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Economic Feasibility of Rainwater Harvesting in Houses in Blumenau, Brazil †

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Abstract: This paper aims to analyse the economic feasibility of using rainwater for non-potable purposes in single-family houses in Blumenau, Brazil. A house was used as a case study to estimate the water end-uses and water consumption. Then, the daily water consumption and water end-uses for non-potable purposes were estimated. Different roof areas, number of residents, daily per capita water consumption and rainwater demand were also considered. The rainwater tank capacities and the potential for potable water savings were estimated using computer simulations. Finally, an economic feasibility analysis was carried out. The potential for potable water savings ranged from 18.76% to 58.06%, and the rainwater harvesting system was found to be economically feasible for most scenarios.

Keywords: rainwater; water end-uses; houses; economic feasibility; potable water savings

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1. Introduction

The storage and use of rainwater, while providing environmental benefits, can also be an investment to reduce potable water costs. The economic benefit of using rainwater has been addressed in several studies, varying the place of study, building and project type, among other characteristics. Ghisi and Schondermark [1] estimated the potential for potable water savings and performed an economic analysis for single-family homes in five cities in the state of Santa Catarina, Brazil. They obtained variable results depending on the water demand and found that, in most cases, the implementation of the system would be economically feasible.

Morales-Pinzón et al. [2] assessed the economic feasibility of a rainwater harvesting system in Spain. Several types of houses were chosen, covering most of the climates in the country. They observed that rainwater harvesting systems had shorter paybacks. In Italy, Liuzzo et al. [3] analysed the economic feasibility of a rainwater harvesting system in a house in Sicily, with a catchment area of 180 m^2. Rainwater usage was considered only to flush the toilet and for irrigation. The system proved to not always be feasible, with a payback period ranging from 15 to 55 years.

Such studies show that the economic feasibility analysis must be conducted on a case-by-case basis, as it depends especially on water demand, rainfall, water tariff, costs, and catchment area. Blumenau is one of the most populous cities in Santa Catarina; and 80% of the households are single-family houses [4]. These factors, added to urbanisation and, sometimes, heavy rains, make the city prone to flooding [5]. Thus, the main objective of this work is to evaluate the potential for potable water savings and to perform an economic analysis considering rainwater usage in single-family houses in Blumenau.

2. Materials and Methods

The study area was Blumenau, in Santa Catarina state, southern Brazil. A case study was performed in a three-storey single-family house with a roof area of 165 m^2 and four people living in the house. As it is a high-standard building, different scenarios of water end-uses were considered to represent the houses in Blumenau.

2.1. Water Consumption and End-Uses

In order to estimate the water consumption and end-uses, questionnaires were given to the four residents. The questionnaires were left close to each fixture, allowing residents to write the frequency and duration of use of each fixture. For a washing machine, the water level was recorded; for a bowl-and-tank toilet, only the number of flushes per day was recorded. The water consumption measured in the water meter was also registered at the end of each monitoring for comparison purposes. This monitoring was performed over seven days (25–31 August 2019). More details, such as flow rate measurements, are presented by Fugi [6]. Based on the frequency and duration of use of each fixture and the corresponding water flow rate, each water end-use and total water consumption were calculated.

2.2. Computer Simulations

The computer programme *Netuno*, version 4, is capable of performing simulations of rainwater harvesting systems [7]. In this study, the programme was used for sizing the rainwater storage tank, estimating the potential for potable water savings and performing the economic feasibility analysis of the three-storey house and the different scenarios.

Rainfall data for Blumenau were obtained from the Brazilian Water Agency [8]. A first flush equal to 2 mm was adopted as recommended in the Brazilian standard NBR 15527 [9]. Due to losses during rainwater harvesting, a runoff coefficient of 0.8 was adopted. The roof area of the house under study is approximately 165 m^2. For the different scenarios, roof areas equal to 60, 100, 140, and 180 m^2 were adopted. Such values were based on the frequency of areas of Brazilian roofs indicated by Ghisi et al. [10].

The number of residents per household has a major influence on water consumption. For the scenarios considered, 2, 3, 4 and 5 persons were adopted per house; this represents 84.3% of households in Blumenau [11].

