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Feasibility, seasonality and reliability of rainwater harvesting in buildings of a university in Campina Grande, Paraíba

Viabilidade, sazonalidade e confiabilidade da captação de água de chuva em edificações de uma universidade em Campina Grande, Paraíba

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ABSTRACT

Urban areas in semi-arid regions are under chronic water stress. In this scenario, expanding water supply with decentralized sources that collaborate with Water-Sensitive Urban Design (WSUD) may be relevant, such as rainwater harvesting (RWH) systems. In this respect, this study aimed to analyze the potential for the use of rainwater in public buildings in the Brazilian semi-arid region, integrating three aspects: environmental and economic feasibility, seasonality, and reliability. The results provide substantial evidence on the benefits of using rainwater, both from an environmental and an economic point of view. This use can significantly reduce the annual consumption of water from the public supply, which would reduce the demand from water bodies. It has also been found that there is considerable variation in the potable water savings potential throughout the year; the systems, however, still provide reliability.

Keywords: Decentralized supply; Alternative sources of water; Efficient consumption of water; Non-potable uses; Water-Sensitive Urban Design.

RESUMO

As áreas urbanas em regiões semiáridas estão sob estresse hídrico crônico. Nesse cenário, expandir o abastecimento de água com fontes descentralizadas que colaboram com um Projeto Urbano Sensível à Água (WSUD) pode ser relevante, como sistemas de aproveitamento de água de chuva (RWH). Assim, este estudo teve como objetivo analisar o potencial de aproveitamento da água da chuva em edificações públicas no semiárido brasileiro, integrando três aspectos: viabilidade (ambiental e econômica), sazonalidade e confiabilidade. Os resultados fornecem evidências substanciais sobre os benefícios do uso da água da chuva, tanto do ponto de vista ambiental quanto econômico. Esse uso pode reduzir significativamente o consumo anual de água do abastecimento público, o que reduziria a pressão sobre os corpos hídricos. Também foi demonstrado que existe uma variação considerável no potencial de economia de água potável ao longo do ano, mas que ainda assim, os sistemas fornecem confiabilidade.

Palavras-chave: Descentralização do abastecimento; Fontes alternativas de água; Consumo eficiente de água; Usos não potáveis; Projeto Urbano Sensível à Água.

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INTRODUCTION

Effective and efficient water supply remains a challenge for developing countries (Stout et al., 2015; Cetrulo et al., 2019). In Brazil, almost 93% of the urban population is served by public supply, a percentage that is reduced to 88% when considering only the Northeast region, where the Brazilian semi-arid region is located (Sistema Nacional de Informações sobre Saneamento, 2020). Even though it seems to be a good number, the semi-arid region is one of the most hydrologically vulnerable regions due to drought events (Gesualdo et al., 2021), which often put the water supply service at risk, conditioning the population to water rationing (Grande et al., 2016). Taking into account water potability and the absence of interruption in the supply service, only 59.9% of the Brazilian population is properly served (Brasil, 2019).

In addition, most of the water supply services are centralized, with distribution networks that use a single supply source that can be a reservoir, a river, or groundwater (Brasil, 2019). This pressures the water bodies even more, raising the need to discuss the implementation of decentralized water sources, such as rainwater harvesting (RWH) systems in buildings (Stout et al., 2015; Souza, 2015; Barbosa, 2019). This action tends to be useful not only to complement the demand from centralized sources, but also to guarantee quality supply to the part of the population that is marginalized in the water supply, making urban systems more resilient (Chelleri et al., 2015; Semaan et al. 2020). Moreover, RWH has proven to be a satisfying alternative even in the face of climate change scenarios (Zhang et al., 2019; Santos et al., 2020; Toosi et al., 2020; Imteaz et al., 2021), and it can contribute to urban sustainability not only in the water supply, but also in urban drainage, another part of basic sanitation (Armitage et al., 2014; Veiga, 2019; Carvalho et al., 2020; Araujo et al. 2021).

In view of this, it is necessary to recognize that the function of tanks in RWH takes on a different role to reduce the impacts on urban drainage systems and on water supply systems. For urban drainage, it is essential that the tanks be empty in each rainfall event in order to minimize water runoff in the drainage system. For supply, it is important that the tanks accumulate enough water to meet the demands that will make use of the stored water. Thus, an RWH system will hardly present a good performance for these two sanitation services at the same time.

RWH systems are relevant technologies to rationalize water consumption (Nóbrega et al., 2012) and thus consolidate two important Brazilian policies: the National Basic Sanitation Policy (PNSB) and the National Water Resources Policy (PNRH). Encouraging the capture, preservation and use of rainwater is, in fact, one of the objectives of the PNRH. In Brazil, of the three planning scales (national, state, and municipal), it is up to states and municipalities to draw up regulations that help disseminate these technologies to favor water supply (Libanio, 2014; Agência Nacional de Águas e Saneamento Básico, 2020a). Legislation in this regard is still poorly enforced, and due to the need for controlling the quality of the water stored in tanks (Farto & Silva, 2020; Machado et al., 2021), the use of this resource for non-potable purposes is generally recommended. An example of the efforts to make RWH viable for non-potable uses occurred with the dissemination of the NBR 15527 (Associação Brasileira de Normas Técnicas, 2019), which presents requirements for projects that aim to include this alternative source of water. The One Million Cisterns Program (P1MC) is the Brazilian highlight for the increase in the use of RWH, which focused on the application of the entire infrastructure to supply the semi-arid rural population (Doss-Gollin et al., 2016). In urban environments, there were no significant advances in public policies and programs related to RWH dissemination.

Reassuring the commitment to capture and use rainwater in buildings in general is relevant when considering that these actions tend to strengthen a Water-Sensitive Urban Design (WSUD) approach (Armitage et al., 2014; Ahammed, 2017; Hoban, 2019; Marinho et al., 2020). WSUD corresponds to the cities that plan to optimize water resources in the urban environment, taking into account the urban hydrological cycle, leading to importing less potable water (using strategies such as RWH systems) and exporting less effluent (using strategies such as greywater reuse) (Wong & Brown, 2009). Furthermore, RWH is a water source that supports Integrated Urban Water Management (IUWM) (Furlong et al., 2017).

In semi-arid regions, diffusing RWH is considered a way to mitigate the impacts of droughts (Tabatabaee & Han, 2010; Kala, 2017; Saurí & Garcia, 2020). The benefit lies in the fact that while buildings replace part of the demand for potable water with rainwater collected from rooftops, there are fewer withdrawals from the water bodies that suffer the impacts of droughts. For Vallès-Casas et al. (2016), drought phenomena are social drivers to making rainwater collection tanks more desirable since they add some water security to users.

The importance and feasibility of RWH in different arid and semi-arid regions in the world have been found in many studies (Stout et al., 2015; Tamaddun et al., 2018; Abdulla, 2019; Molaei et al., 2019; Toosi et al., 2020; Shokati et al., 2020; Al-Qawasmi, 2021). In the Brazilian semi-arid region, there are also some initiatives in this regard in urban areas (Souza, 2015; Santos & Farias, 2017; Jesus et al., 2019; Silva et al., 2021). What can be seen from these studies is that in these regions, the potential for saving potable water is lower (although still significant), and they mostly analyze residential buildings. The water savings potential is low compared to regions where there is a greater volume of rainfall and where rainfall is better distributed throughout the year. Therefore, it might not be possible to meet all the water demand. However, even with this reduced potential, RWH systems tend to provide some relief to water bodies in these regions that live under chronic water stress, which makes this "low potential" a significant measure for rationalizing water consumption.

