Potable Water Savings in Multifamily Buildings Using Stormwater Runoff from Impermeable Paved Streets

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Abstract
Currently, due to the imbalance between demand and supply of water, a short-term possibility of water resources scarcity is a challenge to be faced in several countries. This subject has been a matter of concern for researchers, governments, regulators, and water suppliers. The enforcement of sustainable measures, such as the use of rainwater in buildings, is an alternative to ease the problem; however, the use of stormwater in buildings should also be assessed. The objective of this work is to estimate the potential for potable water savings in multifamily buildings through the use of stormwater runoff collected from paved streets. A case study was carried out, based on actual buildings and catchment areas of urban streets in the city centre of Florianópolis, a city located in southern Brazil. Stormwater runoff is meant to be used for non-potable purposes such as toilet flushing, washing machines, and cleaning. Computer simulations were performed using the *Netuno* computer programme, version 4. Three scenarios of water consumption were simulated (120, 160 and 200 L/person.day). A paved area equal to 9,058 m² and a rainwater tank capacity of 1,000 m³ were obtained. The potential for potable water savings ranged from 16.91% to 33.39% according to the water demand for non-potable purposes. The use of stormwater runoff harvested from paved streets can be an alternative to save potable water in buildings as well as contribute to a sustainable urban drainage.

Keywords: potable water; buildings; stormwater; runoff; paved streets; computer simulation.

1. Introduction

About 75% of the surface of the Earth is covered with water, and the oceans hold 96.5% of all water. Only 3.5% is freshwater (United States Geological Survey [USGS] (2017), United Nation Educational, Scientific and Cultural Organization [UNESCO] (2017)). Global annual water use will grow around 10 to 12% every decade due to population growth and industrialization (McIntire, 2012). The growing water demand and the possibility of water resources scarcity is a challenge to be faced in several countries. This subject has been a source of concern for researchers, governments, regulators, and water suppliers.
According to the Brazilian Water Agency [ANA] (2010), domestic water in Brazil is supplied by surface water and groundwater, in which 47% are exclusively provided by surface water sources, 39% by groundwater and 14% by both types, mixed supply. Also, around 55% of the municipalities have deficient water supplies and need to seek environmental solutions to problems in their supply systems.
In Brazil, 85% of the population lives in urban areas (*Instituto Brasileiro de Geografia e Estatística* [IBGE], (2010)). The growing and disordered urbanization has been changed the land use pattern. As a consequence, the number of impermeable areas also increased. These, associated with deficient drainage systems and the high incidence of rainfall

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events have caused great urban floods. Especially in southern Brazil, frequent floods in urban areas have resulted in human deaths; increase of diseases (leptospirosis, dengue fever, Zika virus) and also in severe economic impacts.

The excessive stormwater runoff over polluted areas can result in the contamination of groundwater and surface water. However, the contaminants can be removed using some technologies (Hardy, Cubillo, Han & Li, 2015).

Rainwater can be used both for potable purposes (after properly treated) and non-potable purposes (toilet flushing, urinals, household cleaning, car wash and in garden irrigation). The feasibility of water recycling projects can be evaluated considering expected savings, health, economic, and environmental issues (Kumarasamy & Dube, 2016). One of the obstacles to rainwater usage is irregular rainfall distribution over the year in many areas. Rainwater is not feasible in places with shortage of rainfall during the dry season (Hardy et al., 2015). Struck (2011) states that it is also important to identify health risks associated with specific non-potable water uses.

Nowadays, water resources management is very important, once the scarcity of water mainly harms social improvements. In addition, water management is an important scientific issue because there is a need to constantly search means to assure the availability of good-quality water and to preserve such resource (Araújo, Alves, Chrispim, Mendes & Silva, 2015).

Several studies have shown that harvested rainwater can be used for many purposes, being essential to water resources management; it is also an alternative to face the water scarcity on the planet and reduce flood risks in the cities (Muthukumaran, Baskaran & Sexton, 2011; Souza & Ghisi, 2012; Stec & Kordana, 2015; Devkota, Schlachter & Apul, 2015; Antunes, Thives & Ghisi, 2016). The use of rainwater reduces pressure on public water systems, on the groundwater, and also on freshwater from rivers and lakes.