The upper tank was sized based on the daily rainwater consumption in each house and scenario, and the sizes were chosen according to availability on the local market. For sizing the lower tank, the minimum and maximum capacities were defined as 500 litres and 20,000 litres, respectively. The programme indicated the capacity to be chosen when the increase in the potential for potable water savings was lower than or equal to 3.5%/m^3.

The total water demand was estimated based on the water consumption and number of residents in the house. Water consumptions equal to 100, 150 and 200 litres/person/day were adopted for the different scenarios. Finally, different rainwater demands were estimated based on the actual house's water end-uses and studies found in the literature: 30%, 40%, 50% and 60% of the total water demand were adopted. In the analysis for the actual house, the water end-use for non-drinking purposes was considered as the rainwater demand.

2.3. Economic Analysis

To perform the economic analysis, the costs of implementing the rainwater harvesting system, water consumption and system operation were obtained. Then, the financial savings regarding the rainwater harvesting system were calculated, i.e., the difference between the water bill with no rainwater harvesting system and that with a rainwater harvesting system. Finally, discounted payback, net present value and internal rate of return were calculated.

The costs of the water tanks and motor pumps were obtained from stores in Blumenau, and the lowest prices found were considered. In order to estimate labour costs, the Brazilian

System of Research on Costs and Indices of Civil Construction was used [12]. The costs of pipes, connections and accessories represented 19% of the total cost related to labour, water tanks and motor pumps [13].

In turn, the energy cost for the pump operation was estimated based on the energy tariff—which was BRL 0.46978 per kWh, according to the local electric utility [14]—and the power and operation of the motor pump. All cash flows from the investment project were brought to day zero, considering the minimum attractive rate of return (MARR). A positive net present value (NPV) indicates that the system is economically feasible. The discounted payback represents the time when savings from using rainwater are equal to the initial investment. The IRR must be higher than the MARR to make the investment feasible.

The minimum attractive rate of return adopted was 0.5% per month, and the analysis period was 20 years. Once it became impossible to predict the future monthly inflation, a constant figure of 0.274% per month was considered.

3. Results

3.1. Water Consumption and End-Uses

The average daily consumption obtained from the water meter was 612.9 litres/day. Based on this consumption and considering that there are 31 days in August, an average monthly consumption of 19.0 m^3 and an average per capita water consumption of 153.2 litres/person/day were estimated. Based on the results from the questionnaires, the consumption was estimated as 3678.9 litres over the period analysed, which is equivalent to 131.4 litres/person/day. Over August, the monthly consumption would be 16.3 m^3.

Water consumption measured by the company responsible for water supply in the city of Blumenau was 21 m^3 in August, when the study was conducted. This volume is 10.5% greater than the estimated consumption. From April to October 2019, consumption varied from 14 to 22 m^3, with a monthly average of 18 m^3 and equivalent to an average daily consumption per capita of 145.2 litres/person/day. Therefore, water consumption when the data were obtained was not atypical.

The difference between measured and estimated consumptions varied from 4.0 to 22.6%, with an average of 11.0%. Such differences may have occurred because of errors in the durations' records and/or because the residents failed to note some uses. One considered that the difference between the estimated and the measured consumptions was evenly distributed among the water fixtures. Thus, the water end-uses were based on questionnaires filled in by the residents. Table 1 shows the water end-uses for an actual house. The water end-uses are similar to those obtained by Freitas [15] and Meincheim [13] studies. The water fixtures with the highest consumptions in single-family homes were the shower, washing machine and toilet.

Table 1. Water end-uses for an actual house.

Water Fixture	Water Consumption	
	Litres	**%**
Showers	985.4	26.8
Washing machine	925.0	25.1
Toilets	777.7	21.1
Kitchen sink	355.9	9.7
Outdoor taps	253.4	6.9
Washing trough	224.1	6.1
Toilet sinks	103.5	2.8
Dishwasher	30.6	0.8
Drinking fountain	23.3	0.6
Total	3678.9	100.0

3.2. Rainwater Demand

The rainwater harvesting system was designed considering rainwater usage only for non-potable purposes (washing machines, toilets, outdoor taps and washing troughs). Therefore, based on the water end-uses of the actual house, the rainwater demand represents 59.3% of the total water demand. According to this result and the literature review, the different scenarios considered rainwater demands equal to 30%, 40%, 50% and 60% of the total water demand. For each scenario, a lower tank capacity was estimated, while the upper rainwater tank capacity was calculated based on the total rainwater demand.