Many other researchers that have assessed the potential use of rainwater focus on residential buildings as a study area (Chaib et al., 2015; Sampaio & Alves, 2017; Teston et al., 2018; Maykot & Ghisi, 2020). However, it is necessary to extend this knowledge to other kinds of buildings since they are also water consumers and need to have a rationalized demand, especially in regions with a semi-arid climate, where the scarcity of water resources is even more pronounced.

Commercial and public buildings, such as university buildings, are significant water consumers because of the large number of users who generally occupy these spaces. In addition, due to the dynamics of use to which these buildings are subject, the water demand is mostly associated with non-potable consumption (Teston et al., 2018), which implies that rainwater could be used satisfactorily. However, studies on rainwater harvesting in these buildings are scarce (Karim et al., 2021).

Previous studies have performed this assessment in a few public buildings located in Brazilian regions with a considerable volume of precipitation (Salla et al., 2013; Ghisi et al., 2017; Cardoso et al., 2020). The authors concluded that the use of this technology is environmentally and economically feasible. However, considering that the rainfall regime plays an important role in the system effectiveness (Peters, 2012; Grant et al., 2018), for places that experience droughts, such evaluation needs to be conducted to ensure efficiency before its implementation. Therefore, analyses in this sense are essential for policy makers to understand the potential of this type of decentralized infrastructure for different types of buildings.

Another relevant factor that must be assessed, which is trivialized in most pieces of research, is the seasonality of the potable water savings potential. Since the amount of precipitation varies monthly, it should not be expected that supplying the rainwater demand stays the same throughout the year. Therefore, intra-annual variations in the volume and distribution of rainfall events should generate intra-annual variations in the potable water savings potential. Recognizing this variation is especially important when planning to use rainwater on a large scale since it can have an impact both on the amount of potable water saved each month and on the reduction of what is paid to water supply companies for the services provided. In addition, the adoption of RWH systems on a large scale can generate global impacts and challenges such as reduced revenue for water supply companies and difficulty in charging for the sewage generated from the use of stored rainwater. Chaib et al. (2015) included the notion of seasonality in the potable water savings potential when analyzing the application of rainwater harvesting systems in single-family dwellings. The authors noticed that there were months in which the rainwater demand was satisfied up to 95.3%, while in others, this value was greatly reduced to 3.2%. Other authors have also presented data on potable water savings potential by month or season (Stout et al., 2015; Cardoso et al., 2020), but have not discussed whether seasonality is a relevant factor or should be considered in planning stages.

The reliability (also called water saving efficiency) of RWH systems is a parameter that has been considered in several recent studies as a way to assess the adoption of this decentralized water source (Liuzzo et al., 2016; Bashar et al., 2018; Lani et al., 2018; Kisakye et al., 2018; Alamdari et al., 2018; Zhang et al., 2018; Toosi et al., 2020; Shokati et al., 2020; Molaei et al., 2020; Islam et al., 2021; Karim et al., 2021). Still, Molaei et al. (2020) explain that there are few studies that discuss the reliability of these systems with other characteristics, such as the rooftop area. The lack of sufficient information about reliability is a discouraging factor for the adoption of RWH systems (Toosi et al., 2020), since it does not guarantee how reliable these systems are to supply the rainwater demand intended to reduce potable water consumption. For Bashar et al. (2018), reliability data from RWH systems are important to guide authorities in defining guidelines and policies for the urban environment. The volumetric reliability (Liuzzo et al., 2016) considers the ratio between the total rainwater used to save potable water and the total rainwater demanded; therefore, it is a way to measure the reliability that these systems offer to their users. In Brazil, there are no substantial applications of this parameter in order to strengthen guidelines for the adoption of RWH systems.

The aim of this study is to analyze the feasibility, seasonality and reliability of the use of rainwater in public buildings in the Brazilian semi-arid region, more specifically in the city of Campina Grande, Paraíba. Therefore, the study presents a methodology that allows investigating these three aspects in an integrated way. The feasibility will have an environmental and financial perspective, that is, it will show how much potable water can be saved and how much the user can save in financial resources with such an implementation. It is a study that contributes to expanding the discussions on the adoption of RWH in a dry climate region located in a developing country, and expands the existing discussions on RWH in public buildings.

METHODOLOGY

Study area

The study area considers public buildings in the Federal University of Campina Grande – UFCG, in the Brazilian Northeast. The studied campus, located in the city of Campina Grande, has approximately 31 hectares, divided into three sectors. Campina Grande is the second most populous city in the state of Paraíba with approximately 411.807 inhabitants (Instituto Brasileiro de Geografia e Estatística, 2020), situated in the Brazilian semi-arid region (Figure 1), a region characterized by the absence of perennial rivers, low rainfall volume (Figure 2), and for its coexistence with drought events.

Campina Grande and seventeen other cities are supplied by a single reservoir (Epitácio Pessoa reservoir), with a storage capacity of 466,525,964 m^3. According to its distribution plan, approximately 68% of total monthly uses correspond to public supply (Agência Nacional de Águas e Saneamento Básico, 2020b). In the last two decades, this water body has gone through two critical periods in water supply (Figure 3), the second almost causing the collapse of the public supply service in 2017 (Rêgo et al., 2017; Cordão et al., 2020). This history shows the need to discuss ways to partially decentralize water supply, with alternative sources of water.

Accordingly, UFCG has sought ways to make more rational use of this resource to increase the water resilience of the institution and, consequently, of the city. The Campina Grande Campus Water Supply System Restructuring Project, which began in 2014, is one of their relevant initiatives. The main goals are to reduce losses, waste and increase water storage capacity (UFCG, 2019).

In the first year, the institution managed to reduce water consumption by 50%, and in four years, it produced financial savings of 1.5 million reais, a value that corresponds to the investment made by the project. The most recent data from 2018 show that even with all the measures taken, UFCG annually consumes around 30,700 m^3 of water; therefore, it remains necessary to think of ways to further rationalize its consumption.