Stormwater harvested from permeable pavements can also allow for potable water savings and runoff reduction. Stormwater can be absorbed by the porous surface of the permeable pavement and drained to a reservoir, which temporarily stores the stormwater before infiltrating it into the soil. This can reduce stormwater runoff volume by 73% to 99%, which in turn reduces the pollutants carried to water bodies (NRDC, 2011). Permeable pavement systems are suitable for a wide variety of residential, commercial and industrial applications, despite their infrequent use (Scholz & Grabowiecki, 2006).

In this scenario, the objective of this study is to estimate the potential for potable water savings in multifamily buildings through the use of stormwater runoff collected from streets paved with conventional pavement, i.e., impermeable surfaces.

2. Water Consumption

According to ANA (2010), the water consumption in Brazil depends on the geographic region, social class, and income. In relation to the geographic region, the water consumption varies from 118.9 L/person.day in the Northeast (semi-arid region) to 187.9 L/person.day in the Southeast (most populous region) (*Sistema Nacional de Informações sobre Saneamento* [SNIS] (2016)). The average water consumption in Brazil is 162 L/person.day (Hafner, 2007; SNIS, 2016). For the main sectors, the distribution is 46% agricultural use; 26% urban consumption and 18% industrial consumption (ANA, 2007).

In Florianópolis, the Building and Construction Code and the Law no. 1231 (2016) states that all new commercial and residential buildings with a floor plan area greater than 200 m² must have rainwater harvesting systems for non-potable uses. The average water consumption in Florianópolis is 186 L/person.day (*Companhia Catarinense de Águas e Saneamento* [CASAN] (2017)).

3. Methodology

The methodology to estimate the potential for potable water savings in multifamily buildings through the use of stormwater runoff collected from paved streets was carried out in three phases, as shown in Fig. 1 and described as follows.

3.1 Data from the Study Area

The study area is located in the city of Florianópolis, southern Brazil (Fig. 2). Florianópolis is an island located between the latitudes 27°10' and 27°50' South and the meridians 48°20' and 48°35' West longitude. Rainfall is significant and well-distributed throughout the year. Florianópolis has no dry season; the highest rainfall occurs over the summer. The study area was selected based on data obtained from the Brazilian Institute of Geography and Statistics (IBGE) that keeps data on size and number of households. The place selected for analysis has a total area of 46,392.48 m² in which the water use scenarios were established. This area entails commercial, public and residential buildings. Once the object of this study is the residential sector, the number of households (single and multifamily) was obtained from IBGE (2010).
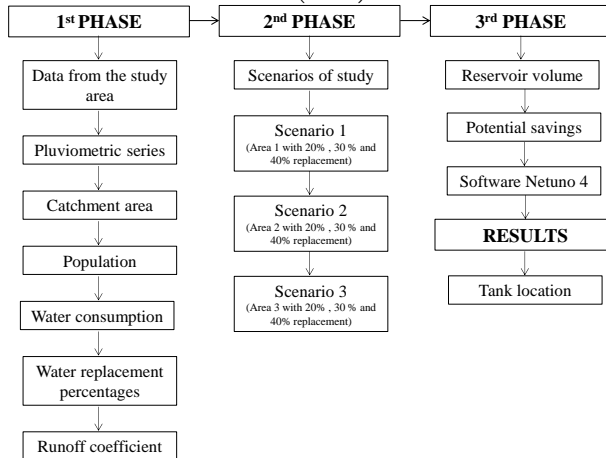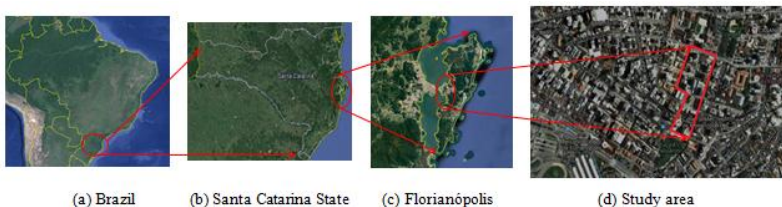

Fig. 1. Flowchart of the method.

(a) Brazil   (b) Santa Catarina State   (c) Florianópolis   (d) Study area

Fig. 2. Maps indicating the location of the study area.

