Periódico Eletrônico "Fórum Ambiental da Alta Paulista"
Electronic Journal "Environmental Forum of Alta Paulista"

ISSN 1980-0827 – Volume 20, Number 2, Year 2024

Rainwater harvesting for non-potable purposes in residential settings: a case study

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ISSN 1980-0827 – Volume 20, Number 2, Year 2024

ABSTRACT
With the current global population of 8 billion inhabitants on planet Earth, the United Nations Educational, Scientific and Cultural Organization estimates that 2 billion people lack access to clean drinking water. This phenomenon is observed not only in less affluent regions but also in major urban centers, such as Olinda, the first capital of the state of Pernambuco, where water supply issues are frequent, even in a city designated as a UNESCO World Heritage Site. This work aims to present an alternative for the better utilization of water by promoting the harvesting of rainwater for use in activities that do not require potable water, thus favoring the reduction of consumption of potable water resources. The object of the study is a residence located in the Historic Site of Olinda, where water supply is provided on alternate days according to the Pernambuco Sanitation Company (COMPESA). The adopted methodology included the following steps: collecting monthly readings from the water meter, analyzing local rainfall conditions, determining the influential coverage area, assessing the effective consumption of potable water, and evaluating the feasibility of implementing a rainwater harvesting system. As a result, a significant percentage of potable water savings could be identified, and the feasibility of implementing a rainwater harvesting system in the residence was also observed.

KEYWORDS: rainwater harvesting. potable water. historical heritage.

1 INTRODUCTION

The frequent water crises faced by Brazil reflect on the management of water consumption and utilization as a vital resource for human survival. Such phenomena were observed more severely in the Federal District in 2016, with the main reservoir reaching 20% of its capacity (SANT'ANA; MEDEIROS, 2017). The Southeast region, specifically the metropolitan region of São Paulo, between 2014 and 2015, experienced severe drought, even resorting to the technical reserve, also known as the "dead volume." (DE NYS; ENGLE; MAGALHÃES, 2016).

With significant national notoriety, the Northeast region faces the worst drought of the century. While the Southeast and Midwest regions have recovered water levels in reservoirs, several Northeastern cities declared a state of public calamity or emergency due to water shortages between 2012 and 2017. (ANA, 2017).

Among the influential factors for the scarcity of potable water supply in urban centers, the following stand out: the demographic growth of large cities, maintenance of living and economic conditions, losses, diversions, and outdated supply infrastructure (CASTRO, 2022).

To reverse this situation, it is necessary to invest in and study new technologies that contribute to increasing the efficiency of the storage and distribution system, favoring the reduction of consumption (ANDRADE SOBRINHO; BORJA, 2016).

As an alternative, there is the use of rainwater in non-potable activities, as highlighted by Sant'ana and Medeiros (2017), who state that the non-potable water plumbing system with rainwater harvesting is a concept of simple implementation and promotes a complementary source of supply for use in activities that do not require water potability and do not pose health risks, such as car washing, sidewalk cleaning, toilet flushing, and clothes washing.

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Evidently, the implementation of a rainwater harvesting system requires a financial investment to be made by the property owner. However, the financial viability of installing the system will enable a reduction in the consumption of potable water supplied by the utility company, contributing to a decrease in the amount paid on the water bill, providing financial returns over time (MOURA; SILVA; BARROS, 2017).

2 OBJECTIVES

Through this work, the objective was to present rainwater harvesting as a means to reduce residential potable water consumption and monthly costs for homeowners by implementing a rainwater capture and retention system.

3 METHODOLOGY

The residence under study in this work is located at 488 Rua do Sol, Carmo neighborhood, Olinda-PE (Figure 01). The building is part of the Historic Site of the city of Olinda-PE, located in the Political-Administrative Region 8 (RPA8) and Administrative Zone 12, close to historically recognized places such as the Olinda Lighthouse, São Francisco Fort, and São Francisco Convent. The building has a length of 40.6 m, a land area of 203.99 m², and a built area of 154.09 m², comprising two living rooms, 2 bathrooms, kitchen, 3 bedrooms, and a backyard of approximately 50 m² (Figure 02). The residence's roof consists of fibrocement tiles, with impermeabilized concrete gutters at both ends for rainwater drainage, as well as vertical and horizontal PVC pipes with a nominal diameter of 100 mm.

