of a RWH system for different cities in order to achieve better water resources management in NSW covering different cities/towns. It is expected that a detailed investigation on RWH systems as proposed here will help local councils of these three cities to develop a comprehensive RWH guideline. The reliability of a RWH system of a detached house with four persons is assessed in this study, which considers three types of water uses, indoor (toilet and laundry use), outdoor (irrigation) and combination of the previous two cases (combined use).

2. Study area and data

Due to future growth potential, three major cities, Sydney, Newcastle and Wollongong of New South Wales (NSW) are considered for this study. Sydney, the capital city of NSW is located on the east coast of the Tasman Sea, which is part of the South Pacific Ocean. Sydney is the largest city in Australia with a population of about 4.9 million. About 120 km north-northeast from Sydney, Newcastle is located on the Hunter River in the eastern NSW. Wollongong is located on the South Pacific Ocean about 70 km southwest of Sydney.

Map of the selected locations showing nine rainfall stations, three from each city, is shown in Figure 1. Table 1 provides the city name, station number, station name, coordinates (latitude and longitude), data length and average annual rainfall (AAR) for the selected rainfall stations. Observed daily rainfall data from the selected stations are gathered from Australian Bureau of Meteorology (BOM) covering 30 years data length. The average annual rainfall values for all the selected locations range 939 to 1173 mm/year. The average monthly rainfall plot for the selected stations is shown in Figure 2, which shows that August, September and October are the lowest rainfall months for these stations.

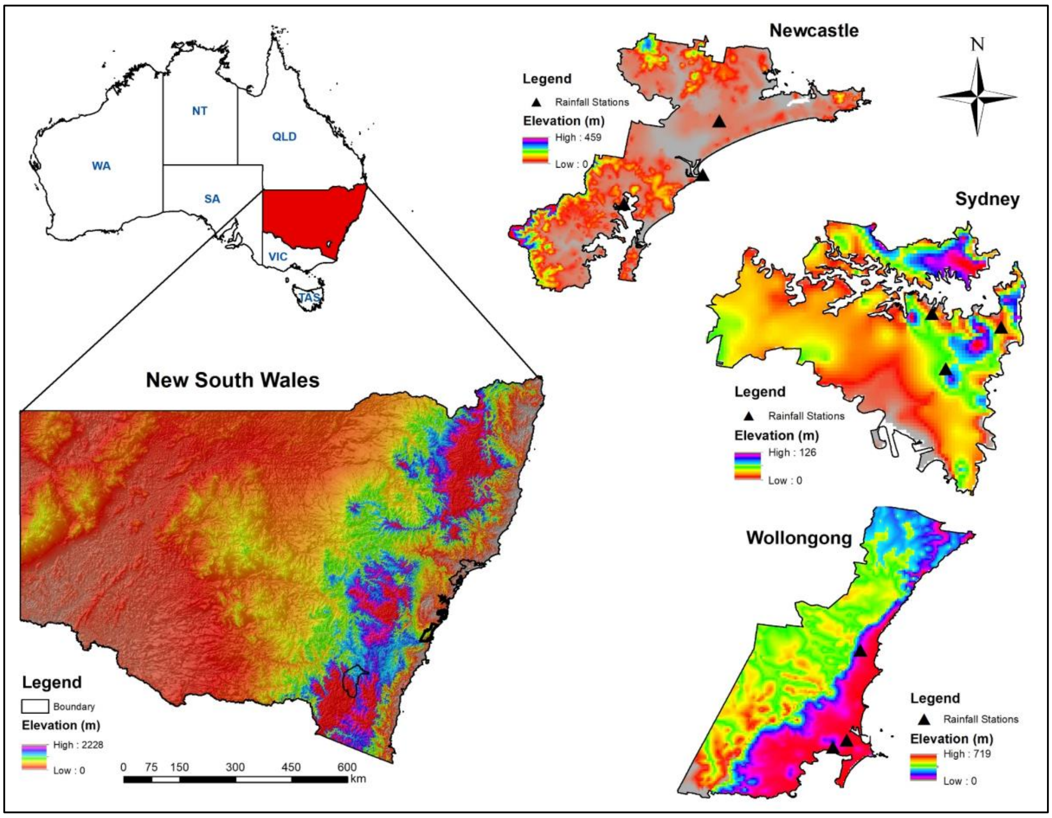

Figure 1. Location of the selected three cities of New South Wales.