3.2 Rainfall Data

Rainfall data were obtained from a meteorological station located in Florianópolis. A series of daily rainfall data over 16 years, from 01/01/2000 to 03/05/2016, was used. Fig. 3(a) presents the annual rainfall over 2000-2015 and Fig. 3(b) shows the monthly rainfall for 2015.
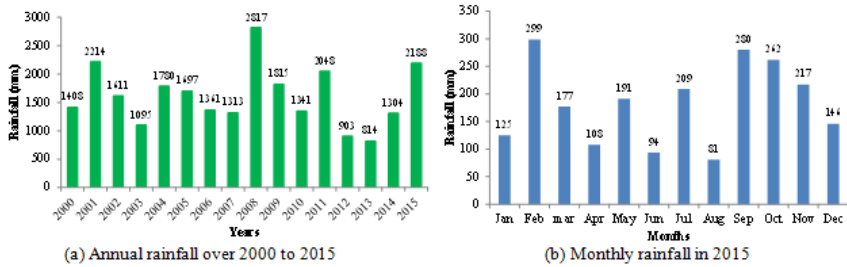

(a) Annual rainfall over 2000 to 2015   (b) Monthly rainfall in 2015

Fig. 3. Rainfall data for Florianópolis over 2000-2015.

Over 2000-2015, daily average rainfall was 4.75 mm/day, monthly average rainfall was 146 mm/month and annual average rainfall was 1,607 mm. From the data, it is observed that the rainfall is significant throughout the years, being favourable to the use of rainwater harvesting systems.

3.3 Catchment Area

The catchment area considered is related to the horizontal projection of the impermeable streets paved with asphalt mixtures. The horizontal projection area (Fig. 4) was calculated through the geoprocessing data that resulted in 9,058 m². From an average error, ± 10%, three areas were considered for the analysis as shown in Table 1.
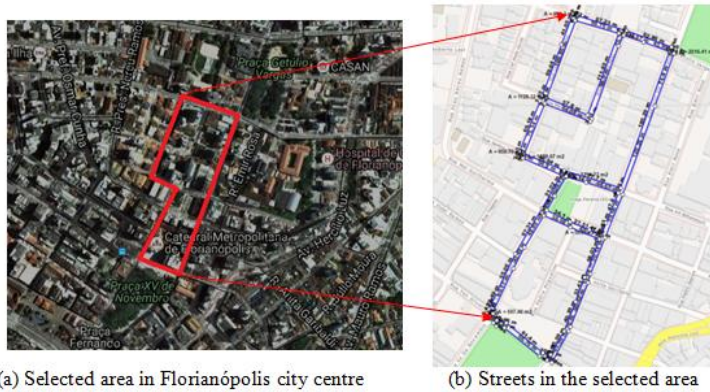

(a) Selected area in Florianópolis city centre   (b) Streets in the selected area

Fig. 4. Catchment area for stormwater harvesting.

Table 1. Areas considered for stormwater harvesting.

Area name	Description	Area (m²)
A1	Catchment area −10%	8,152
A2	Catchment area	9,058
A3	Catchment area +10%	9,964

3.4 Population

The Brazilian last census was conducted in 2010. In order to obtain data for 2016 population growth rates of the municipality were applied. In the selected area, according to IBGE census data, there are 262 flats, in which, 719 inhabitants live.

3.5 Water Consumption

The water consumption was obtained from data measured in Florianópolis (Vieira, 2013, Dalsenter, 2016), provided by SNIS (2016) and from Building Code of the city (*Prefeitura Municipal de Florianópolis* [PMF], (2011). Such consumption ranges from 124 L/inhab.day to 200 L/inhab.day. Thus, three water consumption scenarios were considered in this study: (i) minimum, 120 L/inhab.day; (ii) average, 160 L/inhab.day; (iii) maximum, 200 L/inhab.day.

3.6 Water Demand for Non-potable Purposes

The water demand for non-potable purposes in the residential sector was obtained from the literature. The demand considered includes toilet flushing, washing clothes by hand, washing machine and general cleaning. Based on the data from Barreto (2008), Dalsenter (2016), and Proença, Ghisi, Tavares & Coelho (2011), three scenarios for water demand for non-potable purposes were chosen, i.e., 20%, 30% and 40% of the water demand.

3.7 Stormwater Runoff

The runoff coefficient for paved roads with dense asphalt mixtures (impermeable surfaces) ranges from 0.875 to 0.950 (Souza, Santos, Rios, Silva, Azevedo & Batista (2012); Tucci (2000)). Therefore, a runoff coefficient equal to 0.90 was considered.