3.3. Rainfall

In order to carry out the study, daily rainfall data from the Blumenau rain station from February 1989 to January 2019 were considered, and the average annual precipitation in this period was 1770 mm. The maximum, minimum and average monthly rainfall for Blumenau are shown in Figure 1. From September to March, monthly rainfall was higher than the average (147 mm). In November 2008, rainfall was 1001 mm, the year with the most significant flood over the last 17 years.

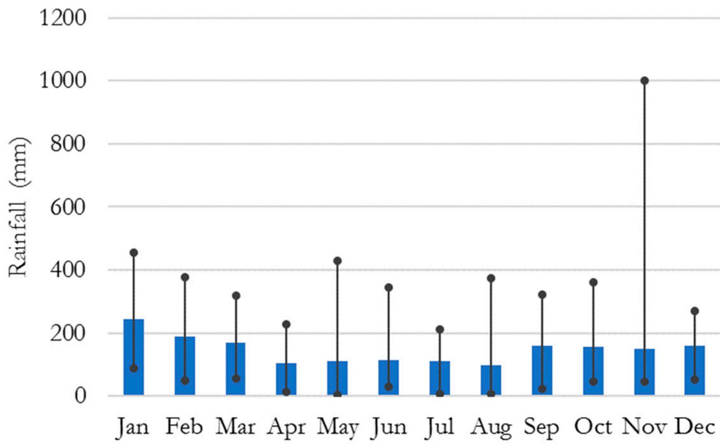

Figure 1. Maximum, minimum and average monthly rainfall for Blumenau over 30 years.

3.4. Potential for Potable Water Savings

Regarding an actual house, the upper rainwater tank capacity was estimated at 363.4 litres. In this way, an upper 500-litre tank was adopted. The ideal capacity for the lower tank was 5000 litres, and the corresponding potential for potable water savings was 50.32%. The house's water consumption was 612.8 litres/day, so that the rainwater system would provide 308.4 litres of rainwater per day. The average monthly consumption of 18 m^3 decreased to 9 m^3. This way, the owners paid only the minimum monthly consumption fee, which is 10 m^3.

Considering the different scenarios simulated, for a potable water demand of 100 litres/person/day or more and equal number of residents, the results were similar. The different roof areas showed little influence on the potential for potable water savings. The rainwater collected from the roof shows that the roof area meets the rainwater demand, so there is no need for a large roof area when the rainwater demand is low. However, as the rainwater demand increases, the roof area significantly influences the potential for potable water savings. The larger the roof area, the smaller the lower rainwater tank capacity. This occurs because the larger the roof area, the more rainwater is harvested, and the replenishment of rainwater in the tank is faster. Similar results were obtained in [1] and [15].

The potential for potable water savings ranged from 18.76% to 58.06%, with an average of 37.90%. As in the study of Lopes et al. [16], it was observed that the larger the rainwater demand and roof area, the greater the potential for potable water savings.

3.5. Economic Analysis

The financial analysis of the implementation and operation of a rainwater harvesting system for the house resulted in the following indices: a net present value of BRL 4814.54, a payback period of 89 months and an internal rate of return of 1.44% per month.

From the 192 different scenarios analysed, 112 scenarios obtained positive net present values, indicating that the rainwater system would be economically feasible for 58.3% of the cases. Payback ranged from 221 to 60 months for economically feasible scenarios. The highest internal rate of return was 2.05% per month.

The scenarios with low water consumption proved to be economically unfeasible. Such infeasibility is due to the flat rate for monthly consumption of up to 10 m^3 of water. Once there is no charge reduction in the water bill but there is still an expenditure of energy for the operation of the pump, the net present value becomes higher than the initial cost. These results were also found by Berwanger and Ghisi [17].