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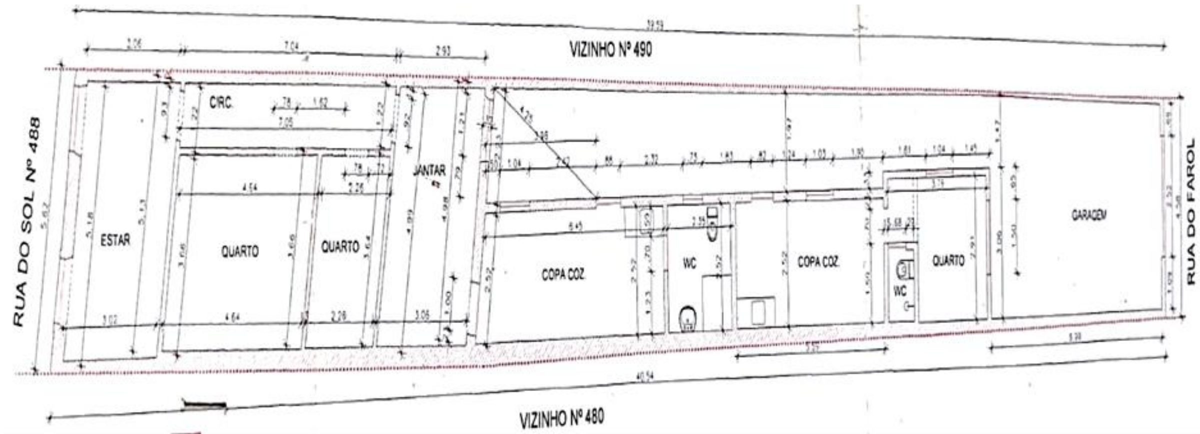
Figure 01 – Facade of the study object

Source: Authors (2023).

Figure 02 – Floor plan of the property.



Source: Authors (2023).

For the analysis of potable water savings obtained through a rainwater harvesting system for non-potable purposes, the following steps were adopted: analysis of water consumption data, collection of rainfall data from the region of the study object, determination of the influential coverage area for rainwater collection for the system, sizing of the reservoir for storing rainwater, and feasibility study for the implementation of the rainwater harvesting system.

To estimate the final water uses and conduct an economic feasibility analysis for implementing a rainwater harvesting system in the residence in question, data collection was

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carried out through monthly water consumption bills from the city's sanitation company. Additionally, areas of influence for collection and rainfall data were verified using information provided by the Pernambuco Water and Climate Agency (APAC, 2020).

Rainfall data was collected from the Rainfall Station at Santa Gertrudes Academy, located in the Carmo neighborhood, municipality of Olinda-PE, at an approximate distance of 2km from the residence under study. The selection of this station was based on its proximity to the study area. Thus, through the collected information, a monthly local precipitation history was obtained over an approximate period of 10 years.

Next, data on water consumption in the residence was surveyed, where the estimated consumption was compared to the actual consumption. To determine the values of monthly consumption, the bills provided by the Pernambuco Sanitation Company (COMPESA), the company responsible for supplying potable water and sanitation in the region of the study object, were used. The measuring equipment was located outside the house, as standardized by COMPESA throughout the state, and therefore, it was subject to vandalism of its protective box, as well as actions of natural elements.

Therefore, daily verification of the water meter was not possible due to the poor condition of its display. The property owner requested its replacement from the water supply company.

It was believed that the readings provided by COMPESA (2020) during the period analyzed in this study were conducted through estimates and consumption averages.

To estimate water consumption for end uses in the residence, consideration was given to sanitary appliances, the number of times they are used, and the duration of use by individuals. Therefore, the types, characteristics, and flow rates of existing sanitary appliances were surveyed. The previously mentioned data proved necessary for the correct understanding of the amount of water used for each activity, allowing verification of the amount of water used for non-potable purposes.