3.8 Computer Simulations

For three study scenarios, twenty-seven simulations were performed. In all the scenarios, nine simulations were performed for each of the three daily water consumptions, having as variables: three non-potable water demands and three catchment areas.

The calculations to obtain the potential for potable water savings were performed using the computer programme *Netuno* version 4 (Ghisi & Cordova, 2014). Input data for the simulations are: (i) daily rainfall (mm); (ii) catchment area (m²); (iii) number of residents; (iv) total potable water demand (L/inhab.day); (v) water demand for non-potable purposes (as a percentage of the total potable water demand); (vi) runoff coefficient; and (vii) upper stormwater tank.

The estimation of the lower stormwater tank capacity was carried out considering several volumes, using intervals of 100,000 litres, until reaching the maximum volume of 10,000,000 litres. The qualitative analysis for the selection of the ideal tank capacity took into account a volume in which the difference among rainwater potentials in the scenarios presented very small variations with each increment of tank capacity.
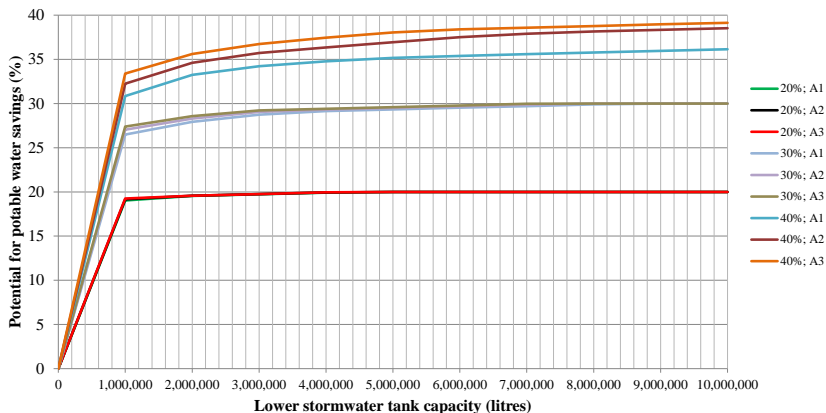
4. Results

The input data used in the simulations for the three scenarios are presented in Table 2. The potential for potable water savings obtained from the computer simulations are shown in Fig. 5.
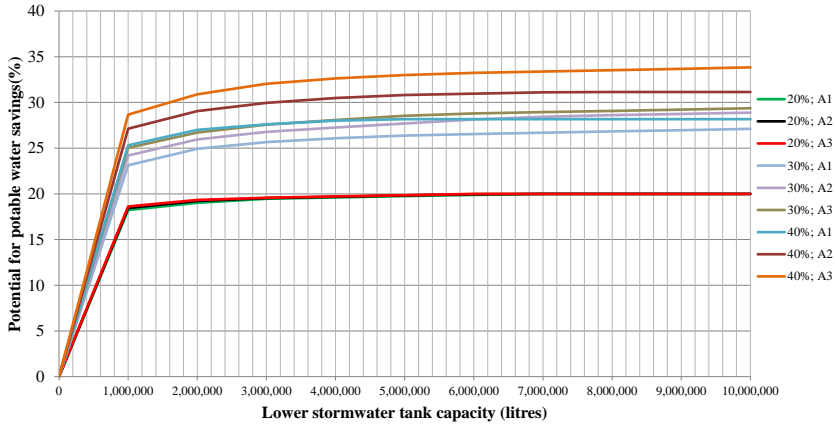
Table 2. Input data used in the computer simulations.

