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Review

Urban rainwater harvesting systems: Research, implementation and future perspectives

Alberto Campisano [a,*], David Butler [b], Sarah Ward [b], Matthew J. Burns [c], Eran Friedler [d], Kathy DeBusk [e], Lloyd N. Fisher-Jeffes [f], Enedir Ghisi [g], Ataur Rahman [h], Hiroaki Furumai [i], Mooyoung Han [j]

[a] Department of Civil Engineering and Architecture, University of Catania, Viale A. Doria, 6, 95125, Catania, Italy
[b] Centre for Water Systems, College of Engineering, Mathematics and Physical Sciences, University of Exeter, Exeter, EX4 4QF, UK
[c] Waterway Ecosystem Research Group, School of Ecosystem and Forest Sciences, University of Melbourne, Burnley, Australia
[d] Department of Environmental, Water & Agricultural Engineering, Faculty of Civil and Environmental Engineering, Technion–Israel Institute of Technology, Haifa, 32000, Israel
[e] Biological and Agricultural Engineering, North Carolina State University, Campus Box 7625, Raleigh, NC 27695, USA
[f] Department of Civil Engineering, University of Cape Town, Private Bag X3, Rondebosch, South Africa
[g] Federal University of Santa Catarina, Department of Civil Engineering, Laboratory of Energy Efficiency in Buildings, Florianópoli, SC, Brazil
[h] School of Computing, Engineering and Mathematics, University of Western Sydney, Sydney, Australia
[i] Research Center for Water Environment Technology, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan
[j] Department of Civil and Environmental Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul, South Korea

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A B S T R A C T

While the practice of rainwater harvesting (RWH) can be traced back millennia, the degree of its modern implementation varies greatly across the world, often with systems that do not maximize potential benefits. With a global focus, the pertinent practical, theoretical and social aspects of RWH are reviewed in order to ascertain the state of the art. Avenues for future research are also identified. A major finding is that the degree of RWH systems implementation and the technology selection are strongly influenced by economic constraints and local regulations. Moreover, despite design protocols having been set up in many countries, recommendations are still often organized only with the objective of conserving water without considering other potential benefits associated with the multiple-purpose nature of RWH. It is suggested that future work on RWH addresses three priority challenges. Firstly, more empirical data on system operation is needed to allow improved modelling by taking into account multiple objectives of RWH systems. Secondly, maintenance aspects and how they may impact the quality of collected rainwater should be explored in the future as a way to increase confidence on rainwater use. Finally, research should be devoted to the understanding of how institutional and socio-political support can be best targeted to improve system efficacy and community acceptance.

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* Corresponding author.
E-mail address: acampisa@dica.unict.it (A. Campisano).

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1. Introduction

Rainwater Harvesting (RWH) is probably the most ancient practice in use in the world to cope with water supply needs. In recent decades, as a result of new technological possibilities, many countries are supporting updated implementation of such practice to address the increase in water demand pressures associated with climatic, environmental and societal changes (Amos et al., 2016).

In urban areas, RWH consists of the concentration, collection, storage and treatment of rainwater from rooftops, terraces, courtyards, and other impervious building surfaces for on-site use. Civil uses of collected rainwater are disparate (e.g. toilet flushing, laundry, garden irrigation, terrace cleaning, and other sporadic outdoor uses such as car washing), but all aim to reduce consumption of drinking water from centrally supplied sources. GhaffarianHoseini et al. (2016) suggest these uses can globally account for 80–90% of overall household water consumption, and highlight the significant water conservation benefits associated with RWH implementation. Consequently, installation of RWH systems increases water self-sufficiency of cities and can help delay the need to construct new centralized water infrastructures (Steffen et al., 2012).

Water scarcity and need for water supply augmentation are not the only reasons that have motivated municipalities to boost RWH system installation. In fact, consolidated scientific and grey literature of the last twenty years shows that RWH belongs to the large family of detention-based Low Impact Development (LID) or Sustainable Drainage System (SuDS) approaches and can be adopted as a complementary measure to reduce frequency, peaks and volumes of urban runoff if systems are appropriately designed. The increase of urban-catchment distributed detention by tank-based RWH systems (and other at-source technologies) may reduce the impacts of urbanization growth on the stormwater drainage system (Brodie, 2008; Burns et al., 2015) and possibly contribute to the mitigation of environmental impacts on receiving water bodies (e.g. Hamel and Fletcher, 2014). For example, studies from Australia show that the installation of rainwater tanks at the allotment scale could return the rainfall-runoff response of the impervious roof close to pre-development levels (Burns et al., 2012a) and reduce disturbance of the catchment water quality regimes (Burns et al., 2012b). Multiple-usage demands ensure a relatively continuous use of the water, thereby maximizing rainfall capture by creating room in the storage tank for upcoming rain events (Domènech and Saurí, 2011; Gardner and Vieritz, 2010). Incorporating demands that align with local rainfall patterns can substantially increase the efficiency of the system in terms of both water conservation and stormwater mitigation (Zhang et al., 2009).

When used in conjunction with infiltration-based solutions, excess overflow water from RWH systems (that would otherwise generate street runoff or enter the storm sewer network) can be infiltrated (often after preliminary treatment, as determined by national regulations) for groundwater recharge (Dillon, 2005). Recent studies have shown that infiltration techniques coupled with RWH can also help in modifying the urban microclimate by increasing moisture content and evapotranspiration (e.g. Hamel et al., 2012), so mitigating the heat island phenomenon (Furumai, 2008; Coutts et al., 2012).

Environmental benefits concerning the reduction of emissions and the decreasing of consumed resources with RWH system implementation have been explored in recent years (e.g. Angrill et al., 2012). In this regard, the scientific literature shows that the selected use of rainwater in the building and the type of implementation project (renovation or new construction) significantly affect the economic viability of the system (Devkota et al., 2015; Morales-Pinzón et al., 2015).

The implications of RWH for energy consumption are currently contested. Parkes et al. (2010) suggest that the water supplied by RWH systems typically requires greater operational energy to deliver than the mains water it displaces. However, Ward et al. (2011) indicate that this is very much context dependent and in fact technological innovation in pump design and in low- or no-energy RWH systems makes this less of an issue going forward. Jiang et al. (2013), for example, found that RWH systems may lead to a decrease of energy usage. Other projects are using harvested rainwater within houses for thermal energy recovery and building cooling (An et al., 2015; Kollo and Laanearu, 2015).

The literature clearly shows that the range of applications of RWH systems in urbanized areas is very large. However, the results and the perception of the extent of potential benefits are varied and controversial. Additionally, methods for the evaluation of the overall efficiency of multi-objective (also competing) RWH systems are still at an embryonic stage. In this light, a critical review of the state of the art of application of RWH systems is carried out in this paper to clarify some key aspects that may determine their successful implementation. The context addressed is that of systems in urban areas already serviced by centralized water infrastructure. The paper is organized as follows. A focus on types and complexities of implemented systems according to the different potential objectives of RWH is firstly presented in section 2. Section 3 briefly explores the degree of application of RWH in the world's continents highlighting experienced benefits and drawbacks. A review of results concerning water quality aspects as well as treatment