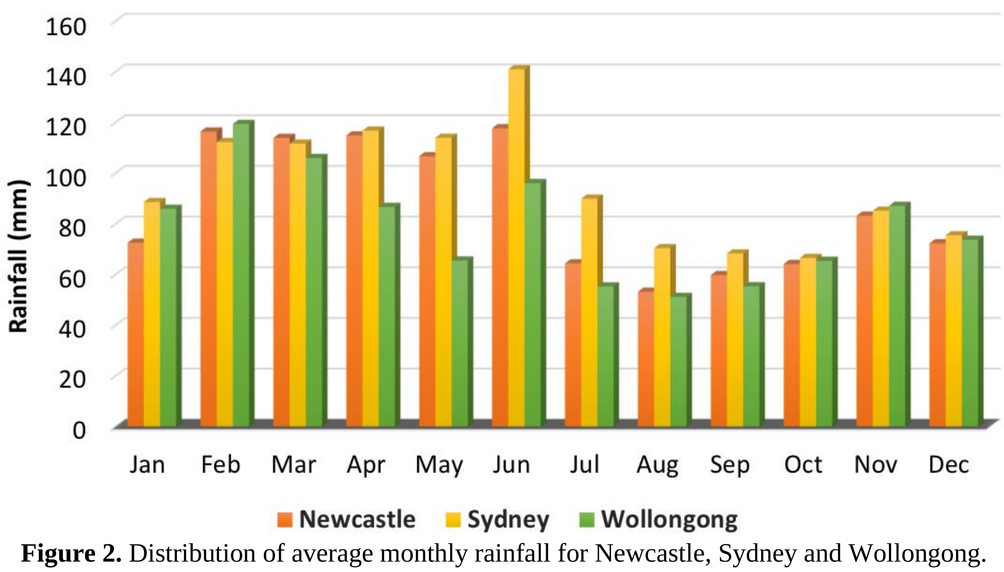

Figure 2. Distribution of average monthly rainfall for Newcastle, Sydney and Wollongong.

Table 1. Summary of rainfall stations for all the selected stations.

City	Station No.	Station Name	Latitude (degree)	Longitude (degree)	Period (daily)	AAR (mm)
Newcastle	61055	Newcastle Nobbys Signal Station AWS	32.92° S	151.80° E	1990-2019	1005
	61078	Williamtown RAAF	32.79° S	151.84° E	1990-2019	1069
	61393	Edgeworth WWTP	32.93° S	151.62° E	1990-2019	1047
Sydney	66006	Sydney Botanic Gardens	33.87° S	151.22° E	1990-2019	1125
	66073	Randwick Racecourse	33.91° S	151.23° E	1990-2019	1126
	66098	Rose Bay	33.88° S	151.27° E	1990-2019	1173
Wollongong	68108	Woonona	34.34° S	150.90° E	1990-2019	947
	68110	Berkeley	34.48° S	150.86° E	1990-2019	961
	68131	Port Kembla	34.47° S	150.88° E	1990-2019	939

3. Methodology

Based on the daily rainfall data at a given station, a continuous simulation model is developed to calculate water balance (based on yield-after-spillage principle) i.e. how much water can be harvested from a given roof area by a given tank size. The model also needs daily water demand, runoff coefficient and first flush data. Five different tank volumes are considered, which are 1, 5, 10, 20 and 30 kL. A detached house with 4 occupants and a total site area of 450 m^2 are adopted. The roof, lawn and other impervious areas are taken as 200 m^2, 150 m^2 and 100 m^2, respectively. Figure 3 illustrate the adopted methodology.