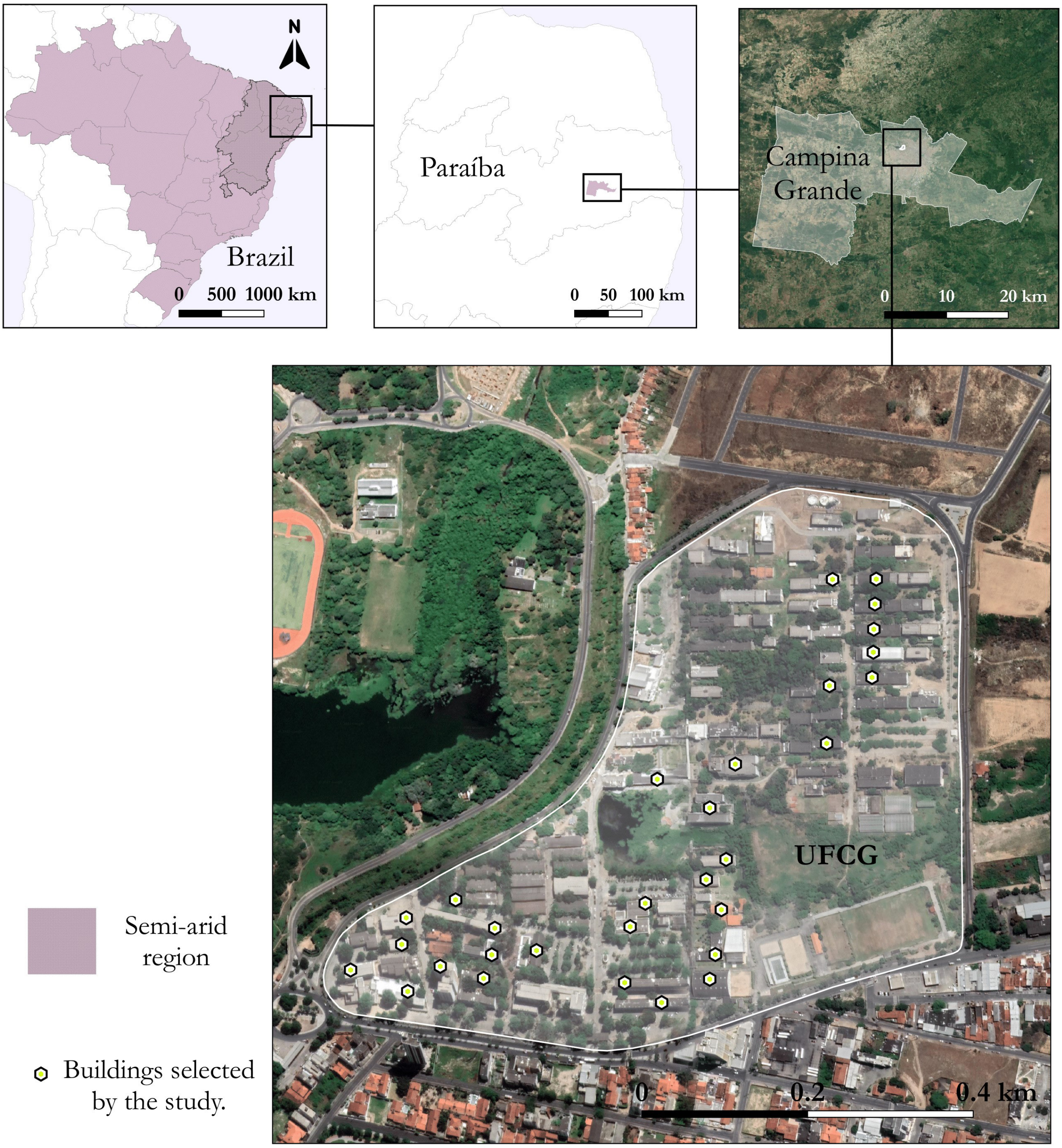

Figure 1. Location of the Federal University of Campina Grande.

Simulations of scenarios

Even considering that many cistern users utilize stored water for potable uses (Doss-Gollin et al., 2016), we chose to simulate the use of RWH systems for non-potable uses since there is uncertainty regarding the quality of the water stored if it is not properly preserved (Farto & Silva, 2020; Machado et al., 2021).

To simulate the potential use of rainwater, the computer program Netuno (Ghisi & Cordova, 2014) was used. This tool uses behavioral models (Fewkes, 2000) for simulations of RWH systems, which means it uses known variables to approximate a behavior; in this case, the consumption of rainwater in buildings. Netuno was validated by Rocha (2009), and its method is summarized in Figure 4 (for more details on how it operates, see Freitas &

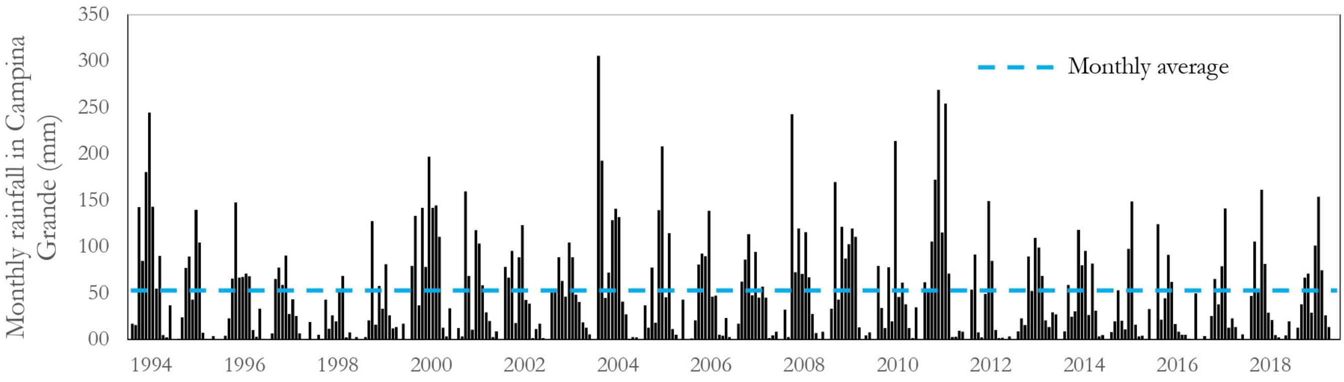

Figure 2. Historical series of monthly rainfall in Campina Grande.

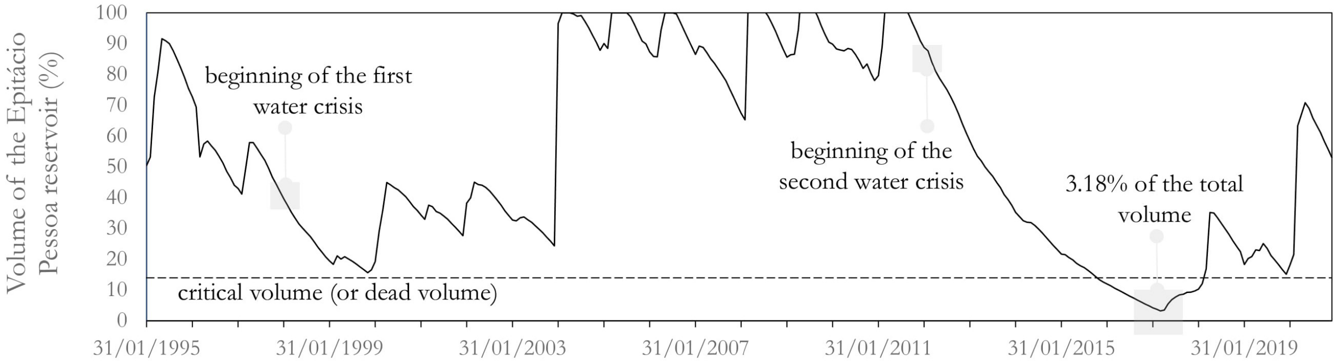

Figure 3. Historical series of the volume stored in the Epitácio Pessoa reservoir.

