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Residential rainwater harvesting: Effects of incentive policies and water consumption over economic feasibility

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ABSTRACT

Rainwater harvesting is currently a recurring theme as part of the sustainable practices for urban constructions. The economic feasibility of implementing a system capable of capturing, treating and distributing rainwater for residential uses concerns the user who intends to benefit from such practice. To this end, twelve single-family houses of different construction standards were selected for this research in the city of Belém, Pará, Brazil. The design and budget for the installation of a rainwater harvesting system were prepared for each house. The hydrological performance and economic feasibility were evaluated under different consumption and economic policies scenarios using the rainwater harvesting simulation software. The main conclusion is that rainwater systems are more economically feasible in households with higher water demand, regardless of the size of the catchment area. The cost of implementing rainwater systems has little variation with the construction standard of the residence where it is installed. The tariff structure makes it economically unfeasible to harvest rainwater in any scenario for houses where water consumption is below the social tariff or receives fixed price water bill. A combination of rising water prices to the same level of water production costs and reduced implementation costs improves the economic feasibility of rainwater harvesting.

1. Introduction

From the beginning of the XXI century, natural resources management has been one of the most important issues for the future of humankind survival. The sustainable use of resources, including water resources, was one of the Millennium Development Goals established by the United Nations, aiming to preserve these resources for the necessities of next generations (ONU, 2015, 2000).

Water resources have been exploited extensively and the trend is increasing. For the year 2050, a 55% increase in world water demand is expected, generating scarcity and competition among water uses (WWAP, 2015). The heterogeneity of water access creates an unbalance in water resource management. Around the world, residential piped water distribution reaches 79% in urban areas, in contrast to 32% of rural areas (WHO/UNICEF, 2015). In this context, rainwater harvesting can be a possible alternative for human water supply (Flores et al., 2012; Leal et al., 2014; Mwabi et al., 2011; Sturm et al., 2009).

The main advantages of rainwater harvesting are the savings in water for drinking as well as non-drinking purposes (depending on the treatment implemented in the system), and improvement in stormwater drainage systems. The percentage of water demand that can be potentially covered by rainwater harvesting (RWH) systems depends on a large number of factors, such as acceptable water uses, quantity and seasonality of precipitation at the installation site, tank size, catchment area and total water demand (Imteaz et al., 2011). On stormwater drainage, the implementation of large scale RWH systems has the effect of peak flow reduction during heavy rains (Campisano et al., 2014) and in the total long-run flow volume (Walsh et al., 2014). The reductions of peak flow may help to increase the useful life of municipal drainage infrastructure where new impervious areas might be developed, while reducing the total volume drained decreases the effluent released into the water bodies.

Government policies are a decisive element for the adoption of sustainable practices in society (Jänicke, 2008). In Brazil, the Brazilian Semiarid Articulation (ASA) has developed one of the world's largest social programs for the use of rainwater deployed in the northeast region, with more than half a million cisterns built by 2016 (ASA, 2016). Other programs have been implemented in several regions of the country, including actions in the city of Belém-Pa, mainly in the surrounding islands (Leal et al., 2014).

However, one of the main barriers for attracting new users initiative in rainwater harvesting is the artificially low cost of drinking water tariffs (Gold et al., 2010). According to the Brazilian National Sanitation Information System (SNIS, 2016) in 2014, 12 of the 26 states,

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including Pará, had an average total cost per m^3 higher than the average tariff charged. This fact exposes a disagreement between the actual cost of supply and the amount charged by the concessionary in roughly half of the Brazilian states. This situation occurs in other areas around the world such as Kenya and Sub-Saharan Africa countries, as pointed out by Amos et al. (2016).

Pannell (2008) suggests a method for the evaluation of public policies in which the actions taken by government authorities depend on the value created for both the general public and for the individual users. From the public point of view, the use of rainwater generates positive externalities that may or may not exceed the individual installation costs. In order to define the effects of rainwater systems, an economic analysis is necessary for the private actors, which is part of the objective of the present study, and another for the externalities generated by the initiative. Amos et al. (2016) emphasize that economic analyses are still limited in literature and relevant when looking for cost- efficiency in RWH systems, particularly in developing countries.

There are numerous examples around the world of legislation that seek to regulate and encourage the rainwater harvesting. Countries such as the United States, Germany, Spain and Australia have implemented rainwater harvesting policies, at different governmental levels, that include economic incentives (Domènech and Saurí, 2011; Gold et al., 2010; Partzsch, 2009; Siems and Sahin, 2015). Brazilian legislation has several laws and regulations, mainly in the municipal sphere, that encourage or require the use of rainwater for projects in civil construction, commerce, industries and other establishments (da Costa et al., 2017). Campisano et al. (2017) stresses that future research must be focused to understand the role of institutional support to the RWH system efficacy.

