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Evaluation of climate change impacts on rainwater harvesting

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A B S T R A C T

Water management is an important issue in urban design due to the growing concern of water scarcity. As a result, rainwater harvesting system has received notable attention as an alternative water source. Rainwater is one of purest form of waters and can easily be accessed via a rainwater harvesting system. In general, performance of a rainwater harvesting system is estimated based on historical rainfall data without the possible impacts of climate change on rainfall. However, rainfall pattern is likely to change in the future as a consequence of climate change that may affect the performance of a rainwater harvesting system. But research on climate change impacts on rainwater harvesting is limited. The objective of this study is to understand the plausible impacts of climate change on the performances (i.e. water savings, reliability and water security) of a residential rainwater harvesting system, based on the projected future rainfall conditions. A continuous daily simulation water balance model is developed based on behavioural analysis and yield-after-spillage criteria to simulate the performances of a rainwater harvesting system. The analysis is conducted at five locations in the Greater Sydney region, Australia.

The results indicate that performances of a rainwater harvesting system will be impacted negatively due to climate change conditions in the future. It is found that a given tank size at the selected locations would not be able to supply expected volume of water under changing climate conditions in future. Water savings is going to be reduced from a rainwater harvesting system in future (e.g. 2%–14% reduction for 3 kL tank for indoor water demand). Moreover, number of days in a year to meet the water demand by a rainwater harvesting system (i.e. reliability) is likely to be reduced (e.g. 3%–16% reduction for 3 kL tank for indoor water demand). Also, the percentage of days a rainwater tank would remain completely empty is likely to increase in future (e.g. 12% in future climate conditions in comparison to 8% in historical conditions for indoor water demand). Furthermore, it is found that the performance of a rainwater harvesting system will be more affected in dry season than the wet season. The findings of the study will help water authorities and policy makers, as well the home owners to improve their understanding of climate change impact on residential rainwater harvesting system, and will assist them in selecting appropriate rainwater tank size in the context of climate change.

1. Introduction

Water supply security has become a major concern worldwide due to ever-increasing water demand resulting from population growth, rapid urbanisation and industrial development. Moreover, availability of water resources is decreasing due to water pollution around the world as a consequence of increasing urbanisation and industrialisation (Simeonov et al., 2003). Currently, it is estimated that approximately 2.4 billion people in the world (i.e. 36% of global population) are facing water shortages (IFPRI, 2012), and water scarcity is more critical in developing countries. United Nation (2013) reported that by 2050 the world population will reach 9.6 billion; about 70% of those populations would be living in urban areas (FAO, 2009). To serve this huge population, water demand in domestic, irrigation and industrial sectors will be amplified across the world (Pohle et al., 2012; Jakimavičius and Kriaučiūnienė, 2013; Price et al., 2014). Several studies (e.g. OECD, 2012; Haque et al., 2014; Wang et al., 2015) predicated that by 2050 global water demand would increase by about 55%, and this growing water demand would make the naturally limited water resources scarcer.

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Moreover, it has been predicted that about 52% of the global population would be exposed to severe water shortages by 2050 if no appropriate adaption and mitigation actions are taken to source new water supplies (IFPRI, 2012).

Besides growing population, rapid urbanisation and industrialisation, changes in the climatic condition is considered to be another major factor in water demand and supply (Chen and Xu, 2005; Elmahdi et al., 2009). For example, in an Australian study, Haque et al. (2013a, b, 2015) found that climate change was one of the influencing factor that impacted catchment water yield negatively (i.e. reduction in volume) and affected water demand pattern. Consequently, water resource availability could be severely impacted due to climate change conditions resulting from global warming. As a result of global warming, evapotranspiration and atmospheric water storages are likely to be affected which in turn would change the magnitudes, frequencies and intensities of future rainfall (Arnell, 1999; Middelkoop et al., 2001; Wang et al., 2015). Moreover, climate change would affect the seasonal and interannual variability of rainfall as well as geographical distributions. These plausible variations in rainfall and increase in temperature are likely to aggravate the water shortage conditions around the world in the future. For example, Ma et al. (2008) found the decreasing trend in annual streamflow 5 catchments out of 8 in Northwest China due to decreased precipitation and increased evapotranspiration.

Evidence of climate change has already been perceived in many parts of the world (Ren et al., 2002; Fang et al., 2007; Shahid et al., 2012). Moreover, confirmation of global warming due to the raised greenhouse gases is accumulating (IPCC, 2013). Intergovernmental Panel on Climate Change (IPCC) has reported based on the prediction from global climate models that global mean air temperature could increase by 1.5 °C–4.5 °C in high greenhouse gas emission scenarios (IPCC, 2013). Hence, climate change issues need to be considered in the planning and management of water resources to ensure adequate water supply in the context of changing environment.