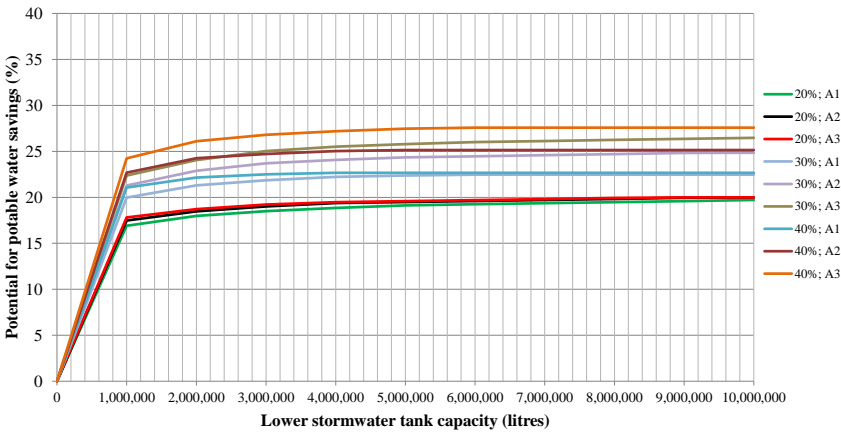| Data	Variables		
Rainfall (years)	2000 to 2016		
Number of days considered in the simulations	5,967		
Paved streets catchment areas (m²)	8,152	9,058	9,964
Runoff coefficient	0.9		
Inhabitants	719		
Rainwater demand for non-potable purposes (%)	20	30	40
Water demand (L/inhab.day)	120	160	200
Maximum tank capacity (L)	10,000,000		
Increment between tank capacities (L)	100,000		

From Fig. 5 it can be observed that there is no great increment in the potential for potable water savings for tank capacities greater than 1,000,000 litres. For example, considering a water demand equal to 120 L/inhab.day, paved area equal to A1 and non-potable water demand equal to 20% of the water demand, the potential savings are equal to 19.55% using a 2,000,000-L tank, while such savings equal 19.03% for a 1,000,000-L tank. Thus, the potential savings increase only 0.52% by increasing the tank capacity in 1,000,000 litres. Therefore, adopting a 2,000,000-L tank would not lead to significant increment in the savings. A stormwater tank capacity equal to 1,000,000 litres proved to be the ideal for all scenarios analysed herein. Table 3 shows the potential for potable water savings for a stormwater tank capacity equal to 1,000,000 litres.

(a) Water consumption equal to 120 L/inhab.day

(b) Water consumption equal to 160 L/inhab.day

(c) Water consumption equal to 200 L/inhab.day

Fig. 5. Potential for potable water savings considering non-potable water demands equal to 20%, 30%, 40% and paved street areas equal to A1, A2, A3.

Table 3. Potential for potable water savings considering a stormwater tank capacity equal to 1000m³.

Catchment area (m²)	Water demand for non-potable purposes (%)	Potable water savings (%)			Stormwater to supply the non-potable demand (%)
		120 (L/inhab.day)	160 (L/inhab.day)	200 (L/inhab.day)	
A1		19.03	18.24	16.91	
A2	20	19.16	18.45	17.48	84.55−96.30
A3		19.26	18.61	17.81	
A1		26.48	23.13	19.67	
A2	30	27.04	24.19	21.29	65.57−91.33
A3		27.40	25.04	22.37	
A1		30.84	25.31	21.06	
A2	40	32.25	27.13	22.68	52.65−83.47
A3		33.39	28.67	24.23	

From Table 3 it was observed that considering a stormwater tank capacity equal to 1000m³:

• For non-potable water demand equal to 20% of the water demand, the potential for potable water savings ranged from 16.91% to 19.26%. Therefore, there would be enough stormwater to supply 84.55−96.30% of the non-potable water demand;

• For non-potable water demand equal to 30% of the water demand, the potential for potable water savings ranged from 19.67% to 27.40%. Therefore, there would be enough stormwater to supply 65.57−91.33% of the non-potable water demand;

• For non-potable water demand equal to 40% of the water demand, the potential for potable water savings ranged from 21.06% to 33.39%. Therefore, there would be enough stormwater to supply 52.65−83.47% of the non-potable water demand.

From previous studies that assessed the potential for potable water savings in three multifamily buildings in Florianópolis by using rainwater collected from their roofs, savings ranging from 14.7% to 17.7% were obtained (Ghisi & Ferreira, 2007). Dalsenter (2016) obtained savings ranging from 7.21% to 8.42% in three other multifamily buildings. Therefore, collecting stormwater runoff from paved roads would lead to potable water savings higher than those obtained from rooftop rainwater.

