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Assessment of the length of rainfall time series for rainwater harvesting in buildings

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ABSTRACT

In this study, the possibility of using short-term instead of long-term rainfall time series in simulations of rainwater harvesting in buildings was evaluated. The main objective was to determine the required length of a short-term time series in order to produce results similar to those obtained with a long-term time series. The study was conducted using daily rainfall data on thirteen cities located in different countries. The 30-year time series were used as a reference and, from these, short-term time series were extracted, i.e., 30 series of 1-year length, 29 series of 2-year length, and so on. The computer programme Netuno was used to carry out the simulations with short-term and long-term time series and the results were compared. A simulation model was defined and some parameters were fixed, such as the catchment area and number of inhabitants, and others were varied, such as the time series length and the rainwater demand. The results obtained using the short-term time series were compared to those using the long-term time series considering three factors: potential for potable water savings obtained for the same rainwater tank size; the optimal rainwater tank size; and the ideal potential for potable water savings. For each city, the representative time series length was determined based on the frequency of similar results, i.e., when at least 90% of the results were similar to those obtained using a 30-year time series. A validation of the representative time series length was performed using a different period from that used in the initial simulation. Different representative time series lengths were found for each city, the shortest being 6 years and the longest 20 years. A time series of 15 years was sufficient to obtain results similar to the 30-year time series in seven out of the thirteen cities. It was concluded that the use of short-term time series instead of 30-year time series for the simulation of rainwater harvesting systems is valid, depending on the rainfall characteristics of the region.

1. Introduction

As the population increases and public supply systems fail to keep pace with this growth, access to water becomes a problem. This has already been experienced in some cities, such as the severe crisis that affected the southeast region of Brazil in 2015, where the water supply was reduced by around 56% in São Paulo and Rio de Janeiro that suffers with a drought period (SABESP, 2015). Concerns regarding water scarcity have led to several studies to evaluate the impact at the local level (Jiang, 2009; Hadadin et al., 2010; Liu et al., 2017) and the global level (Vörösmarty et al., 2010; Kummu et al., 2016). Several initiatives have been explored to reduce water consumption and seek alternative sources of water. The use of rainwater is a widely disseminated and accepted strategy as an efficient approach to promoting potable water savings and mitigate water scarcity.

To benefit from a rainwater harvesting system, the system components need to be properly designed, economically viable and attend the water supply and demand scenarios. In this regard, empirical equations can be used, or sizing methods based on computer simulations can be employed to estimate how much water is saved by adopting a given rainwater tank size. A design criterion can be established in order to obtain an optimal rainwater tank size, which is associated with an ideal potential for potable water savings.

To perform a rainwater harvesting system simulation, a rainfall database obtained from precipitation series records is used. This database has a major influence on the design of the system since a longer rainfall time series will offer better reliability in the simulation process, providing a good representation of the precipitation phenomena over time and, consequently, better results. The World Meteorological Organization (WMO) recommends at least 30 years of observations as a database of representative climate information for a given region (WMO, 1989). However, many cities do not have a collection of climatic data going back this far.

In studies reported in the literature, rainfall time series of various

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lengths have been used according to the availability of rainfall data. Ward et al. (2010) used a 25-year rainfall time series to analyse different methods for designing rainwater harvesting systems. Basinger et al. (2010) also used a time series length of 25 years to assess a non-parametric reliability model. Shorter time series lengths have been used for similar purposes, as in the study by Herrmann and Schmida (2000), where 10-year series were used to evaluate rainwater harvesting systems in Germany, and Villarreal and Dixon (2005) used a 10-year series length to size rainwater tanks in Sweden. Given that researchers have used different time series lengths to assess rainwater harvesting systems, it is important to evaluate the influence of this variation on the design process.

Some authors have addressed this issue, for instance, Ghisi et al. (2012) studied the significance of the rainfall time series length on the simulation of rainwater harvesting systems for the city of Santa Bárbara do Oeste in São Paulo State, Brazil. Short-term time series with different lengths and a 30-year time series were compared in terms of the results obtained for the rainwater tank size and the potential for potable water savings. It was found that with the use of 13 years of rainfall time series data, the results for the rainwater tank size potential for potable water savings were similar to those obtained using a 30-year time series. Mitchell (2007) analysed the importance of the accuracy of the variables used for the design of rainwater harvesting systems, including the length of the rainfall time series. The results obtained using 1-year and 10-year time series lengths were compared to those provided by 50-year time series for the cities of Melbourne, Sydney, and Brisbane, in Australia. It was found that only the results obtained using the 10-year time series were as accurate as those provided by the 50-year time series. Geraldi and Ghisi (2017) also evaluated the possibility of using different time series lengths in a case study for the city of Berlin, Germany. The values for the optimal rainwater tank size obtained with several short-term time series lengths were compared to those obtained with 30-year time series. It was found that the 10-year time series presented the same results to those obtained with the 30-year time series, but only for the location analysed.