To identify the flow rates of the sanitary appliances, a container with a known volume was used, and the time to fill it was timed. The showers and faucets in the kitchen sinks, bathrooms, and backyard were used, seeking standardization in their usage, although they were made of different materials and from different manufacturers. The appliances were opened to their maximum flow rate, and an average of three measurements was taken. The flush tanks were from the same manufacturer, material, and model, and were adjusted to their maximum capacity, which, according to the manufacturer, was 9 liters. An average of three measurements was taken.

Afterwards, the total daily water consumption for each appliance was estimated using the data obtained from frequency, usage time, and flow rate. Then, the average water consumption per person for each appliance was calculated using the Equation1.

$$Cma = \Sigma (f * t * Q) \qquad \text{[Eq. 1]}$$

Cma = average daily total *per capita* consumption per appliance (L/day/person)
f = daily frequency of appliance use (number of times/day)
t = daily usage time of the appliance (seconds/day)

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Q = appliance flow rate (liters/second)

To determine the savings from implementing the rainwater harvesting system, the amount of potable water used in non-potable activities was analyzed, allowing for the estimation of the ideal volume of the rainwater storage reservoir.

For the determination of the Rainwater Reservoir, considered one of the main components of a rainwater harvesting system, the reservoir must be properly sized. This involved considering the total potable water consumption for non-potable purposes, the demand for rainwater, the influential catchment areas, the amount of precipitation, and the financial cost for its implementation.

After verifying the potential for potable water savings and the demand for rainwater, the costs and economic feasibility for the proper implementation of the rainwater harvesting system were assessed. The costs for implementation primarily included materials, maintenance, operation, labor, and electricity for water pumping.

Next, the material costs were estimated by surveying the prices of PVC pipes, fittings, water pump, filter, and reservoir from the 3 main construction material stores in the region. The costs of gutters and vertical and horizontal conduits were not considered, as they already existed in the building.

Then, the calculation of labor costs for installing the system was estimated. This took into account the estimated number of days for implementation, the daily wage of the professionals required for this task, based on data from the Union of the Civil Construction Industry in the State of Pernambuco (SINDUSCON-PE, 2020), as well as the number of professionals required for its completion.

The operational costs mainly consist of electricity, which is responsible for the operation of the water pump. Although ABNT NBR-5626 recommends the installation of two water pumps to ensure supply, for the purposes of this study, only one water pump was considered to reduce costs. (ABNT, 2020).

For the calculation of electricity costs, the information provided by the manufacturer about the chosen water pump was considered, as well as the cost per kWh charged by the Electric Company of Pernambuco (CELPE, 2023) for the category of residence in question.

With this data, it is possible to calculate the electricity costs using the Equation 2.

$$CeEl = Pmb*tmb*Nd*Vce \quad \text{[Eq. 2]}$$

CeEl = Monthly electricity consumption for the water pump (R$)
Pmb = Power of the water pump (kW)
tmb = Operating time of the water pump (h/dia)
Nd = Number of days the water pump operates in the month
Vce = Cost per kilowatt-hour charged by the electric company (R$/kWh).

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Taking into account the reduction in consumption of potable water supplied by COMPESA, calculations were performed to determine the savings on the water bill from the utility company. Thus, the values of the new bill were determined using the Equation 3.

$$Cap = (Cm - Dap) * Vca \qquad [Eq. 3]$$

Cap = Average monthly cost of potable water per month after the implementation of the rainwater harvesting system (R$/mês)
Cm = Average monthly consumption in the building (m^3/mês)
Dap = Rainwater demand (L)
Vca = Cost charged by COMPESA for the consumed potable water (R$/$m^3$)

After analyzing the discounts resulting from the rainwater harvesting system, the period for the return of the investment in the system was estimated, ensuring continued savings on the sanitation company's bill.

The estimation of return on investment was conducted using the Equation 4.

$$PR = \frac{VI}{(Cmi - Cap)} \qquad [Eq. 4]$$

PR = Payback Period (months)
VI = Investment Value (R$)
Cmi = Initial monthly cost with potable water (R$/mês)
Cap = Average monthly cost of potable water per month after the implementation of the rainwater harvesting system (R$/mês).

The detailed steps taken to carry out this work can be identified through the Figure 03.