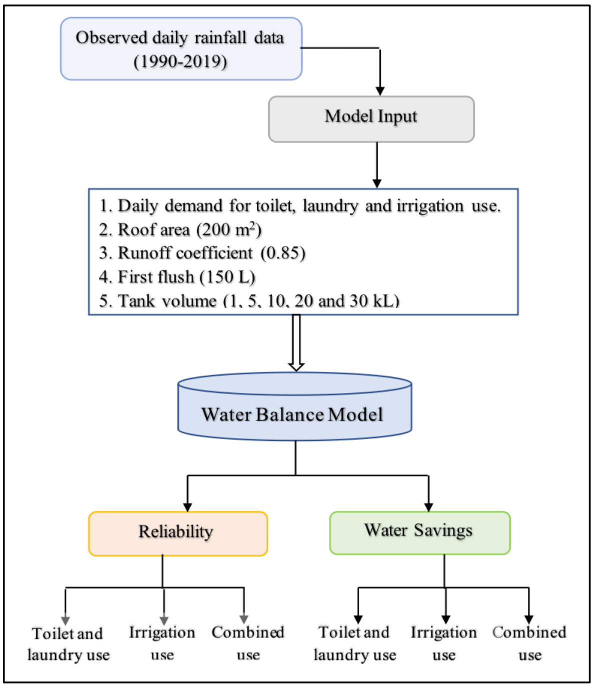

Figure 3. Flowchart showing the adopted methodology.

3.1. Reliability

It is important to know how many days the total water demand can be met by a proposed RWH system. In this regard, 'reliability' is used, which is simply the fraction of the days total water demand is met considering the period of simulation. The equation to calculate reliability is expressed as follows:

$$R\ (\%) = \frac{N\text{-}X}{N} \times 100 \tag{1}$$

where R is the reliability of RWH system (%), X is the total number of days in a year when intended water demand is not met, and N is the total number of days of the simulation period.

3.2. Water demand

The water demand for toilet is taken as 0.018 kL/person/day based on a 6 L/flush and total of three flush per person per day. The laundry demand is assumed to be 50 L/wash at 0.43 washes/day resulting in 0.0215 kL/day of water use. The irrigation demand is taken as 10 mm depth of irrigation.

4. Results and discussion

4.1. Reliability analysis

Figure 4 shows the reliability of a RWH system for different tank sizes and water uses for three selected cities. For toilet and laundry use, reliability is about 80% for 1 kL tank size, which is increased to 100% for a 5 kL tank. However, the irrigation reliability and combined water use reliability does not reach 80% even with a 30 kL tank size. The reason for low reliability in these cases is that irrigation demand is too high. To increase the reliability for these cases, larger roof area would be needed.

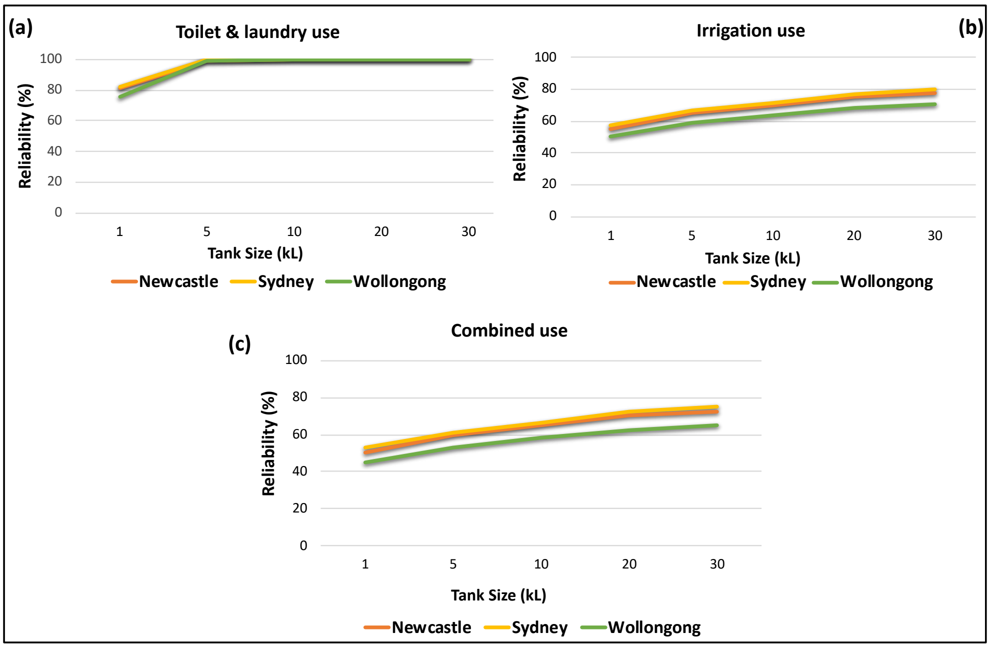

Figure 4. Reliability of rainwater tanks for toilet and laundry, irrigation and combined uses.

