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Full length article

Influence of the length of rainfall time series on rainwater harvesting systems: A case study in Berlin

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A B S T R A C T

This study evaluated the influence of using different rainfall time series lengths on the rainwater harvesting systems sizing. The main objective was to determine a short-term rainfall time series length can lead to results similar to those obtained with long-term rainfall time series. The study was conducted using daily rainfall data from Berlin, Germany. A 30-year time series was used as a reference and then shorter series were detached, i.e., 30 sets of 1-year, 29 sets of 2-year, and so on. A single-family house was used as a simulation model fixing the catchment area and a number of residents, and varying the time series length and the rainwater demand. Two simulation variables were evaluated: "optimal rainwater tank capacity" and "ideal potential for potable water savings". The results obtained from the simulations for each short-term time series were compared to the results for the 30-year time series. The frequency of the optimal rainwater tank capacity results that were similar to those obtained for the 30-year time series and the relative and absolute differences between the ideal potential for potable water savings were evaluated. It was found that a series of 10 years of daily rainfall data is enough to generate results significantly similar to those of a 30-year time series. To validate the results obtained, the model was simulated again, using a series of 10-years of daily rainfall data not included in the 30-year time series used in the experiment. The validation has confirmed the experiment results.

1. Introduction

Potable water shortage is a great global concern and a recurrent issue for the environmental leaderships. The demand for potable water grows as the population and the number of new buildings increase, which in turn increases the water crisis. The rational use of water at all society levels has been the focus of discussions and studies about water resources (Shiklomanov, 1998).

The largest part of water demand in buildings could be reduced by replacing potable water with alternative water sources for uses that do not require potability. Rainwater is the most accessible source because it can be collected where it is needed. Besides, it is free and can be treated to make it potable for all uses, if necessary.

The main information for designing a rainwater harvesting system is the rainfall database. This information influences directly the sizing of the rainwater tank as well as costs, benefits, payback and operation of the system (Fewkes, 2012).

Long-term rainfall time series provides greater accuracy in the simulation process as it best represents the precipitation phenomena along the time. The World Meteorological Organization suggests a length of at least 30 years of rainfall data compose a representative time series (WMO, 1989). Ward et al. (2010) stated that the appropriate length of a rainfall time series should be at least 25 years irrespective of the method used. However, there are no long-term rainfall time series in many cities around the world.

A great variation of rainfall time series length to assess rainwater harvesting was found in the literature. In Australia, Zhang et al. (2009) used 80-year time series to assess the potential for rainwater in houses. Ghisi (2010) used rainfall time series ranging from 58 to 64 years in a rainwater harvesting study in São Paulo (Brazil), and Ghisi and Oliveira (2007) used a 34-year time series for the analogous purposes. Ward et al. (2010) used a time series of 25 years to analyse different methods for rainwater harvesting systems sizing. Basinger et al. (2010) also used a 25-year time series to analyse the reliability of a non-parametric model of rainwater harvesting systems. Silva and Ghisi (2016) performed a sensitivity analysis of rainwater harvesting systems using a 1961–2013 daily rainfall time series for eight cities in Brazil to assess the influence of the simulation input parameters on the simulation results.

On the other hand, shorter rainfall time series were used for the same purpose, as Herrmann and Schmida (2000) who used 10-year time series to evaluate rainwater harvesting systems in Germany, and

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Villarreal and Dixon (2005) who used 3-year time series to design rainwater tanks in Sweden. Ghisi and Ferreira (2007) also used a 3-year rainfall time series to assess the potential for potable water savings by using rainwater in the city of Florianópolis, Brazil. Mrowiec (2009) used a rainfall time series of two years only as the rainfall distribution in Poland using as a pattern with low variation, considering the annual average values and differences between seasons. Silva et al. (2015) used 10-year rainfall series to assess the most relevant parameters in rainwater harvesting for domestic uses in Portugal.

Other kinds of hydrological studies also need rainfall time series. Stovin et al. (2017) used two different models of green roofs to evaluate the detention performance, one based on a 30-year time series and another based on a storm approach. Locatelli et al. (2014) assessed a green roof model based on retention characteristics of the layers in order to test the simulation in long-term and single event hydrological performance. The model was calibrated and validated using two-year experimental data from three different roofs in Denmark. A 22-year rainfall time series was used to run the hydrological simulation about the runoff performance. Even in other kinds of studies, short-term time series were used, as in the work of Dotto et al. (2008) that used shorter time series to determine a statistical model to represent the annual rainfall. Four-year time series were used to analyse the uncertainty in forecasting the flow and quality of rainwater in the city of Victoria, Australia.

