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Reliability Analysis of Rainwater Harvesting Systems in Southern Italy

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Abstract

Water scarcity is a current problem for many urban areas in the Mediterranean region due to the increasing water demand related to the population growth and the expansion of urban and industrialized areas. Climate change will intensify the pressure on water resources. Rainwater harvesting (RWH) may be an effective alternative water supply solution to face water scarcity. It has recently become a particularly important option in arid and semi-arid areas, mostly because of its many benefits and relative low costs. The present study aims to analyse the reliability of a RWH system installed to supply water for toilet flushing purpose with reference to a single-family house in a residential area of Sicily (Southern Italy). Historical water consumption data were analysed to obtain a flushing water demand pattern. A water balance simulation of the rainwater storage tank was performed, and the yield-after-spillage algorithm was used to define the tank release rule. The model's performance was evaluated using data from more than 100 different sites located throughout the Sicilian territory. This regional analysis provided results having practical applications, e.g. the identification of the optimal rainwater tank size and the annual system reliability curves as a function of mean annual precipitation. The uncertainty related to the regional model predictions was also assessed. Results showed that RWH systems can provide environmental and economic advantages in Sicily over traditional water supply methods. In particular, the regional analysis identified areas where the application of this system would be most effective.

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1. Introduction

The rainwater harvesting (RWH) to supply water for domestic purposes is a common practice in developing countries, especially in arid and semi-arid areas affected by water scarcity [1 - 3], but also in urban areas [4, 5]. Recently, RWH systems have been widely identified as a measure of adaptation to the effects of climate change on water resources [6, 7]. Indeed, the availability of an alternative water supply reduces pressure on aquifers and surface water sources. RWH systems also have important economic advantages because they reduce the amount of water purchased from public systems by the consumers. For these reasons, several studies investigated the implementation of RWH systems as a response to the growing water demand in Africa [3, 8], Asia [9, 10] and Australia [11, 12]. In the Mediterranean region some analysis have been carried as well with regard to Greece [13], Italy [14, 15] and Spain [16].

A RWH system includes the catchment area, the collection device and the conveyance system. Rainwater is usually collected from rooftops, courtyards or other compacted or treated surfaces before being filtered and collected in storage tanks to be used. The performance of a RWH system is evaluated in terms of water saving efficiency and depends on the temporal and spatial distribution of the rainfall, the size of the catchment area, the capacity of the storage tank and the water demand pattern. Therefore, the storage capacity of a RWH tank cannot be standardized, nevertheless an optimal size can be identified on the basis of the system reliability or economic criteria [4].

In this study, the reliability of a RWH system for a single-family house in a residential area with four inhabitants has been evaluated, considering the use of rainwater for toilet flushing. The system performance has been tested for different catchment surfaces, tank sizes and mean annual precipitation using data from over 100 different sites in Sicily. In order to define a temporal pattern for flushing water demand, water consumption data have been recorded from single-family houses in Palermo (Northwestern Sicily). The application of the Yield-After-Spillage algorithm allowed to evaluate the system efficiency in each site of the study region. Simulations have been performed at daily scale using data from 2002 to 2004. Once the system reliability has been assessed, the tank sizes related to three thresholds of reliability (75%, 85% and 95%) have been determined. In order to provide a useful tool for practical applications, the spatial distributions of these tank capacities has been reported in some maps. To estimate the payback period on the capital cost for the RWH system installation, a cost-benefit analysis has been performed. Finally, for given tank sizes (10, 15 and 20 m^3), mathematical relationships between mean annual rainfall and water saving efficiency have been determined. The uncertainty related to these relationships has been evaluated through a data resampling procedure.

2. Methodology

2.1. Inflow to the RWH tank

The rainwater tank is filled using rainfall volumes collected from a building's rooftop, courtyard and pedestrian areas. Under the assumption of constant rainfall within each time step *t*, the rainwater volume can be calculated as follows:

$$Q_t = \phi \cdot A_{TOT} \cdot R_t = A \cdot R_t \tag{1}$$

where Q_t is the inflow volume supplied to the tank at time step *t* (m^3), ϕ is the runoff coefficient depending on water loss (dimensionless), R_t is the rainfall at time *t* (m), A_{TOT} is the total catchment surface area (m^2), and A is the effective impervious surface area (m^2). Evaporation losses from the tank are neglected. In this study, ϕ was set equal to 0.9 [17].

The stormwater quality of the initial discharge from the roof surface is of poor quality due to the presence of dust, sediments, ect. [18] , that are accumulated during dry periods and washed off at the beginning of the next rainfall event. The first flush is defined as the initial period of a rainwater runoff where a pollutant concentration is remarkably