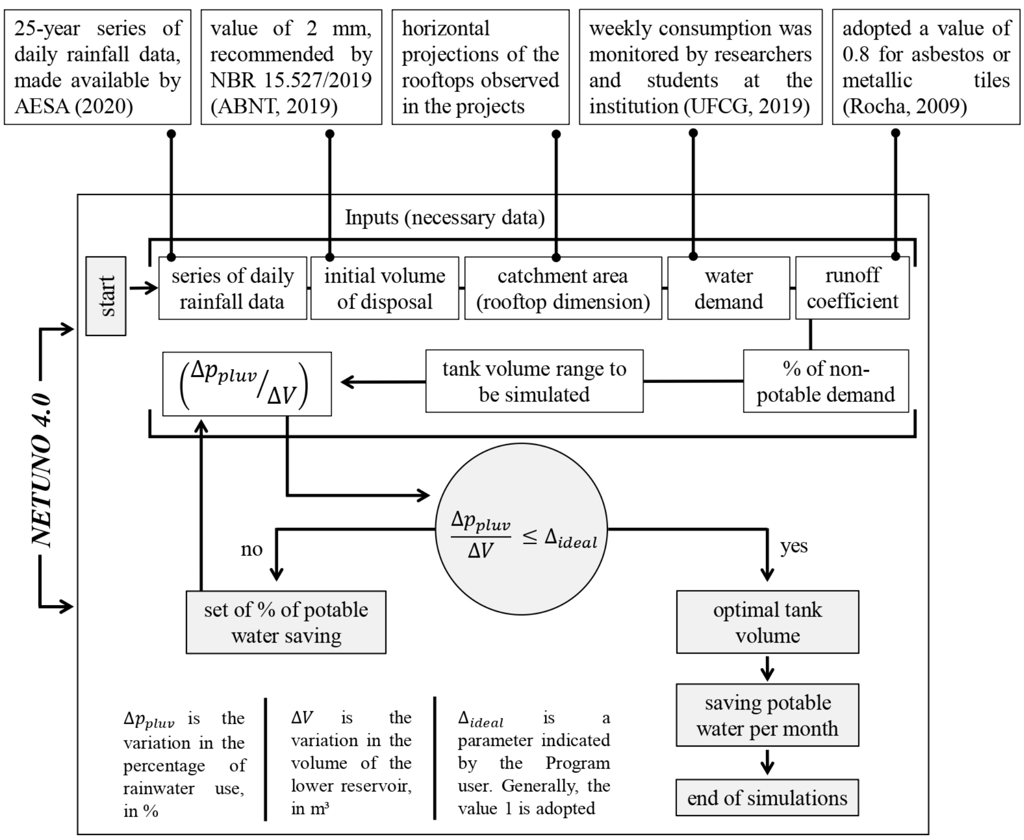

Figure 4. Methods and data used for the simulations. Source: Authors' own elaboration based on Cardoso et al. (2020).

Ghisi, 2020). Among other equations, it uses Equation 1 and the algorithm presented by Cardoso et al. (2020) to obtain the average value and monthly variation of the potable water savings potential, the ideal volume of the tanks, among other results. It was satisfactorily used by Chaib et al. (2015), Cardoso et al. (2020), Freitas & Ghisi (2020), and Maykot & Ghisi (2020).

$$E_{pot} = 100 * \sum_{i=1}^{N} \frac{V_C^i}{D_{tot}^i} \tag{1}$$

where Epot is the potable water savings potential, in %; V_C^i is the rainwater volume consumed on day *i*, in liters; and D_{tot}^i is the total demand for non-potable uses on day *i* (greater than or equal to V_C^i), in liters (Ghisi & Cordova, 2014).

In the simulations, all the collected rainwater was destined for non-potable uses. Therefore, in order to know the potential for potable water savings, values of this resource were replaced by rainwater. In research conducted in Brazilian public buildings, the water percentage for non-potable uses ranged between 63.5% and 77% (Marinoski & Ghisi 2008; Kammers & Ghisi 2006; Soares, 2019; Cardoso et al., 2020). The studies that indicate these values were not carried out in buildings located in the semi-arid region. Considering that it is a large percentage of the total consumption and that Campina Grande does not have a high rainfall volume, we chose to verify the potable water savings in four more modest scenarios: replacing potable water with rainwater by 10%, 20%, 30%, and 40%.

Several input data were necessary to start the scenarios simulations: daily water consumption per building, historical series of rainfall, rooftop dimensions, surface runoff coefficient of the collection surface, and initial runoff disposal value. The sources for these data are shown in Figure 4.

This study considered real consumption data. Weekly consumption was monitored by the Campina Grande Campus Water Supply System Restructuring Project between 2016 and 2017. In total, 105 water meters were monitored with different amounts of monitored weeks. For this research, ten buildings were chosen from each sector of the main campus, totaling 30 buildings for analysis (Figure 5), following two criteria:

(1) Present more than ten weeks of monitored consumption;

(2) Be the buildings with the highest average weekly consumption among those that satisfy the previous condition.

There are no consolidated recommendations regarding the minimum monitoring period to represent water consumption in public buildings. In view of this, the minimum period of ten weeks was adopted in order to exclude some buildings from the analysis that had little consumption data observed. Since they are university buildings, it was assumed that the greatest variation in consumption would be linked to break periods. Thus, all monitoring was carried out while school terms were taking place. The variation in consumption was also not considered in other studies that did not use real demand data (Ghisi et al., 2017; Cardoso et al., 2020).

