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A global performance assessment of rainwater harvesting under climate change

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ABSTRACT

Given that water security is likely to worsen with climate change, rainwater harvesting is one solution that may improve drinking water access directly at home. Although rainwater harvesting devices may be able to reduce drinking water insecurity, this has never been tested systematically across a variety of climates for different climate change scenarios using consistent assumptions. Therefore, the goal of this paper is to assess the ability of rainwater harvesting devices to improve domestic water security in each of the major climate zones under different climate change scenarios and to make design recommendations to achieve levels of reliability for each climatological region. The coupled model incorporates a stochastic weather generator (LARS-WG) to simulate synthetic daily rainfall using historic weather data from 94 sites chosen to represent all Koppen – Griegel climate classification zones. Simulations are run up to year 2099 for three different climate change scenarios using 15 downscaled General Circulation Models. Combinations of different roof area and tank sizes are studied to assess rainwater harvesting system reliability. Results indicate that climate change will have little impact on rainwater harvesting and that rainwater harvesting can reduce domestic water insecurity even in arid regions. Results of this study can be used by implementing agencies to prioritize regions where rainwater harvesting can be effective and to help communities design systems to meet given levels of reliability.

1. Introduction

Globally, more than 2.1 billion people lack access to safe, readily available water at home, whereas a further 2.3 billion do not have improved sanitation (WHO and UNICEF, 2017). Even those that have access to improved water supplies often need to travel several kilometers every day in search of water sources (Mellor et al., 2012), which can seriously impact health (Pickering and Davis, 2012). Moreover, even improved water supplies frequently contain microbial contamination (Bain et al., 2014).

Water security, particularly in low income regions, will be progressively threatened as the climate changes (Field et al., 2014). Consistent with observed warming, almost all glaciers in the tropical Andes have been shrinking rapidly (Rabatel et al., 2013). Similarly, Himalayan glaciers are also losing mass, with serious implications for runoff contributions, especially in the drier westerly dominated headwaters (Bolch et al., 2012). A global analysis of streamflow showed decreasing trends in low and mid – latitudes consistent with recent drying and warming in West Africa, southern Europe, southern and eastern Asia, eastern Australia, western North America, and northern South America (Dai, 2013). Global mean precipitation is likely to increase, but with substantial regional variations, including some decreases. Precipitation trends are likely to decrease in subtropical latitudes, particularly in the Mediterranean, Mexico and central America, and parts of Australia, and to increase elsewhere, notably at high northern latitudes, in India and parts of central Asia (Field et al., 2014). Regions where drought is projected to become longer and more frequent include the Mediterranean, central Europe, central North America, and southern Africa (Field et al., 2014). Increased precipitation and temperature variability as well as extreme events related to it are predicted to affect the availability and quality of water globally (Mellor et al., 2016).

A possible solution to improve water security is the use of rainwater harvesting (RWH) which allows water collection to occur directly at home. Such systems can supply between 12% and 100% of a household's potable water according to the specific environmental and social conditions (Herrmann and Schmida, 1999; Sazakli et al. 2007; Ghisi et al. 2007; Zhang et al. 2009; Abdulla and Al-Shareef, 2009). The storage of rainwater harvesting was simulated in three cities of varying climatic conditions in Iran. In humid, Mediterranean and arid Iranian

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climates, the study found that it is possible to supply at least 75% of residential water demand 70%, 40% and 23% of the time respectively (Mehrabadi et al., 2013). Results from an arid region of Jordan show potential water savings from RWH from 0.3% to 19.7% (Abdulla and Al-Shareef, 2009). A tank of 5 m^3 is suggested for Abeokuta, Nigeria to supply 51% of water during dry periods (Aladenola and Adeboye, 2010). These results suggest that RWH can help maintain water security for households in arid regions.

Since household water consumption is low in developing countries, RWH can provide a large proportion of household water supplies as demonstrated by Handia et al. (2003) in Africa. Large survey use of GIS tools have also shown opportunities for RWH in selected countries in Africa such as Botswana, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda, Zambia, and Zimbabwe (Mati et al., 2006). This has led to the spread of RWH across Africa, and the formation of Rainwater Harvesting Associations in a number of countries (Campisano et al., 2017).

RWH plays an important role in many Asian countries (Campisano et al., 2017). The Thai government has also supported RWH because of its low implementation costs using jar tank systems with different tank sizes ranging from 0.1 to 3 m^3. Harvested rainwater is used during the dry season – up to six months a year (Wirojanagud and Vanvarothorn, 1990). More than 5.5 million tanks have been built to supply supplemental drinking and irrigation water throughout China since 2001 (Gould et al., 2014).