4.2. Water savings and demand analysis

Figure 5 depicts water saving curves for three different water uses. The average yearly water savings for a 1kL tank are 29 kL for Sydney, 28 kL for Newcastle and 26 kL for Wollongong, with a mean value of 27 kL for all the three cities. For toilet and laundry use, it can be seen that after 5 kL tank size, the water savings nearly become constant for all the sites. This is because the amount of water used from a tank mostly depends on the number of people living in the house, with a larger tank, if the number of users is not increased, the water savings do not increase because most the collected water remains unutilised. It can be seen that water savings increase with tank size for irrigation use, which is due to higher demand for irrigation need. This is due to the fact that irrigation demand is far higher than toilet and laundry demand. It is found that the average annual water savings (irrigation use)for a 1 kL rainwater tank is 22 kL, which increases to 64 kL for a 5 kL tank to 129 kL for 30 kL tank. Similar trends can be seen for combined use as well.

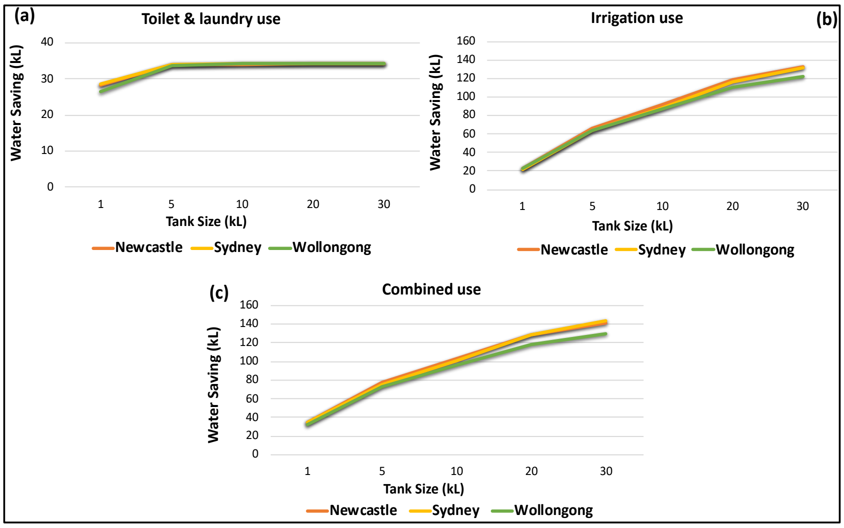

Figure 5. Mean yearly water savings for toilet and laundry, irrigation and combined uses.

Figure 6 depicts the monthly variation in number of days when water demand is fully satisfied by the RWH systems in these three cities. It can be seen from this figure that Wollongong is performing poorer as compared to Sydney and Newcastle. With a 5 kL tank, the toilet and laundry demands can be met on all the months. Winter (July and Aug) has the lowest number of days when a tank can meet the full demand for irrigation and combined use.

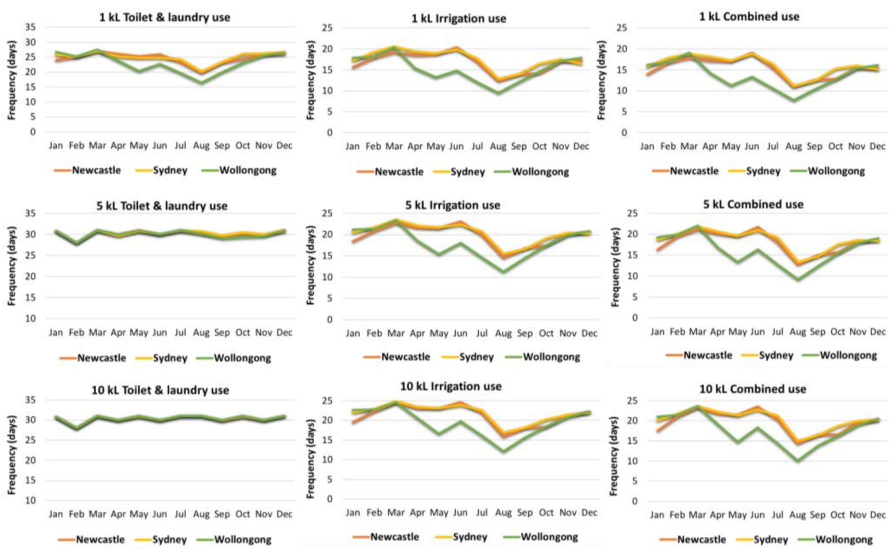

Figure 6. Number of days when monthly water demand is satisfied for 1 kL, 5 kL and 10 kL tanks.

