Journal of Arid Environments 111 (2014) 35–41

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Rainwater utilization from roof catchments in arid regions: A case study for Australia

Evan Hajani, Ataur Rahman*

School of Computing Engineering and Mathematics, University of Western Sydney, Australia

ARTICLE INFO

Article history:
Received 10 January 2014
Received in revised form
15 July 2014
Accepted 16 July 2014
Available online

Keywords:
Arid region
Life cycle cost analysis
Rainwater harvesting system
Rainwater tanks
Reliability analysis
Water conservation

ABSTRACT

Water is a scarce resource in arid regions, and hence water harvesting is critically important in these regions for which many different means are adopted including groundwater and rainwater harvesting. This paper examines the feasibility of rainwater harvesting from roof catchments in arid regions of Australia. For this, ten representative locations in the arid regions of Australia are selected. Also, ten different sizes of rainwater tanks ranging from 5 kL to 50 kL and three different combinations of water uses are considered. A model is developed to simulate the performance of a rainwater harvesting (RWH) system. It is found that the reliability of a RWH system is highly dependent on mean annual rainfall at the location of interest. It is found that a 20 kL tank can provide a reliability of 61%–97% for toilet and laundry use depending on the location within the Australian arid regions. At the current water price, RWH system is not financially viable in the Australian arid regions. The methodology adopted in this paper can be adapted to other similar arid regions of the world.

1. Introduction

Currently around half of the countries in the world face aridity of various degrees where water is a limiting factor to agricultural development (Zhang et al., 2013). There is an obvious need to have a better understanding of the hydrology in arid regions for the proper utilization of water resources (Pilgrim et al., 1987). In an arid region, evaporation is much higher than rainfall; hence most of the generated runoff is lost due to evaporation unless it is preserved by appropriate means.

In arid regions, most rainfall occurs from a few intensive convective storms. A small fraction of rain is absorbed by the soil which does not penetrate deeply into the soil profile and is mostly lost by direct evaporation into the atmosphere after the rainfall (Zhang et al., 2013). Various techniques of runoff collection are practiced in the arid regions across the world ranging from rainwater tanks to shallow aquifers. Harvested runoff in an arid region may be used for many useful purposes, e.g. household use, food and fuel production, flood management, erosion control and landscape development (Mzirai and Tumbo, 2010). In terms of combating desertification and degradation, water harvesting appears to be a viable solution in an arid region (Ben-Asher and Berliner, 1994).

Streams in the arid regions are characterised by extreme flow variability, with distinct periods of runoff separated by periods of no flow (Knighton and Nanson, 2001). The combination of high intensity and short durations of convective rainfall may sometimes generate extensive overland flow. This overland flow, concentrated by the topography, converges on the wadi channel network and may cause flush flooding. The runoff generation in the arid region is highly localised in space and generally occurs from only part of a catchment, and disappears quickly. Hence most of the arid regions do not have a perennial river system.

Water conservation in arid regions can be achieved through a number of ways such as rainwater harvesting, which is defined as a method of inducing, collecting, storing and conserving local surface runoff for agricultural production, domestic uses and groundwater recharge (Sonbol, 2006). There have been numerous studies in the world highlighting the benefits of harvesting runoff in arid regions. For example, Abu-Awwad and Shatanawi (1997) investigated rainfall runoff characteristics and infiltration in soils affected by surface crust by using three micro-watersheds within the Muwaqar region in Jordan. It was found that the rainwater harvesting works best on sloped soil with a surface crust that has a low infiltration rate. Shadeed and Lange (2010) analysed two different types of rainwater harvesting (RWH) systems in urban and rural areas in Faria Catchment in Palestine. The study demonstrated that rainwater harvesting could help to supplement the water available for dry periods to urban and rural areas and could reduce competition

* Corresponding author. Tel.: +61 2 47360145; fax: +61 2 47360833.
E-mail addresses: a.rahman@uws.edu.au, ataur38@yahoo.com.au (A. Rahman).

http://dx.doi.org/10.1016/j.jaridenv.2014.07.007
0140-1963/

between agricultural and household demands when the supply-demand gap is comparatively higher.

Zhu et al. (2004) examined the quality of harvested rainwater in arid regions of North China. Water samples from different catchment systems were analysed and it was found that the rainwater harvested from a roof-yard catchment system mostly agreed with the WHO standards for drinking water. Hatibu et al. (2004) evaluated farmer-initiated and managed RWH systems in semi-arid regions of eastern Africa to produce maize, paddy and vegetables. The economics of these practices was analysed in two contrasting districts over a period of five years. It was concluded that rainwater harvesting could contribute to improved incomes and food security of farmers in these regions.

Fox et al. (2005) assessed the economic viability of a RWH system with a water storage component for supplemental irrigation for a small landholdings farmer at two locations in semi-arid sub-Saharan Africa. Different scenarios were assessed which were dedicated to improve rain fed farming practices in order to secure annual household grain consumption. It was found that rainwater harvesting could provide significant economic benefits. Sonbol (2006) presented an evaluation of a number of RWH systems including rainwater harvesting, water storage tanks, seasonal subsurface and various surface reservoirs for the Sinai Peninsula in Egypt. The best methods were identified to use water resources and manage flooding as well as the development and structural design visualization for some rainwater harvesting projects where this water could be utilized for domestic purposes, drinking, agriculture, and in the shallow aquifer recharge. Amin et al. (2013) presented an analysis of the daily, monthly and annual mean, maximum and total rainfall records to identify the changing pattern of rainfall in different cities in Saudi Arabia. They found that the harvested rainwater can be a reasonable solution for water shortage and flooding problems in urban areas of Saudi Arabia.