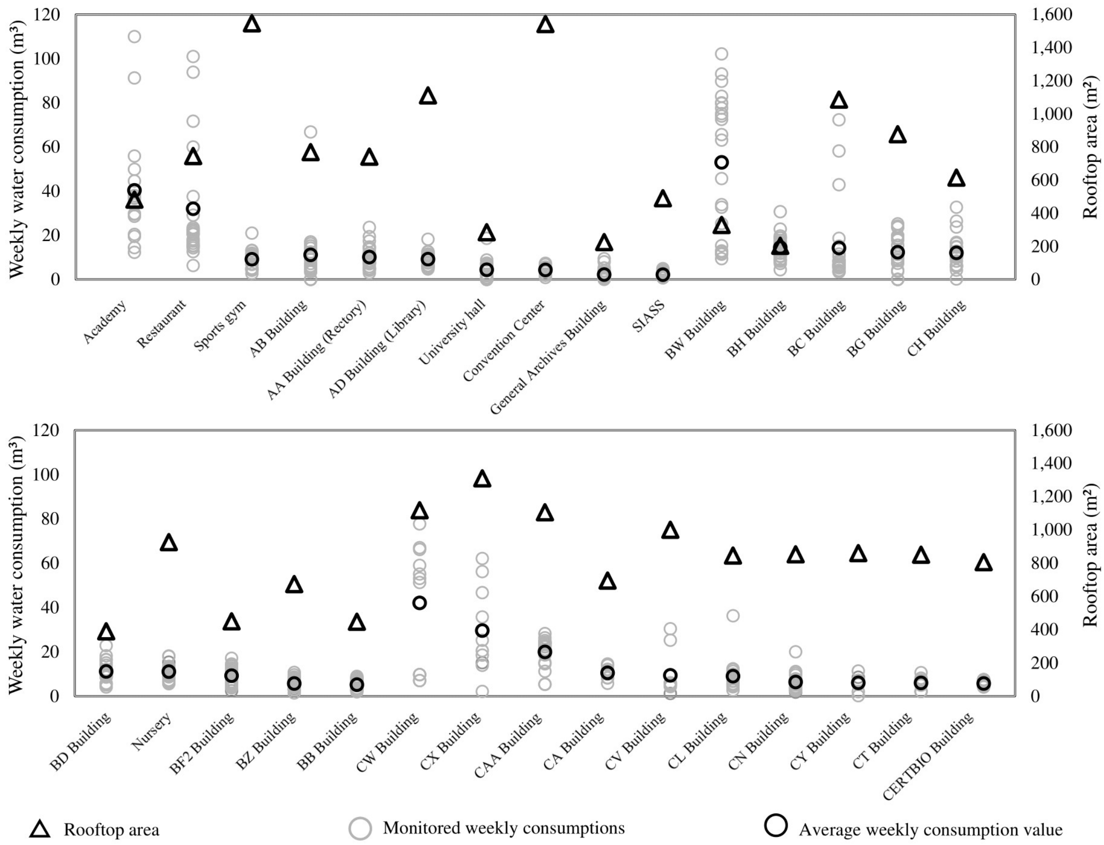

Figure 5. Weekly water consumption and rooftop sizes of the analyzed buildings.

To convert weekly water consumption into daily consumption, the average between the values for each building was calculated and this average value was divided into five days (which correspond to the days when the buildings are used intensively). Therefore, on Saturdays and Sundays, water consumption was considered null in the daily simulations that were performed.

The characteristics of the precipitation data series are decisive for the process. The daily data used are part of a 25-year series (1994-2019), with characteristics shown in Table 1 (Agência Executiva de Gestão das Águas do Estado da Paraíba, 2020). The series has 58% of non-rainy days, 23.94% of rainy days less than or equal to 2 mm (initial volume of disposal) and 18.06% with rainfall greater than 2 mm (a value exceeding 2 mm can be stored).

The financial evaluation was performed using the following indicators: payback period (Abdulla, 2019), Net Present Value (NPV) (Equation 2) and Internal Rate of Return (IRR) (the i in Equation 2 assuming an NPV equal to zero). These three indicators were also chosen by Matos et al. (2015) and presented a satisfactory assessment of the financial feasibility.

$$NPV = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} \quad ; \quad \begin{matrix} \text{if } NPV < 0, \text{unfeasible investment} \\ \text{if } NPV = 0, \text{indifferent} \\ \text{if } NPV > 0, \text{viable investment} \end{matrix} \tag{2}$$

where R_t is the Cash Flow (relationship between financial input and output of a project, in this case, the output being the investment to build the system, and the input the amount saved on the water bill); i is the discount rate; t is a specific month in the simulation, and N is the number of months of the simulation.

The feasibility of a project, and consequently its acceptance, can be assessed through the IRR as follows:

- If IRR > Discount rate: Economically feasible project;
- If IRR < Discount rate: Economically unfeasible project;
- If IRR = Discount rate: Economically indifferent project.

Based on previous research (Zhang et al., 2009; Farreny et al., 2011; Matos et al., 2015; Ghisi et al., 2017), the project addressed in this paper was conceived with a useful life of 20 years. Three discount rates were taken into account (0.5%, 1.5%, and 2.5% per month), considering that the value of this variable can be different for each type of project or economic scenario. The discount rate of 0.5% per month is close to that recommended by Ministry of Economy (Brasil, 2020) for cost-benefit analyses in infrastructure projects, and the other rates are higher to enable a visualization of less favorable scenarios for the implementation of RWH systems.

The considered investment value was only the price of the tanks since they correspond to a substantial part of the total invested in projects of this kind (Chaib et al., 2015). The tank typology adopted for the budget was based on the concrete cisterns built by the One Million Cisterns Program (Articulação Semiárido Brasileiro, 2020). Based on this type of construction, the necessary materials and services were defined, and the values followed the price quotation of the National System of Survey of Costs and Indexes of Civil Construction (Sistema Nacional de Pesquisa de Custos e Índices da Construção Civil, 2020) for the month of May 2020. The costs with piping and electricity are variable for each building and unnecessary in a preliminary analysis (Lima et al., 2017; Souza et al., 2016).

Table 1. Characteristics of the pluviometric data used for the simulations.

Time scale	Average (mm)	Median (mm)	Standard deviation (mm)
Annual	627.1	574.7	224.7
Monthly	52.3	50.9	32.7
Daily	1.71	0	4.88

It is known that there is seasonality in how potable water savings will vary with each season or month of the year. The effect of rainfall variation in the use of this resource was analyzed by observing the average potential for potable water savings in each month and for each scenario (10%, 20%, 30%, and 40% of potable water being replaced by rainwater). Therefore, the seasonality in the analyzed potable water savings corresponds to the intra-annual variation and is related to the rainfall regime. In order to capture the effect of seasonality in the system performance, the buildings were categorized using the α index (Equation 3), which correlates the rooftop area and the average weekly consumption. This index is a novelty in the present study. The standard deviation was used as a dispersion indicator of the potable water savings values obtained for the different months of the year, and such dispersion values were compared with the α index calculated for each building. The interpretation was the following: the greater the standard diation, the greater the dispersion of the values of potable water savings among the months of the year and, consequently, the greater the effect of seasonality on these savings.

$$\alpha = \frac{\text{catchment area}\left(m^2\right)}{\text{average weekly consumption}\left(m^3\right)} \tag{3}$$

Volumetric reliability (or system efficiency) was used as a parameter to analyze the security that the system offers to its user (Liuzzo et al., 2016; Bashar et al., 2018) (Equation 4). The total amount of rainwater required by the buildings in this study corresponds to what we consider the percentage of non-potable uses (10%, 20%, 30%, and 40%).

$$R_{e(v)} = \frac{\text{Volume of rainwater stored during the simulated period}\left(m^3\right)}{\text{Total rainwater demand during the simulated period}\left(m^3\right)} * 100. \tag{4}$$

Where, Re(v) is the efficiency or volumetric reliability of a RWH system (%).

RESULTS AND DISCUSSIONS

Four simulations were carried out for each building, substituting the potable water replacement percentage for that of rainwater, which resulted in 120 simulations with results shown in Figure 6. A large part of the buildings managed to reach a potable water savings potential close to the expected.