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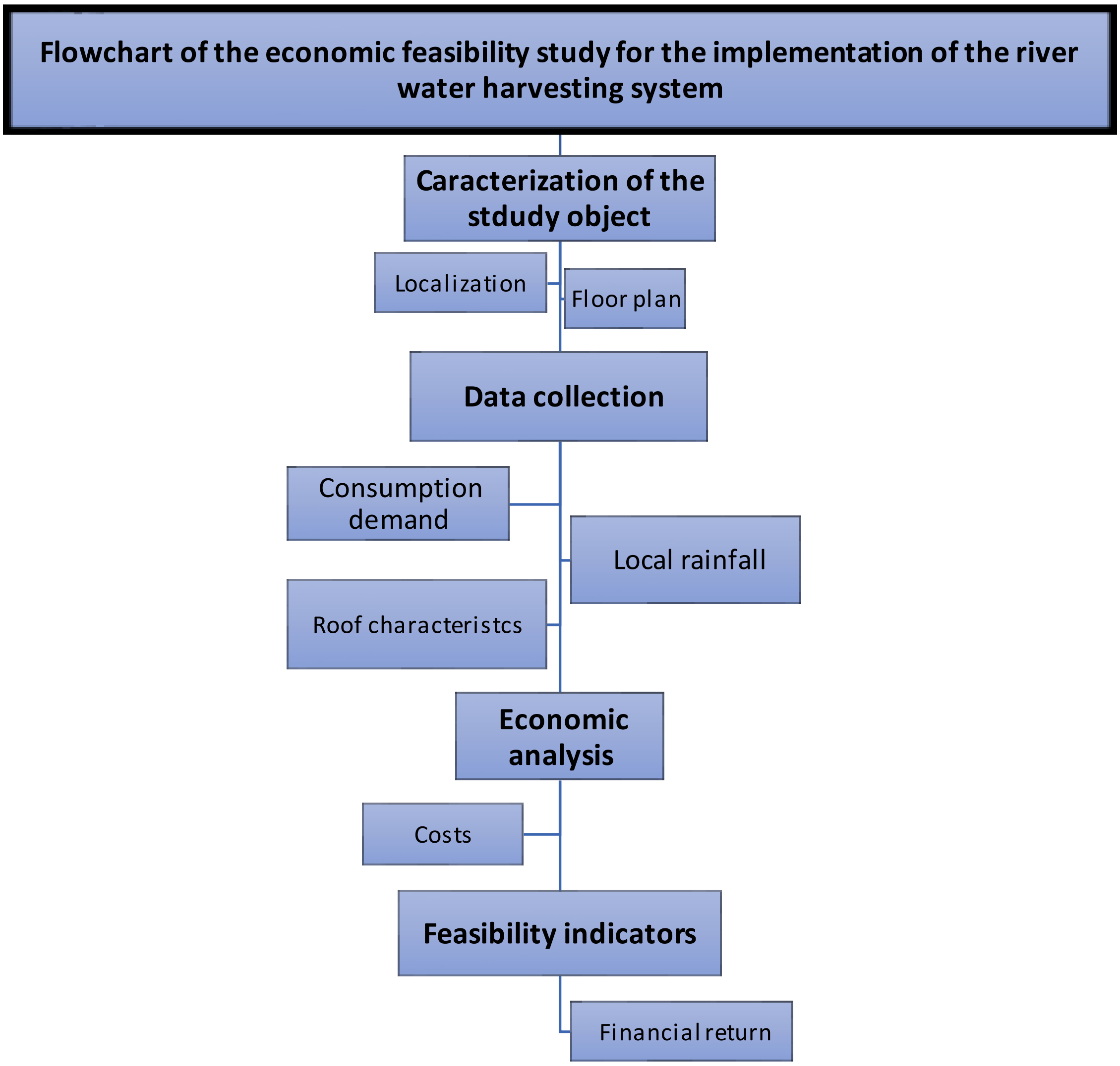
Figura 03 – Flowchart of the economic feasibility study for the implementation of the rainwater harvesting system.



Source: Adapted from Marinoski and Ghisi (2018).

4 RESULTS

In this study, the potential for saving potable water was investigated by estimating the water consumption for non-potable uses through the identification of appliance usage for toilet flushing, car washing, building washing, irrigation, and yard cleaning. Subsequently, the reservoir for rainwater storage was sized. Then, an economic analysis was conducted to determine the feasibility of implementing the system.