Australia is considered as the second-driest continent in the world after Antarctica, with an average annual rainfall below 600 mm over 80% of the country, and below 300 mm over 50% (Australian Bureau of Statistics, 2013a, b)). The UNESCO (1999) suggested the ratio of precipitation (P) to potential evapotranspiration (ET) as an aridity index, with the following categories: (i) $P/PET < 0.03$: hyper-arid region; (ii) $0.03 < P/PET < 0.2$: arid region; and (iii) $0.2 < P/PET < 0.5$: semi-arid region. According to these critera, the arid and semi-arid areas constitute over 70% of the total land area of Australia (James et al., 1995; Zaman et al., 2012). There have been a limited number of studies on the potential of RWH system in the arid regions of Australia in contrast to the urban areas of Australia where RWH system has become popular in recent years due to government incentives and a greater environmental awareness in the community (e.g. Eroksuz and Rahman, 2010; Imteaz et al., 2011; Khastagir and Jayasuriya, 2009; Rahman et al., 2010, 2012; Zhang et al., 2010).

The climates within the arid regions of Australia can be highly variable. The mean annual rainfall in Australian arid regions is typically below 300 mm with a very high annual evaporation rate that often exceeds 2000 mm. The Central Australian arid region experiences summer dominant rainfall while the Southern and South-western Australian arid regions have a Mediterranean climate characterised by hot, dry summers and cool and wet winters (Smithies, 2012). Australia can experience up to 4000 mm of average annual evaporation in some arid locations. It is estimated that up to 95% of Australia's rainfall evaporates and does not contribute to runoff (Craig, 2008). In harvesting the runoff in the arid region, it is important to capture as much rainfall as possible and to reduce the evaporation from water storage tanks.

In many remote rural arid regions of Australia, rainwater harvesting is often the only viable potable water supply and is thus an important component of rural water provision (Pigram, 2007). As noted by CAT (2005), RWH system can provide a significant source of water in the arid regions of Australia. For example, in South Australia, the most arid state of Australia, 51% of people use RWH system and 80% of these are located in arid parts of the state (Australia Government, 2004). Conway et al. (1999a) assessed the rainwater harvesting potential in Giles central Australia, where the median rainfall is 119 mm per year. They found that in an average year, a house with 266 m^2 of roof area could collect 61 kL of water in a year. Conway et al. (1999b) examined the rainwater harvesting potential in ten remote indigenous communities in arid Australia and found that a 200 m^2 roof area fitted with a 22 kL rainwater tank could provide 5 people with 15 L of water per day, even in the lowest years of rainfall on record.

Smithies (2012) investigated the feasibility of different types of RWH systems (such as rainwater catchment dams, roof and tank systems and ponding banks) at seven locations in the arid regions of Western Australia, South Australia and the Northern Territory. He found that the arid regions in Australia are predominantly groundwater reliant; however, many areas have issues with groundwater quality. He noted that, despite various limitations in the arid regions, rainwater harvesting has a number of potential applications as a supplementary water supply to increase water quality and security.

Sample and Liu (2014) evaluated RWH system across a wide range of land uses and locations in Virginia, USA and found that for a 10 kL tank in high density residential area having a roof area of 1000 m^2 and irrigation area of 1200 m^2 and with 50 occupants RWH system reliability ranges from 0.25 to 0.35. They also found that the current water price needs to be increased by about 100% to achieve a benefit cost ratio of 1 at most of the study locations. In another recent study, Walsh et al. (2014) presented the results of a long-term, continuous hydrologic simulation analysis of a catchment-scale residential RWH system in a semi-arid catchment located in San Diego, USA. They found that use of catchment-scale RWH system can reduce the runoff volume from the catchment by 10.1%–12.4% for rainwater tank sizes ranging from 227 to 7571 L.

This paper examines the feasibility of rainwater harvesting as a means of water utilization in arid region of Australia with two objectives. Firstly, how much water can be harvested from roof catchments in various parts of the arid regions of Australia using rainwater tanks of different sizes. Secondly, how many days in a year a RWH system can provide sufficient water for various domestic water uses. To answer these questions, we developed a model to simulate the performance of a RWH system and apply this model to ten different locations covering the whole of the arid region of Australia. This is perhaps one of the most detailed rainwater harvesting analyses undertaken based on a comprehensive database of daily rainfalls in the arid regions of Australia and evaluating rainwater tanks of many different sizes. The findings of this paper are expected to provide important insights about the feasibility of a RWH system in arid regions of Australia and other similar countries of the world where water is a limiting resource for economic development.

2. Data and method

Ten different locations covering the arid regions of South Australia (SA), Western Australia (WA), the Northern Territory (NT), Queensland (QLD) and New South Wales (NSW) are selected as shown in Fig. 1. Appendix 1 (electronic version only) shows the list of the selected rainfall stations, rainfall data lengths and average annual rainfalls. The daily rainfall data at the selected stations are obtained from the Australian Bureau of Metrology (BOM, 2013). The rainfall data length ranges from 34 years to 77 years. The mean