Australia, being one of the driest inhabited continents with highly variable rainfall, has one of the highest prevalence of RWH systems. According to the results of a survey by the Australian Bureau of Statistics (ABS, 2010), 19.3% or slightly 1.5 million households had fitted rainwater tanks to their households as a source of water for domestic purposes (Eroksuz and Rahman, 2010).

The implementation of RWH systems in Europe is varied. Germany leads in the promotion and widespread use of this technology for domestic non-potable purposes with one third of new buildings are equipped with this system (Schuetze, 2013).

Application of systems varies in North and South America. More than 100,000 residents use RWH in the form of a simple rain barrel or large volume tanks including those used for drinking in the United States (Lye, 2002). Brazil launched the “One Million Cistern” RWH program in 2001 to supply about two million people who live in rural areas (De Moraes and Rocha, 2013).

Although prior research has established the potential efficacy of RWH to improve water security, there is a need to investigate how effective the technology can be in a variety of climates using consistent assumptions as they are impacted by climate change. Moreover, key design factors including household water demand, roof area and

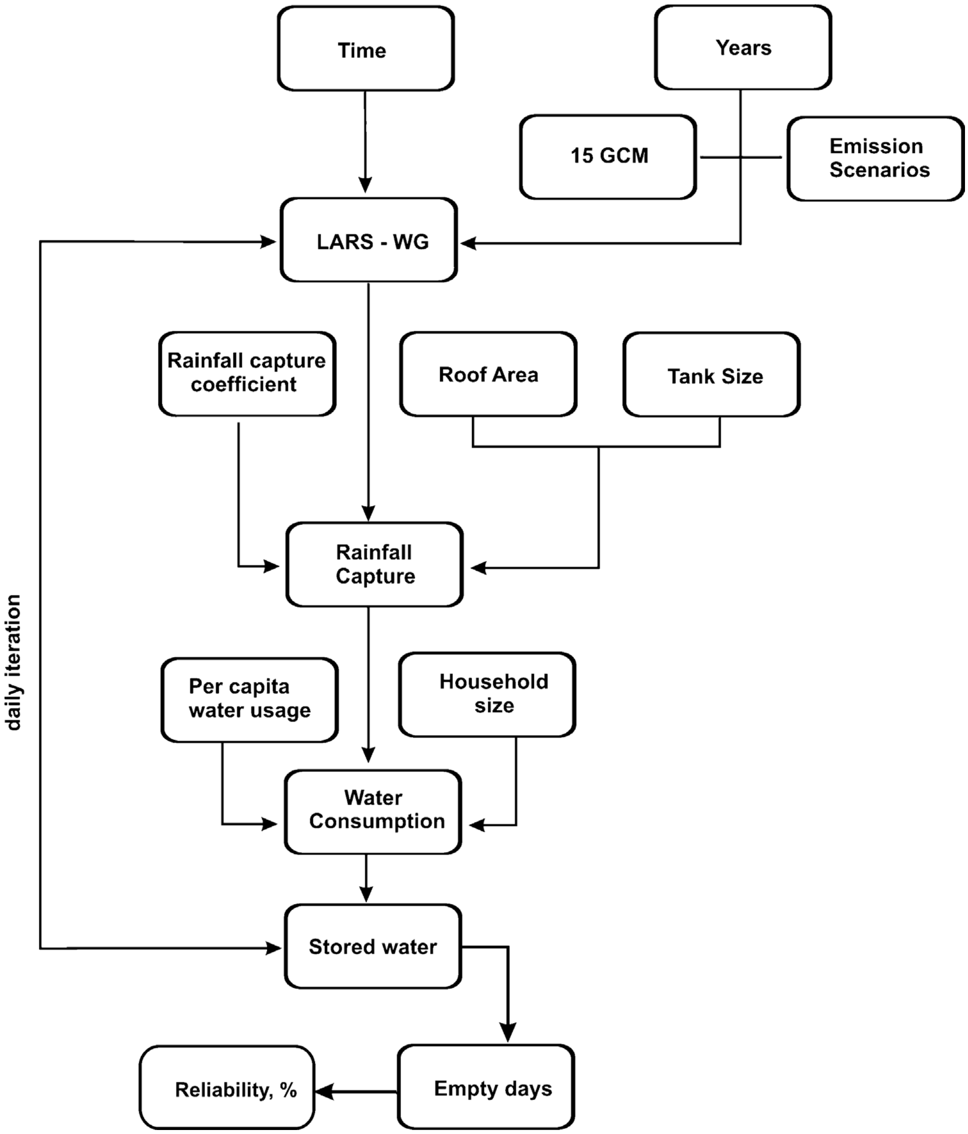

Fig. 1. Flowchart of rainwater harvesting model algorithm with model elements and daily iteration cycle.