5. Conclusion

This study investigates RWH system viability for three major cities of NSW in Australia in terms of reliability and water savings. It is found that when the tank capacity is between 1 and 5 kL, reliability is quite high (75-99%) for toilet and laundry use. For a 10 kL tank size, Wollongong has the lowest reliability (75%) while Sydney has the highest (99%) one. It is also found that as the tank size increases the reliability increases up to 10 kL tank size, and thereafter, reliability stabilises. Usage of tank volume larger than this would not be economical unless the roof area is increased. For irrigation and combined use, the water demand is quite high, which results in lower reliability for all the selected sites. Wollongong has the lowest reliability ranging from 44-64% for all the tank sizes, while Sydney has the highest ranging from 52-75%. Moreover, the reliability for irrigation and combined use is highly variable across the selected sites because irrigation demand is dependent on the number of rain days in a year, which varies from location to location. Further research is needed to assess the financial and environmental viability of the RWH systems.

6. References

[1] Preeti P, Jakhar S and Rahman A 2019 Rainwater Harvesting in Australia Using an Australia-Wide Model: A Preliminary Analysis. *Proc. Int. Conf. on Water and Environmental Engineering (Dhaka, Bangladesh)*

[2] Bashar M Z I, Karim M R and Imteaz M A 2018 Reliability and economic analysis of urban rainwater harvesting: A comparative study within six major cities of Bangladesh, *Resources, Conservation and Recycling*. **133** 146-154.

[3] Hajani E and Rahman A 2014 Reliability and cost analysis of a rainwater harvesting system in peri-urban regions of Greater Sydney, Australia, *Water* **6(4)** 945-960.

[4] Toosi A S, Danesh S, Tousi E G and Doulabian S 2020 Annual and seasonal reliability of urban rainwater harvesting system under climate change, *Sustainable Cities and Society*. **63** 102427.

[5] Notaro V, Liuzzo L and Freni G 2016 Reliability analysis of rainwater harvesting systems in southern Italy, *Procedia engineering* **162** 373-380.

[6] Basinger M, Montalto F and Lall U 2010 A rainwater harvesting system reliability model based on nonparametric stochastic rainfall generator, *Journal of Hydrology* **392(3-4)** 105-118

[7] Shokati H, Kouchakzadeh M, and Fashi F H 2020 Assessing reliability of rainwater harvesting systems for meeting water demands in different climatic zones of Iran, *Modeling Earth Systems and Environment* **6(1)** 109-114

[8] Fewkes A and Butler D 2000 Simulating the performance of rainwater collection and reuse systems using behavioural models, *Building Services Engineering Research and Technology* **21(2)** 99-106

[9] Hajani E and Rahman A 2014 Rainwater utilization from roof catchments in arid regions: A case study for Australia, *Journal of Arid Environments* **111** 35-41

[10] 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. *Resources, Conservation and Recycling* **73** 86-93.

[11] Imteaz M A, Ahsan A, Naser J, and Rahman A 2011 Reliability analysis of rainwater tanks in Melbourne using daily water balance model, *Resources, Conservation and Recycling* **56(1)** 80-86.

[12] 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, *Building and Environment* **42(4)** 1654-1666.

[13] Muthukumaran S, Baskaran K, and Sexton N 2011 Quantification of potable water savings by residential water conservation and reuse–A case study, *Resources, Conservation and Recycling* **55(11)** 945-952.

[14] Farreny R, Morales-Pinzón T, Guisasola A, Tayà C, Rieradevall, J and Gabarrell X 2011 Roof selection for rainwater harvesting: quantity and quality assessments in Spain, *Water research* **45(10)** 3245-3254.

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