4.1 Potable water consumption

Surveys were conducted on the flow rates of sanitary appliances, rainfall in the region over 10 years, billing for potable water consumption, and verification of the catchment area. Data collection on the monthly consumption of potable water supplied by COMPESA was

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only possible from July 2019 onwards due to the absence of previous bills with respective measurements from residents and the lack of an available database at the potable water supply company. The monthly consumptions obtained, measured by COMPESA, were from July 2019 to April 2020. Table 01 shows the details obtained through the data collected from the COMPESA bills.

Tabela 01 – Detail of potable water consumption for 2019 and 2020

Item	2019	2020
Total consumption	65	66
Average consumption (m³)	10.83	16.50
Average daily consumption (m³)	0.36	0.55
Average cost (R$)	R$ 49.97	R$ 78.51
Average daily cost (R$)	R$ 1.67	R$ 2.62
Increase percentage - Consumption	65.66%	
Increase percentage - Average Cost	63.65%	

Source: Authors, 2023.

Throug *in loco* visits, the characteristics, models, materials, and respective locations of the sanitary appliances in the building were verified. The activities carried out by the residents and the respective appliances used were also analyzed.

It was found that the bathroom and yard faucets are made of plastic material with manual operation, while the kitchen faucet is made of stainless steel with manual operation. The toilets had plastic flush tanks with a total volume of 9 liters at their maximum setting, according to the manufacturer (TIGRE, 2020). The showers were made of plastic material, with a simple model from the manufacturer FAME. The external faucets (yard) were used with the help of a hose for washing the car, yard, interior of the house, and for plant irrigation.

To determine the flow rates of each appliance, a container with a known volume was used. With the aid of a stopwatch, and the appliances set to their maximum flow rate, the container was filled to capacity, and the time required for this was determined. This procedure was carried out for all appliances, regardless of brand, model, or material, as some were located farther away from the upper reservoir than others.

It was identified that the showers have flow rates below expected levels. This was attributed to the poor condition of the appliances, which influenced the results obtained. For the faucets, it was found that the one in Bathroom 2 has low flow, as observed in the Table 02.

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Table 02 – Flow rates of sanitary appliances

Appliance	Container volume (L)	Time (s)	Flow (L/s)
Kitchen faucet	1.5	7.55	0.20
Bathroom 1 faucet	1.5	12.27	0.12
Bathroom 2 faucet	1.5	23.21	0.06
Yard faucet 1	1.5	9.16	0.16
Yard faucet 2	1.5	12.13	0.12
Bathroom 1 shower	1.5	26.79	0.06
Bathroom 2 shower	1.5	26.34	0.06
Toilet 1	9	120	0.075
Toilet 2	9	120	0.075

Source: Authors, 2023.

With this data, the daily consumption of the appliances was verified, taking into account their respective flow rates. For the calculation of the daily consumption of the washing machine, since it is not used daily, the ratio was calculated between the number of times it is used in a week and the number of days in the week. This was then multiplied by the amount of water needed for a complete wash, which according to the manufacturer was 139 liters of water (BRASTEMP, 2020).

Regarding the water consumption by toilets, the frequency of use and the amount of water needed to flush at its maximum setting, which according to the manufacturer is 9 liters (TIGRE, 2020), were taken into account. Table 03 details the consumption obtained by appliance, and its percentage is represented by the Figure 04.

Table 03 - Total daily and monthly consumption of potable water

Appliance	Daily total consumption (l)	Monthly total consumption (l)	%
Kitchen faucet	369.54	11,086.09	33%
Bathroom 1 faucet	66.01	1,980.44	6%
Bathroom 2 faucet	58.16	1,744.94	5%
Yard faucet 1	39.30	1,179.04	3%
Yard faucet 2	14.84	445.18	1%
Bathroom 1 shower	251.96	7,558.79	22%
Bathroom 2 shower	136.67	4,100.23	12%
Toilet 1	54	1,620	5%
Toilet 2	54	1,620	5%
Washing machine	79.43	2,382.86	7%
TOTAL	**1,123.92**	**33,717.56**	**100%**

Source: Authors, 2023.