The location of the stormwater tank should be close to the lowest point of the drainage basin in order to collect the stormwater runoff by gravity. It was observed that one of the lowest points in the study area is located in a square opposite to the City Cathedral. Fig. 6 shows the study area with the location of the stormwater tank and the stormwater runoff flowing towards the tank. Underneath the square there is space for placing a stormwater tank measuring 10m x 50m x 2m which results in a capacity equal to 1000m³. Fig. 7 shows a view of the square and the stormwater tank. Then, stormwater will be pumped from that tank to non-potable water tanks located in each multifamily building.
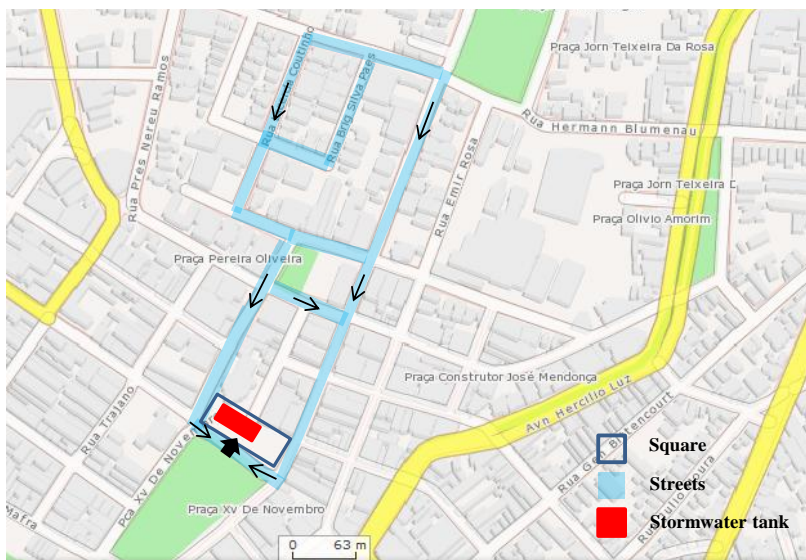

Fig. 6. Map showing the location of the stormwater tank (Based on PMF, 2016).
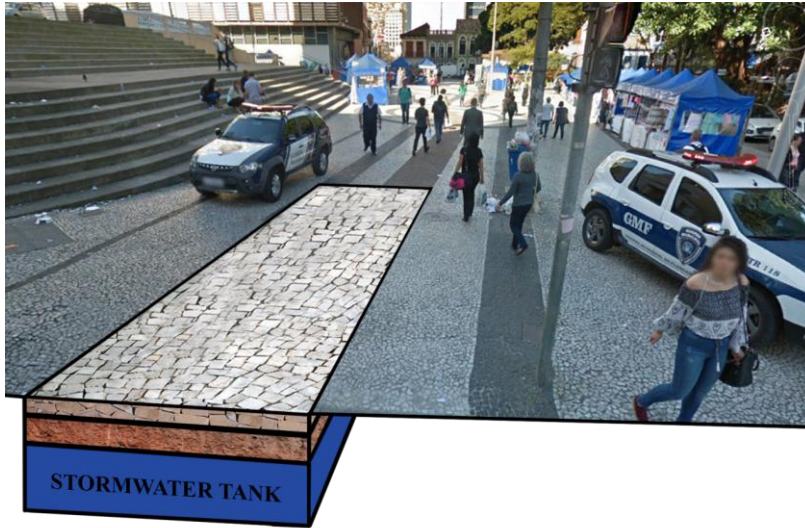
Fig. 7. View of the square and the stormwater tank.

5. Conclusion

The objective of this work was to estimate the potential for potable water savings in multifamily buildings through the use of stormwater runoff collected from paved streets for non-potable purposes. Thus, an area in the city centre of Florianópolis, southern Brazil, was evaluated using real data from paved streets area, population and buildings.

For stormwater tank capacities greater than 1000m³, there was little increase in the potential for potable water savings. Thus, a stormwater tank capacity equal to 1000m³ was considered as ideal. Comparing the potable water savings obtained from all simulations, it was concluded that the lower the water consumption, the greater the potential for potable water savings.

In general, the potential for potable water savings by using stormwater runoff collected from streets in Florianópolis would range from 16.91% to 33.39% for non-potable water demands ranging from 20% to 40% of the water demand. And there would be enough stormwater to supply 52.65−96.30% of the non-potable water demand.

The results obtained in this work showed that collecting stormwater runoff from paved streets or roads can be an interesting alternative for saving potable water in buildings, besides contributing to a sustainable urban drainage. The quality of such stormwater and an investment feasibility analysis are also matters of concern, but they were not addressed in this work.

6. Acknowledgments

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