In this study, the effect of the length of the rainfall time series was assessed in order to enable the use of simulation in the design of rainwater harvesting systems. The main objective was to determine the optimal rainfall time series length, which can provide results similar to those generated with longer rainfall time series in simulations of rainwater harvesting systems in thirteen cities around the world.

2. Method

The study was organized in three stages: definition of the simulation model, model inputs, and comparison of the results. The comparison involved three types of analysis based on: the potential for potable water savings; the optimal rainwater tank size; and potential for potable water savings associated with the optimal rainwater tank size.

2.1. Cities

In order to cover a wide range of climatic conditions and variations in rainfall patterns, thirteen cities were selected and their geographical coordinates, the rainfall data obtained, and corresponding countries are showed in Table 1. Fig. 1 shows the locations of the cities in the global context.

Thirty-year time series of uninterrupted rainfall data were used as a reference for the long-term time series for each city. From each long-term time series, the short-term time series (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15 and 20 years) were extracted, by increasing the length and overlapping the years, in order to cover all data and possible combinations. For example, the one-year time series is comprised of rainfall data from January 1 to December 31; therefore, there are 30 × one-year series for each city. For the subsequent series there was overlapping with subsequent years; therefore, there are 29 × 2-year series, 28 × 3-year series, 27 × 4-year series and so on for each city.

Rainfall data were obtained from previous studies (Souza and Ghisi, 2012) and were first obtained from the database of the GHCN (Global Historical Climatology Network).

2.2. Model definition

The simulations were performed using the computer programme Netuno (Ghisi and Cordova, 2014), that makes a daily balance of the hydric availability (rainfall that runs on the roof, discounting the runoff coefficient and first flush) and demand information (water demand times number of inhabitants), for a given tank size (or interval). The programme considers a YAS (yield after spieling) approach, which implicates that the demand is taken after the rain event that was harvested and reserved. The programme algorithm has been validated and its accuracy considered as acceptable (Rocha, 2009).

The simulations provided the potential for potable water savings for each rainwater tank size inputted, and to compare the simulations with each other, two sizing indicators were considered: the optimal rainwater tank size and the potential for potable water savings corresponding to the optimal rainwater tank size, or the "ideal potential for potable water savings". The "optimal rainwater tank size" indicator is a discrete quantitative variable, and the "ideal potential for potable water savings " indicator is a continuous quantitative variable.

For each location, the simulations were designed to cover all possible combinations for all-time series lengths. For example, to analyse the 1-year series of city 'A' 120 simulations were performed, for the 2-year series 116 simulations, for the 3-year series 112 simulations, and so on. The total number of simulations performed for city "A" was 1132. This process was repeated for the 13 cities studied, totalling 14,716 simulated cases.

2.3. Model inputs

A model representing a residential building of simple architecture inhabited by four people was used. Some parameters were varied, and others were fixed, so the model was representative of all cities studied. The fixed parameters were: the roof area (100 m^2); the first flush (2 mm); the number of residents (4 inhabitants), the total daily water demand per capita (150 L/cap.day); the runoff coefficient (80%); and the size of the upper rainwater tank (600 L). The varied parameters were: the size of the lower rainwater tanks (volumes varying from 1000 L to 70,000 L, in intervals of 1000 L); and the rainwater demand, given as a portion of the total demand (varying from 20% to 50% of the total demand, in increments of 10%). The range of variation in the rainwater demand is based on studies reported in the literature (Fewkes, 2012; Souza and Ghisi, 2012; Coombes and Barry, 2007), which indicate that the use of non-potable water in residential buildings varies around this interval. Table 2 summarizes the data used in the model definition.

2.4. Comparison of results for potential for potable water savings

The comparison between the simulation results obtained with the short-term and long-term time series was conducted by identifying similar/equivalent results for different simulations.

The verification of similar/equivalent results was carried out considering the difference between potential for potable water savings obtained with a short-term time series and with the 30-year time series for the same rainwater tank size. The sum of these differences was divided by the total number of rainwater tanks simulated in the range, creating a similarity index. The comparison is expressed mathematically by Eq. (1).