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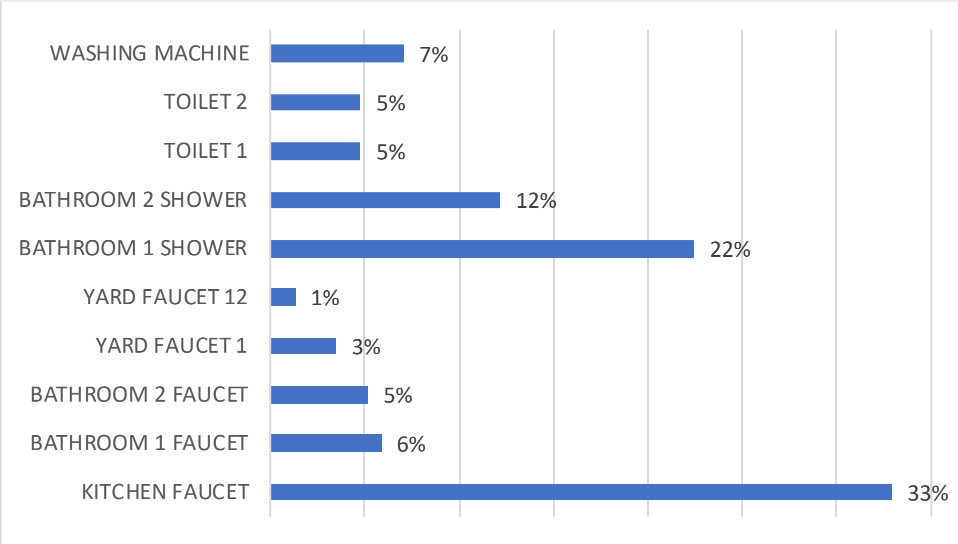
Figure 04 - Percentage of potable water consumption by appliance



Source: Authors (2023).

4.2 Potential for potable water

For assessing the potential for potable water savings, the amount of potable water used in activities that could utilize rainwater was considered, enabling the sizing of the ideal volume for rainwater storage reservoirs.

It was identified that the percentage of potable water usage for activities that can be replaced by rainwater reached 21% of the total consumption. These activities were carried out using the following appliances: washing machine, yard faucets 1 and 2, and toilets 1 e 2.

Next, the area of the influential roof for the system to be implemented was determined. Although the residence had a gabled roof, only one side of the roof was considered to determine the coverage area, aiming to reduce costs associated with additional plumbing. Considering the distance to the rainwater storage reservoir, approximately 40 meters, including the entire roof would significantly increase costs. Therefore, only the portion of the roof closest to the storage reservoir, which already has most of the necessary components for the system, was taken into account.

Thus, the influential coverage area is 45.19 m², considering the plan, then it was multiplied by the correction factor of 1.059 for the 35% roof inclination, resulting in 47.86 m² of influential coverage area for rainwater harvesting destined for the utilization system. (ABNT, 2007).

The pluviometric data were collected from the database of the Water and Climate Agency (APAC, 2020). Information was gathered from the Santa Gertrudes Pluviometric Station, located approximately 2 km from the studied residence, as illustrated in Figure 05. It was observed that the period with the highest rainfall index is between the months of March and August.

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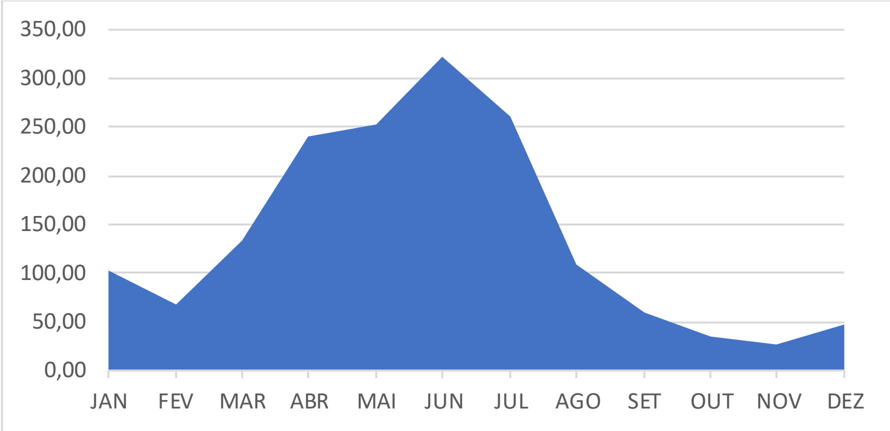
Figure 05 - Monthly average rainfall from January/2010 to April/2020



Source: Authors (2023).