If the α index (Equation 3) is used in the analysis, which corresponds to the ratio between the rooftop area and the average weekly consumption. It can be noted that the lowest service

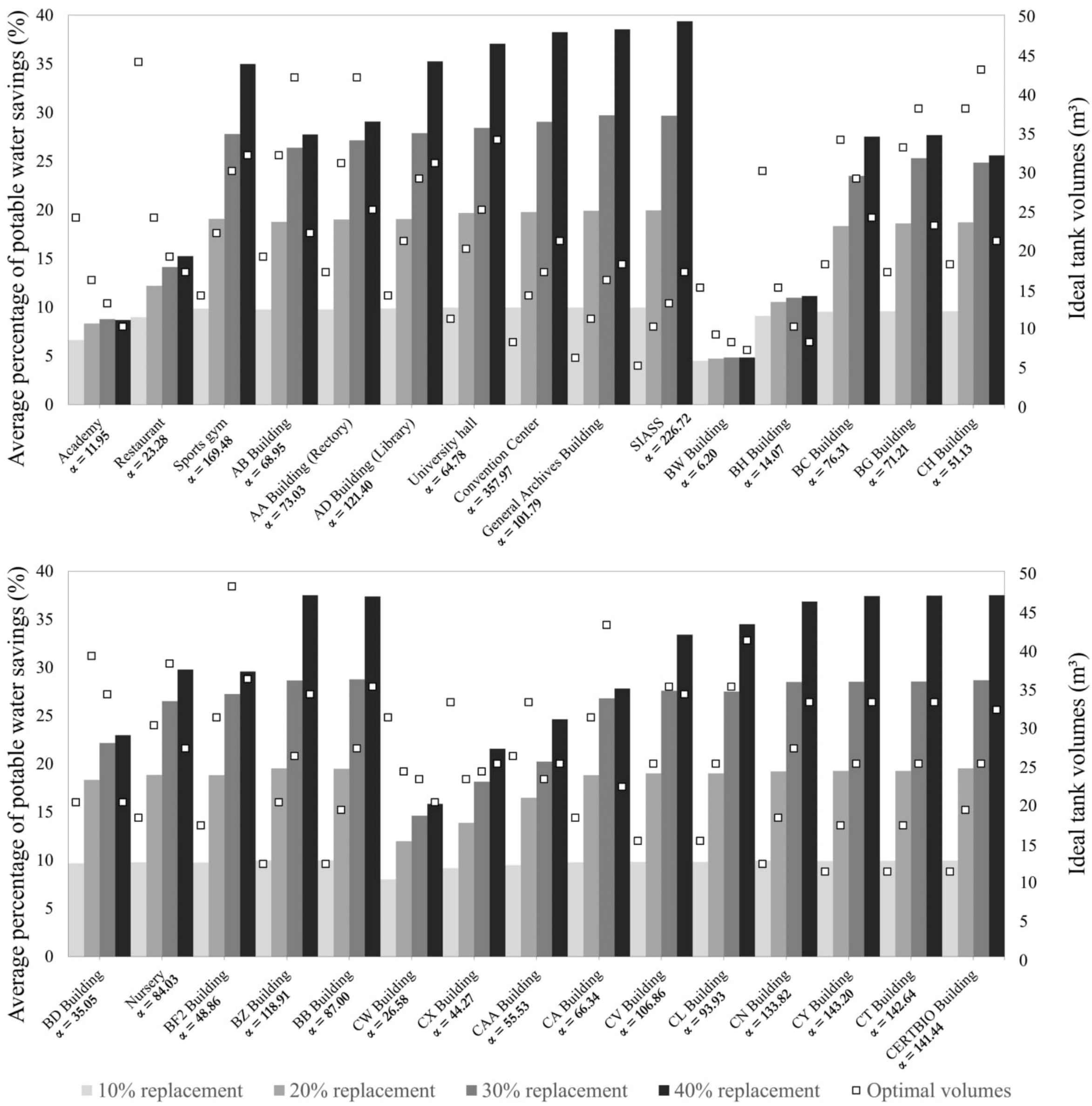

Figure 6. Average percentage of potable water savings and ideal tank volumes for the analyzed buildings.

percentages are related to buildings with the lowest values of α. An index such as this one becomes important because it allows us to have an idea of the potential for potable water savings even before performing the tank dimensioning, as having a very low α means that potable water savings may not be as satisfactory since either the rooftop area is too small, consumption too high or both.

The ideal volumes of the tanks are quite variable (Figure 6) since the demands and rooftop dimensions are also variable. The results demonstrate that even with high demands and buildings in a semi-arid climate, it is possible to adopt this type of decentralized structure with acceptable sized tanks considering the magnitude of the buildings. Since tanks with a capacity of up to 52 m^3 (Articulação Semiárido Brasileiro, 2020) are well known in the Brazilian semi-arid region, the tanks dimensioned in the simulations are acceptable. Karim et al. (2021) also demonstrate that it is possible to use RWH systems satisfactorily even with much larger tanks than those defined here as ideal.

The results show that the adoption of RWH systems is environmentally favorable and feasible. Furthermore, even though larger tanks are needed in some cases, it is possible to observe how promising it is to implement RWH to complement the demand for potable water in public buildings in this site-specific situation. This measure can be an important tool for urban planning that considers a water-sensitive urban metabolism and the construction of more resilient cities (Armitage et al., 2014; Hoban, 2019; Marinho et al., 2020), which can also include cities in semi-arid regions.

When comparing the results obtained in other Brazilian regions that present a more regular and voluminous rainfall regime (Ghisi et al., 2017; Cardoso et al., 2020), it is clear that the difference comes down to the sizes of the tanks needed and the percentage of potable water savings, which is lower in the semi-arid region. Still, these results were expressive since with the simulated use of RWH, UFCG could save between 142 m^3 and 356 m^3 of potable water per month. If the institution uses the tanks in all its buildings (more than one hundred buildings), the savings could be even more expressive.

Figure 7 shows the variation of the values of the dimensioned tanks taking into account the price quotation of the National System of Survey of Costs and Indexes of Civil Construction. It can be observed that in the first scenario (10% replacement) the average values are lower. The highest values, on average, are for the third scenario (30% replacement). Therefore, there is no tendency to increase the average tank costs by increasing the percentage of potable water replaced by rainwater. This is because the Neptune program algorithm (Figure 4) considers that increasing the tank volume will not always allow a proportional increase in the potable water savings, and so it defines a smaller ideal volume compared to a scenario in which less water is demanded. Smaller tanks therefore mean cheaper tanks. This behavior can be observed in the results of buildings such as BW, BH, BC, BG and CH.

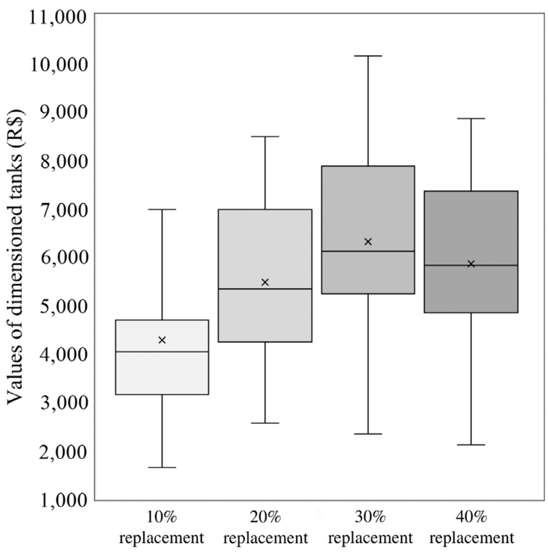

Figure 7. Variation of tank values for different scenarios of potable water replacement with rainwater.