In general, risk of water inadequacy is lesser in developed countries than developing countries (Silva et al., 2015). But supplying adequate water to the cities requires a notable amount of other resources such as energy and infrastructure. Hence, even countries with good water balance conditions between demand and available water resources are continuously evaluating alternatives (e.g. reduction in water consumption and identification of new sources to supply water) to optimise water management. One of the most common and adaptable alternative sources is the rainwater for use in the buildings, in particular residential buildings (Eroksuz and Rahman, 2010; Imteaz et al., 2012; 2013). The centuries old practice of using rainwater has been revived and the world has seen a greater attention in the past decade to harvest rainwater to lessen the pressure on main water supplies and to provide water for living in many regions. For example, installation of rainwater tanks in residential houses has become popular in many Australian cities as a result of greater environmental awareness and employment of mandatory water restrictions (Rahman et al., 2010). Rainwater utilisation is also perceived as a sustainable design approach for water resources management (Devkota et al., 2015; Morales-Pinzón et al., 2015).

Rainwater is used as either the principal or a supplementary source of water to the main water supply system in a residential building, which is generated from rainwater harvesting (RWH) system. However, use of RWHS is not limited to residential buildings only; it has been implemented to some other types of buildings such as commercial buildings and collective houses in countries such as Japan, UK, Australia and Germany (http://www.sciencedirect.com/science/article/pii/S0921344914002365, Zaizen et al., 2000, http://www.sciencedirect.com/science/article/pii/S0921344914002365, UNEP, 2002). RWHS, in general, contains three modules: collection, storage and treatment, and the generated rainwater are used for both potable and non-potable applications depending on water demand and supply conditions at the location (Fewkes, 2006). RWHS is mainly used to manage shortages in water supply in the developing countries for both the potable and not potable uses such as Bangladesh, Botswana, China, India, Kenya and other countries in Africa (http://www.sciencedirect.com/science/article/pii/S0921344914002365, UN-HABITAT, 2005, http://www.sciencedirect.com/science/article/pii/S0921344914002365; Meera and Ahammed, 2006). On the other hand, in the developed countries such as Germany, France, Japan, Singapore and United States, it is mainly used to supplement main supply for non-potable use e.g. toilet and laundry use, and garden irrigation (http://www.sciencedirect.com/science/article/pii/S0921344914002365, Kloss, 2008, http://www.sciencedirect.com/science/article/pii/S0921344914002365, Schets et al., 2010). However, rainwater is also used for potable use in some developed countries; for example, in Australia rainwater is used for drinking in some rural and peri-urban areas where mains water is not available (http://www.sciencedirect.com/science/article/pii/S0921344914002365, MPMSAA, 2008, Hajani and Rahman, 2014).

Rainfall is the main variable of interest for a RWHS system (Silva et al., 2015), especially temporal variability of rainfall is the critical governing factor in its performance. Design of RWHS is generally concerned with determining the optimum tank size to ensure water supply for the anticipated use. An oversized tank is a loss of resources (e.g. energy, time and money); on the other hand an undersized tank will not be able to fulfil the required water demand. Therefore, needs of households and the characteristics of the geographical locations should be considered when designing a RWHS. Many studies are available in literature on the benefits, design, performance and feasibility analysis of a RWHS, for example in Germany (Herrmann and Schmida, 2000), in China (Fengtai and Xiaochao, 2012), in Brazil (Ghisi and Ferreira, 2007), in USA (Aladenola and Adeboye, 2010; Steffen et al., 2013), in Italy (Palla et al., 2012), in Virginia (Sample and Liu, 2014), in Mexico (García-Montoya et al., 2015) and in Australia (Imteaz et al., 2011a, 2011b; Rahman et al., 2012).

Most of these studies are based on the historical climate conditions in the study location to perform such analysis. Only a few studies incorporated future uncertain rainfall event in estimating reliability of a RWHS. For example, Basinger et al. (2010) generated ensembles of synthetic rainfall time series adopting a Markov Chain algorithm to incorporate rainfall uncertainty in a RWHS. Wallace et al. (2015) used daily rainfall data which was statistically downscaled from Global Climate Models (GCMs) in estimating required catchment area and tank size for a given reliability. Lo and Koralegedara (2015) also incorporated statistically downscaled rainfall data from GCMs along with historical rainfall conditions to incorporate variability in rainfall in a RWHS. However, as mentioned earlier that rainfall pattern and variability are likely to be altered in future in the context of climate change, which can introduce uncertainty in designing a RWHS if the plausible changes in rainfall are not taken into consideration. Understanding how performance of a rainwater tank changes in response to variation in the climate conditions is a vital component in the planning, management and development of RWHS as an alternative water sources to supply water. However, research on climate change impacts on rainwater harvesting is still very limited.

The objective of the present study is to understand the plausible impacts of climate change on the performance of a residential RWHS. The study attempts to answer the following questions: (i) Will a given tank size at a given location be adequate in changing