The feasibility analysis showed that the greater the water consumption and the greater the rainwater demand, the more economically feasible the rainwater harvesting system. Figure 2a shows the number of scenarios in which the NPV was positive or negative as a function of the water demand. For water demand equal to 150 and 200 litres/person/day, the NPV was positive for 75% of the cases. For consumptions of 100 litres/person/day, only 25% of the cases had positive NPVs. Figure 2b, in turn, shows the number of scenarios in which the NPV was positive or negative as a function of the roof area. One observes that the scenario number does not vary as a function of the roof. Thus, the roof area showed no influence on the economic feasibility of rainwater harvesting systems.

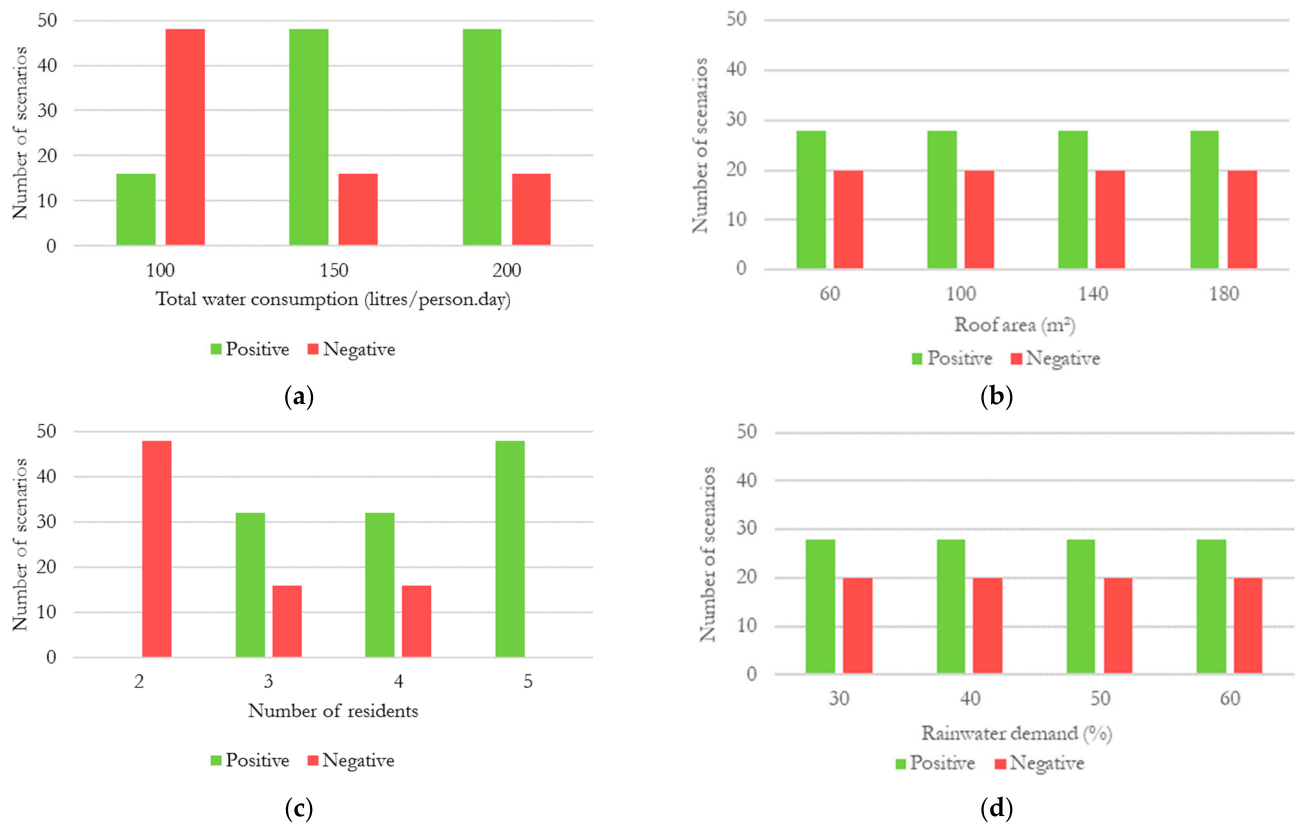

Figure 2. Number of scenarios in which the NPV was positive or negative as a function of the water demand (**a**), roof area (**b**), number of residents (**c**), and rainwater demand (**d**).