The financial evaluation considered the tariff structure of the Water and Sewage Company of Paraíba (Companhia de Água e Esgotos da Paraíba, 2020) for the year 2021: the minimum tariff costs R$ 82.35 for consumption of up to 10 m^3; R$ 13.82 per m^3 for consumption above 10 m^3. Regarding payback, NPV, and IRR, the values found were organized in Table 2 according to each evaluated scenario. The results for the economic analyses are presented globally, that is, considering how much the institution can save using RWH in all thirty buildings that were simulated.

As for the payback, by making more use of rainwater, the return on investment time is reduced. This indicates that even making the project more expensive with larger tanks to increase the rainwater storage, the savings in financial resources to pay the potable water bill are greater. The payback values found here are lower than in other research that has analyzed residential buildings (Abdulla, 2019; Freitas & Ghisi, 2020). Compared with research that analyzed public and commercial buildings, the payback values found here are either lower or very similar (Cardoso et al., 2020; Karim et al., 2021).

The NPV and IRR indicate that there is financial feasibility for the idealized project in any of the scenarios. The situation improves since there is a tendency for the tariff charged for water distribution to become more expensive, making it financially advantageous to save potable water. The main reason for the adjustments made is inflation accounting and aims to compensate for inflationary losses, as well as include labor and input costs.

In any case, the indicators used have shown that it is possible to use this decentralized technology to reduce the number of financial resources spent on supplying public buildings. This is particularly advantageous for developing countries, where funding for the public sector is generally scarce.

Considerable seasonal behavior was observed in the potable water savings (Figure 8). The increase in the monthly variation in potable water savings tends to be directly proportional to the increase in the demand for rainwater. One of the buildings (the CX building) has a savings percentage ranging from 35.82% to 3.83% in the same year when the demand for rainwater is 40% (amplitude of 31.99%). For the same building, the variation is between 9.92% and 7.3% when the demand for rainwater is 10%

Table 2. Financial indicators for the analyzed scenarios.

Scenario (% of potable water replacement)	Discount rate per month	Payback (years)	NPV	IRR
10%	0.5% per month	3.30	R$ 325,257.52	2.52%
	1.5% per month		R$ 82,069.60	
	2.5% per month		R$ 1,091.10	
20%	0.5% per month	3.08	R$ 456,216.43	2.70%
	1.5% per month		R$ 123,687.39	
	2.5% per month		R$ 12,959.43	
30%	0.5% per month	2.94	R$ 561,361.87	2.84%
	1.5% per month		R$ 159,074.98	
	2.5% per month		R$ 25,118.53	
40%	0.5% per month	2.46	R$ 655,258.26	3.39%
	1.5% per month		R$ 209,989.14	
	2.5% per month		R$ 61,720.15	

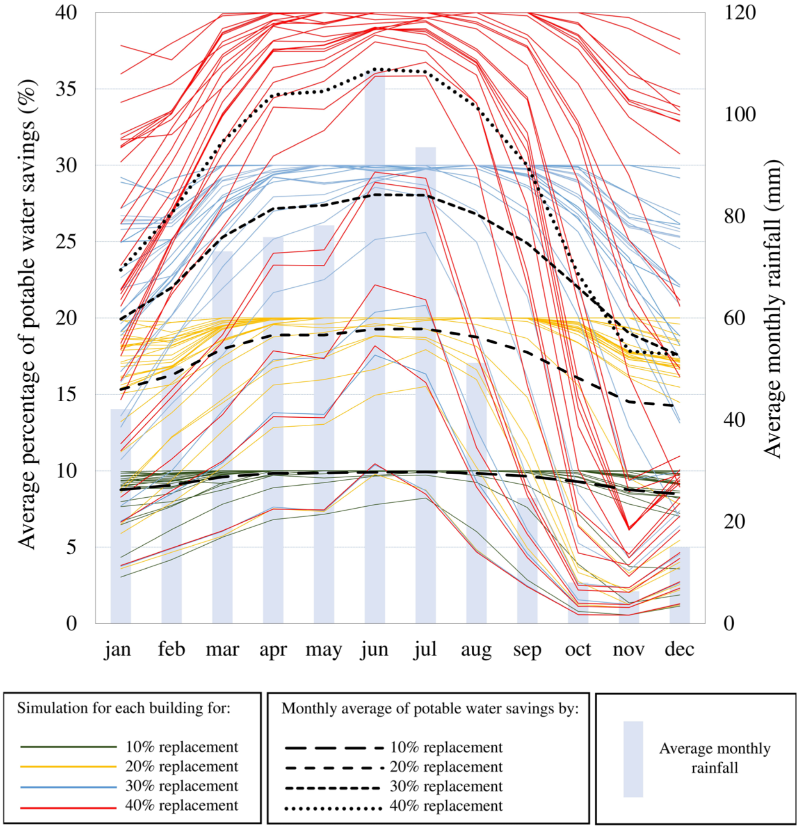

Figure 8. Seasonality of potential for potable water savings for the different analyzed scenarios.

(amplitude of 2.62%). This occurs because when the demand for rainwater is small, the amount precipitated throughout the month or the rainiest month's remaining volume (still stored) tends to be sufficient to satisfy consumption.

In addition to rainfall and the percentage of the rainwater demand, variation in the savings also depends on the relationship between the rooftop area and the potable water consumption, represented here by the α index. Using the standard deviation of the potable water savings potential of each month as a dispersion parameter, it can be identified that the higher the value of α, the smaller the variation in the water savings potential (Figure 9). The dispersion of the water savings potential increases when the value of α decreases and when the rainwater demand (10%, 20%, 30%, and 40%) increases.

Seasonality in the potable water savings potential proved to be a noteworthy feature for RWH in Campina Grande. This factor must be considered by the users of the systems since in some months, they will be able to count on a smaller amount of rainwater, which will affect the water bill. The entities responsible for the management and planning of water resources should also consider this seasonality if RWH becomes a strategy adopted collectively since this will change the amount of water that the urban infrastructure will demand from a centralized public supply. These factors are not necessarily a problem for RWH implementation, especially if implemented following the patterns of participatory water governance in urban areas, making users actively part of the dynamics of water supply.

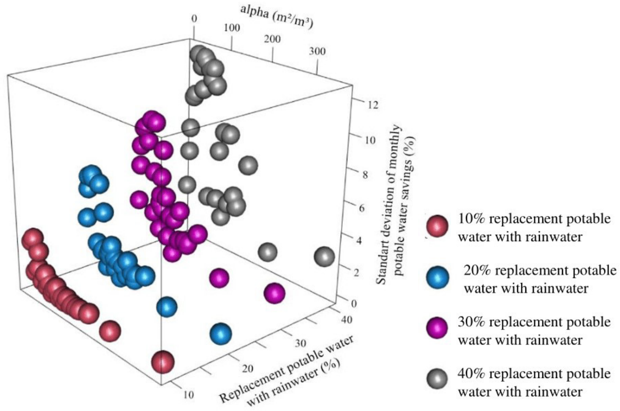

Figure 9. Relation between the variation of potable water savings, buildings characteristics and rainwater demand.