It is also important to mention the climate change issue. Haque et al. (2016) studied the influence of the climate change in rainwater harvesting in Australia. A rainwater harvesting system was simulated based on rainfall data predictions that consider the future climate conditions. It was found that the rainwater harvesting systems designed using long-term data will suffer negative impact due to climate change conditions, considering the unstable and unpredicted climate conditions that have been noted such as isolated storms and dry seasons.

Only two papers focused on the influence of the length of the rainfall time series on the assessment of rainwater harvesting systems were found. Ghisi et al. (2012) analysed such influence in a study case in the city of Santa Bárbara do Oeste, São Paulo. The conclusion was that the recommended length for rainfall time series is dependent on the rainwater demand. In general, the length recommended ranged from 1 to 13 years. For low rainwater demands, one or two years could represent similar results to those for the long-term time series. Mitchel (2007) also performed a similar analysis and evaluated the sensitivity of the results for time series length of 50, 10 and 1 year. It was concluded that series of 50 and 10 years result in similar and representative values, but one-year series result in discrepant values.

Although many studies used different lengths of rainfall time series for rainwater harvesting systems simulation, there is a limited number of studies about the influence of the time series length on both the rainwater tank capacity and the potential for potable water savings. The possibility of using short-term rainfall time series for simulating rainwater harvesting systems is important as there are no long-term rainfall time series in many cities all over the world. Thus, the main objective of this research was to determine the length a short-term rainfall time series can have in order to produce results similar to those of a long-term rainfall time series.

2. Method

The study was organized in six steps: the first was to determine the simulation model, the second was to obtain a long-term rainfall time series and prepare all the short-term rainfall time series, the third was to simulate the model using all the rainfall time series, the fourth was to compare the results, the fifth was to determine a representative short-term time series length, based on specific criteria and, finally, the sixth was to validate the representative short-term time series length. Fig. 1 shows a flow chart of the steps used in the method.

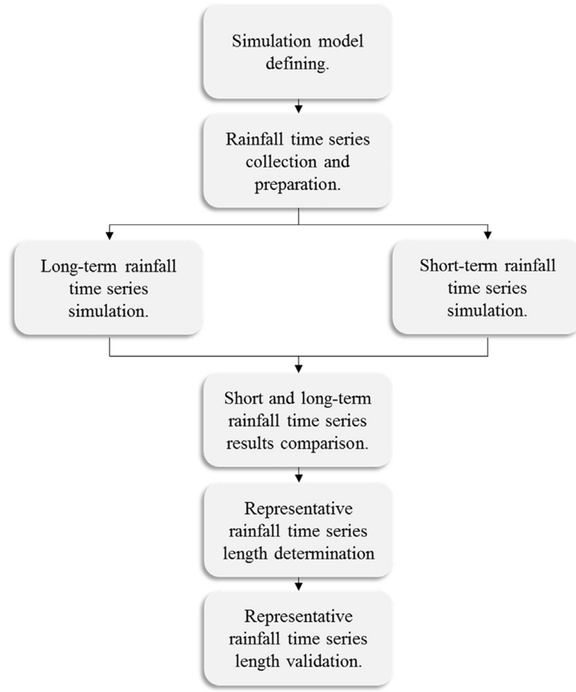

Fig. 1. Steps used in the method.

2.1. The city

The city used for this study was Berlin, the national capital of Germany, located in the central region of Europe. According to Köppen classification, Berlin has a Maritime temperate climate (Cfb). The average annual temperature is 9.4 °C and the average annual rainfall is 578 mm. Fig. 2 shows the location and political boundaries of Berlin (WRI, 2016).

2.2. Simulation model

A model was defined to simulate a single-family house using behavioural approach. To simulate a rainwater harvesting system, the input data required are the building information (roof area, runoff coefficient, and first flush); the water demand (potable water demand, the number of residents and rainwater demand) and simulation parameters (upper and lower rainwater tank capacities). The simulation output is the potential for potable water savings for every rainwater tank capacity used as input.

Considering sizing perspective, it is possible to determine an optimal rainwater tank capacity and its corresponding ideal potential for potable water savings using a criterion defined in the simulation input. The optimal rainwater tank capacity and the corresponding potential for potable water savings were chosen as indicators to compare the simulation results obtained for different time series size.

Parameters such as roof area, first flush, run-off coefficient, the number of residents, total water demand, rainwater losses and the upper tank capacity were taken as constant figures. The variable parameters were: length of rainfall time series and rainwater demand; rainwater demand was varied from 20% to 50% at intervals of 10%, as a percentage of the total water demand. As for the lower tank capacity, it ranged from 1000 L to 70,000 L at increments of 1000 L. Table 1 shows the input data used in the simulations.

2.3. Rainfall time series

Rainfall data were obtained from the work of Souza and Ghisi (2012), which in turn obtained the data from the GHCN (Global