The greater the number of residents, the more positive NPVs were obtained. This influence is directly related to water consumption. Figure 2c shows the number of scenarios in which the NPV was positive or negative as a function of the number of residents. For scenarios with two residents, all NPVs were negative; however, for five residents, all NPVs were positive. In 66.6% of scenarios, the NPV was positive for scenarios with either three or four residents. The NPVs were shown to be equally distributed for each rainwater demand. For all demands, the NPV was positive for 58.3% of the scenarios. Figure 2d shows the number of scenarios in which the NPV was positive or negative as a function of the rainwater demand.

As in Ghisi and Schondermark [1]'s study, economic feasibility is directly related to the number of residents and water consumption per capita. Homes with a low number of residents and/or low water consumption should use the rainwater harvesting system only for environmental benefits, not economic ones. Figure 3 shows the NPV as a function of the rainwater demand (in litres/day) for all scenarios. For houses with rainwater demand equal to 60–120 litres/day, all scenarios proved to be economically unfeasible. In cases where the rainwater demand was greater than or equal to 250 litres/day, all scenarios proved to be economically feasible. For cases in which the rainwater demand ranged from 135 to 240 litres/day, it was found that economic feasibility does not have a trend. The absence of a tendency in such cases may occur because high water consumptions and low rainwater demands result in the same rainwater demand as a scenario with low water consumption and high rainwater demand, requiring analysis on a case-by-case basis.

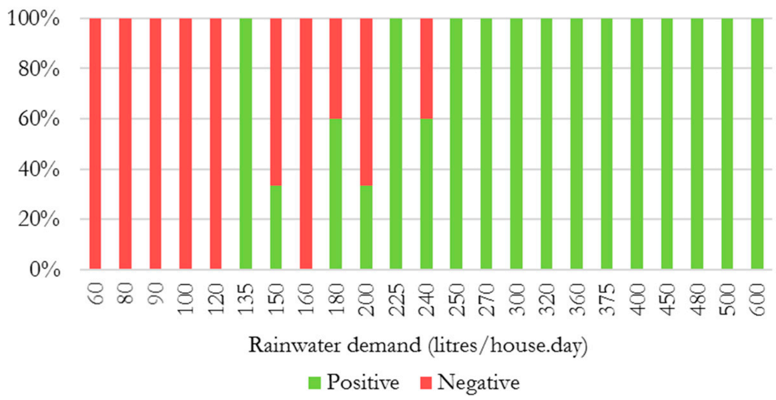

Figure 3. NPV as a function of the rainwater demand for all scenarios.

The actual house obtained better economic rates than the scenarios with 140 and 180 m^2 of roof area and water demand equal to 150 litres/person/day and for the four residents and rainwater demand equal to 60% of the water demand. The comparison was made with these two scenarios, as they have the most similar characteristics to the house. For the scenario with a roof area of 140 m^2, a payback period of 96 months was obtained, and for the 180 m^2, a payback period of 93 months was obtained. The payback period for the actual house was 89 months, indicating better economic feasibility.

4. Conclusions

This study showed that the higher the water consumption and the higher the rainwater demand, the greater the potential for potable water savings. The potential for potable water savings increases as the roof area and the rainwater demand increase. In houses with low water consumption, the roof area had little influence on the sizing of the lower rainwater tank. In contrast, for higher consumptions, the tank capacity increased with increases in the roof area. In houses with high water consumption, the rainwater harvesting system proved to be economically feasible. In cases with high rainwater demand and small roof areas, the potential for potable water savings was low, but they were still economically feasible.

The rainwater harvesting system was not economically feasible for a low number of residents and/or low water consumption cases. Therefore, implementing a rainwater harvesting system for single-family homes in Blumenau is economically feasible for most cases, including the actual house. However, performing the economic feasibility analysis for each case is recommended.

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