As for the reliability of RWH systems (Figure 10), in the scenario with the lowest use of rainwater (10%), this parameter ranged between 45 and 100%, while in the scenario with the highest use of rainwater (40%), reliability varied between 12 and 98%. Furthermore, it can be observed that the smaller the catchment area and the greater the consumption, the less reliable the system is, something also found by Bashar et al. (2018). The authors also state that in dry regions the reliability is low; however, here it was

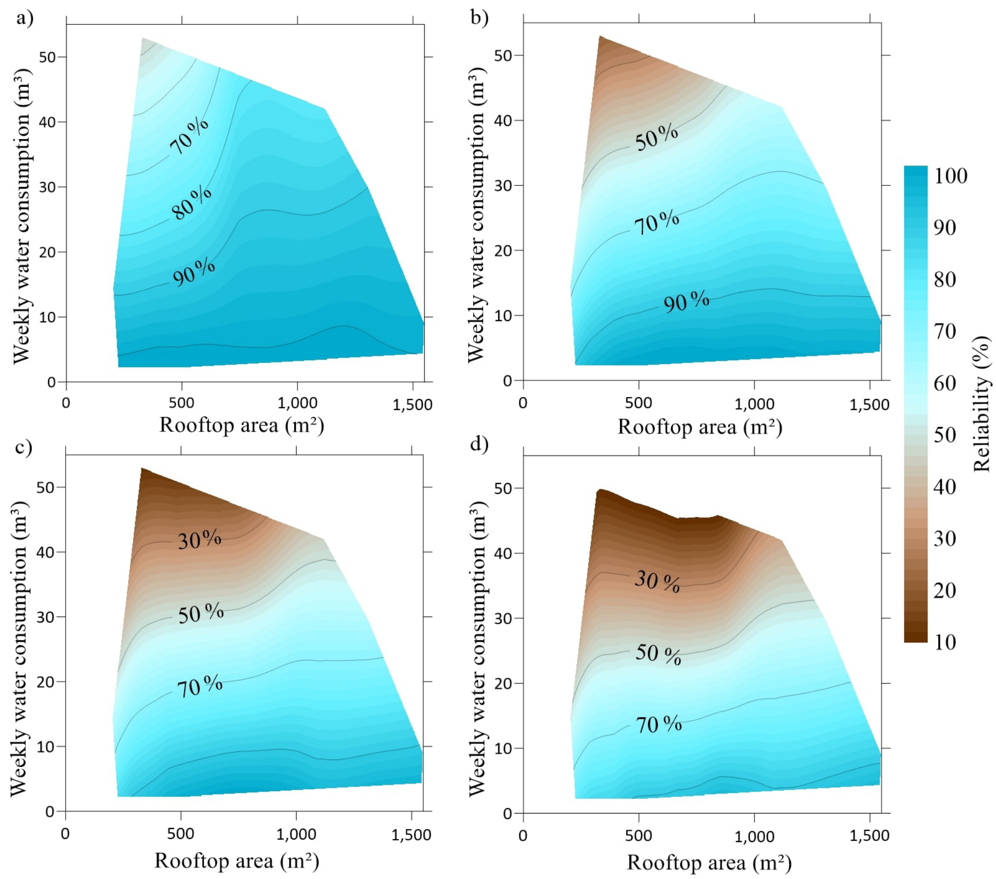

Figure 10. Relation between reliability, water consumption and rooftop area for a) 10%, b) 20%, c) 30%, and d) 40% of potable water replacement.

possible to verify that even in a semi-arid region, it is possible to have reliable RWH systems as long as the demand for rainwater is not so great.

The systems simulated by Molaei et al. (2020) reached a maximum reliability of 70%, and the authors showed that there is satisfactory potable water saving potential. In the scenarios analyzed by Karim et al. (2021), the volumetric reliability varies between 6% and 27% and, even with such values, the recommendation is for the diffusion of RWH systems since the environmental and economic benefits are considerable. The same has occurred in the present research since, even in the face of the scenario with the lowest reliability values (40% replacement of potable water with rainwater), the amount of potable water and the financial resources that were saved are quite considerable. The use of this parameter allows users (in this case UFCG) to understand that during a certain period of time, the demand for rainwater will not be supplied, which will cause fluctuations in the potable water savings and, consequently, in the reduction of the water bill. This type of discussion demonstrates that there is a need to consider the reliability when analyzing RWH systems.

Considering RWH systems as complementary supply systems allows us to suggest the adoption of RWH in scenarios where reliability is not so high, since in periods when the demand for rainwater is not fully supplied, the remaining portion will be satisfied by the public water supply.

If a collective effort is made and other public and commercial buildings in the city implement RWH systems, it will be possible to put less pressure on the Epitácio Pessoa reservoir, the water body responsible for Campina Grande's public supply. Furthermore, Cordão et al. (2020) concluded that a considerable portion of commercial and institutional (or public) buildings is at risk of water scarcity in Campina Grande, which could be minimized by the decentralization of supply, as shown in this study results.

The municipality should encourage the adoption of RWH, considering the possibility of making water consumption more rational in part of the buildings. Legislation plays a significant role in this regard (Ward et al., 2019), which needs inspections to prove if the prerogatives are being fulfilled. In addition, this scenario would change if the country, states, and municipalities also acted with financial incentives, making the implementation of RWH even more attractive, as demonstrated by other studies (Hameed et al., 2020; Sheikh, 2020).

CONCLUSION

In many developing countries, such as Brazil, water supply does not reach the entire population in sufficient quantity and quality, making it necessary to think of ways to expand such supply. RWH is one of the alternatives for this purpose; however, it needs to have its potential analyzed locally and by the type of building since these characteristics comprise several peculiarities, for example, the rainfall regime and the cost paid for the water supply service.

This research expands the discussions on the use of rainwater in urban areas and brings other contributions about the feasibility of these systems in public buildings located in semi-arid regions; robust financial assessment with more than one indicator; seasonality effect on the potable water saving potential; and discussion of the reliability of water storage systems.

In this region, marked by drought phenomena, RWH systems in public buildings are attractive both from an environmental and economic perspective since, in addition to significantly reducing the annual water consumption, there is also a reduction in the amounts paid for consumption to water supply companies. Using RWH in less than a third of the buildings, UFCG could save up to 356.76 m^3 of potable water and 5,953.99 reais per month, very significant values given the severe water crises that have taken place in the country and the reduction in public investment in educational institutions.

The application of the methodology used adds important information to many other pieces of research that have focused on analyzing RWH systems with a focus on residential buildings. This knowledge serves to collaborate with urban planning that takes into account the complex issues inherent to water resources and the various types of urban land use, contributing to the idea of a Water-Sensitive Urban Design approach.

Seasonality in rainwater use is something to be considered by users and, especially, in the management of water resources in urban areas that adopt this technology on a large scale. However, this condition is something that does not make its adoption unfeasible. New investigations can analyze how this characteristic of RWH in semi-arid climates can be attenuated when integrated with other actions, such as the reuse of greywater and water-saving equipment. Interannual seasonality can also be investigated by other studies, that is, how the potable water savings potential will vary for each month of the year in different years of a historical series.

It is also important to highlight that more essential than seeking new water bodies to meet society's growing demand for this resource, it is necessary and extremely important to rationalize water consumption to make better use of the available resources with measures that contribute to this. Therefore, although the results presented cannot be extended to cities with different climates, it presents very motivating scenarios and a methodology that can be adopted in other investigations, integrating the notion of feasibility, seasonality and reliability of RWH systems.

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