Partzsch (2009) identified three policies as the main causes for Germany becoming a world reference in the use of rainwater. These include the investment subsidies for decentralized technologies, the imposition of water extraction rates and the separate charging of drinking water and drainage bills. These measures fall within the "smart regulations", defined by Jänicke (2008) as those that fulfill three main objectives: (1) mobilize all major actors, (2) create horizontal rather than vertical relations between actors and state institutions, (3) focus on the goals and not the methods to achieve them.

Subsidies to consumers of basic services aim to ensure coverage expansion and at the same time improve the distribution of resources among socioeconomic classes. Subsidies in infrastructure are justified by universal access to basic services, even when they are inefficient (Komives et al., 2005). In the state of Pará, Brasil during 2014, the average water tariff was 1.70 R$/$m^3$ while the average total expenditure was 3.48 R$/$m^3$ (SNIS, 2016), indicating that approximately 48.85% of the cost is being subsidized. The price of the water tariff has a negative correlation with the consumption of water (Romano et al., 2015, 2014) and is usually a main factor of financial analysis of RWH system (Morales-Pinzón et al., 2015). Consequently, this type of subsidy increases water consumption while making alternative supply technologies less attractive.

The redirection of subsidies, as incentives for the installation of RWH systems, could increase the number of users of these systems (Guedes et al., 2014; Roebuck et al., 2011; Stec and Kordana, 2015). Rahman et al., (2012) found that partial reimbursement of initial installation costs economically makes certain system configurations viable. Domènech and Saurí (2011) felt that the partial subsidies, in addition to making the rainwater harvesting profitable, also encourage the user's participation in the project, increasing their environmental awareness. Campisano et al. (2017) verifies the variability of economic results around the world and stresses the need for research which include the effect of institutional and socio-polticial policies in RWH implementations.

From the above, this work puts forward the evaluation of economic feasibility for RWH implementation in residences under different conditions of water consumption and incentive policies, in order to provide authorities, designers, and users with relevant information for the decision-making process of this technology.

2. Materials and methods

2.1. Study area

The area selected for this study was the urban region in the municipality of Belém, the capital of the state of Pará located in the Brazilian Amazon. This municipality has an approximate area of 507 km^2, with 35% corresponding to the continental area and the remaining 65% to insular area. The urban area represents 243 km^2 (SEGEP, 2012). In 2014, the total population estimated was 1,432,844 inhabitants, 1,420,582 of which live in the urban area and 12,262 in the rural area (IBGE, 2014). The public utility in charge of drinking water supply is the Companhia de Saneamento do Pará (COSANPA), which supplied water for a total of 1,302,345 inhabitants through 219,653 active connections during 2014 (SNIS, 2016). This means that 130,499 people needed alternative sources of water.

The climate of Belém can be characterized as Afi (rainy) according to the Köppen's classification and 4a (humid) according to Thornthwaite's, both within the tropical climate class (Bastos et al., 2002). The city has an average precipitation of 2,921.7 mm, with temperatures ranging from a minimum of 22.1 to maximum 31.5 °C (INMET, 2009). There are two distinct rainfall periods, with October being the month with the lowest cumulative mean rainfall (119.3 mm) and March the month with the highest (441.2 mm) (Bastos et al., 2002).

For the system performance simulations, historical daily precipitation data from the Brazilian Weather Bureau (INMET) weather station (Code 82191-Belém-Brazil) were used. Although the measurements at this station started in 1921, the period selected for the simulations ranged from January 1, 1991 through December 30, 2015, for a total of 25 years. This period was chosen for its temporal relevance and for its data completeness, with only two missing dates of the 9132 possible, resulting in a 99.98% complete series. Days without measurement were considered without precipitation. Ghisi et al. (2012) determined that series above thirteen years are suitable for the chosen simulation method.

Twelve households were selected as case studies, three single-family units to fit each residential standard (Table A1). The spatialization of these houses and weather station is presented in Fig. 1. All residences are located at a distance of between 2.1 and 12.6 km from the INMET weather station.

2.2. Software for simulated performance of RWH systems

For the execution of this study, simulations were carried out using rainwater software NETUNO 4.0, developed by Ghisi and Cordova (2014). This tool has been used in several studies to determine the potential economic and water savings generated by the implementation of RWH systems in several types of buildings (Berwanger and Ghisi, 2014; Chaib et al., 2015; Fasola and Marinoski, 2011; Ghisi and Schondermark, 2013; Salla et al., 2013). The program has been validated and compared with other sizing methods established by NBR 15527 (ABNT, 2007) in different pluviometric regimes in Brazil, obtaining satisfactory and better results than other methods (Rocha, 2009; Rupp et al., 2011).

The program has two different and complementary options, with their respective input and output variables:

- To test the hydrological performance of the RWH system for different volumes of reservoirs. For the purpose of this work, this stage is called Water Performance Evaluation (WPE).
- To determine the Net Present Value (NPV), Internal Rate of Return (IRR), and Payback period for a recovery system with a predefined storage volume. For the purposes of this paper, this stage was named Economic Analysis (EA).