4.3 Reservoir Volume and Economic Feasibility

The volume of the reservoir for storing rainwater was determined by calculating the total monthly consumption of non-potable water, which amounted to 228.41 liters per day, and multiplying it by 2 to account for the variability of rainfall in the region. Thus, a water reservoir of 1,000 liters was established to meet the demand and accommodate any excess.

Therefore, to assess the economic feasibility of implementing the rainwater harvesting system, the costs of materials, electricity, equipment, and the savings from using less potable water were calculated.

The estimate of expenses for materials and equipment was carried out through price quotes from the largest companies in the civil construction materials sector in the region. The quoted materials included: a 1,000-liter lower reservoir, a 500-liter upper reservoir, a water pump, a filter, a foot valve, a float valve, a horizontal diverter, electricity, and labor. Due to the fact that the property already had pipes and fittings that met the demand, these items were not included in the calculations. For easier understanding, the items, quantity, unit price, and total cost are detailed in Table 04.

Tabela 04 - Unit and total costs of materials, equipment, and labor

Item	Amount	Unit cost	Total cost
Upper reservoir	1	R$ 379.90	R$ 379.90
Lower reservoir	1	R$ 229.90	R$ 229.90
0.5 hp Pump	1	R$ 200.00	R$ 200.00
Float valve	2	R$ 15.90	R$ 31.80
Foot valve	1	R$ 72.90	R$ 72.90
Horizontal diverter	1	R$ 200.00	R$ 200.00
Filter	1	R$ 310.00	R$ 310.00
Piping	-	-	-
Labor	10 DAYS	R$ 80.00	R$ 800.00
Electricity	1 h/day (30days/month)	R$0.54 / kW/h	R$ 16.20
		TOTAL	**R$ 2,240.70**

Source: Authors, 2023.

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To determine the power of the pump, it was calculated using Schneider's manufacturer method in their pump catalog, taking into account the Total Manometric Head (m.c.a), calculated at 4 m.c.a, and the desired flow rate m³/h.

To determine the desired flow rate, the volume of the upper reservoir was analyzed, and its capacity was estimated to be filled twice to meet the daily demand. Thus, a 1/2 HP pump was chosen.

After determining the costs of materials, equipment, and labor, the estimate of savings in potable water due to the use of rainwater in non-potable end uses was calculated.

It was identified that the average cost charged for 1m³ of potable water is approximately R$ 4.41. The quantity of potable water used in non-potable uses that could be replaced by rainwater was also analyzed, resulting in a total of 7,080.68 liters per month. Therefore, a total monthly savings of approximately R$ 31.22 was obtained, which translates to an annual savings of R$ 374.67.

Taking into account the total consumption of potable water in the residence, a total monthly consumption of 33,717.56 liters and an annual consumption of 404,610.72 liters were obtained, resulting in a monthly cost of R$ 148.61 and an annual cost of R$ 1,783.40. Subtracting the amount saved through the implementation of the rainwater harvesting system annually from the total annual expenditure on potable water, the total amounted of R$1,408.73.

To estimate a payback period for the investment made in implementing the system, a ratio was calculated between the total implementation cost, R$ 2,240.70 as shown in Table 04, and the annual savings through rainwater harvesting, R$ 374.67, resulting in an approximate period of 5 years and 10 months.

That being said, it is evident that mismanagement of water resources leads to water crises worldwide. Despite Malaysia's annual precipitation of 2900 mm, it faced a water crisis exacerbated by population growth (SHAHEED; MOHTAR; EL-SHAFIE, 2017). In order to mitigate the impacts of reduced water supply services, countries like the United States, Israel, Germany, and Japan have been adopting rainwater harvesting techniques, previously used for flood control, to combat the risk of scarcity (KOTOWSKI, 2002).

In China, due to the inadequacy of potable water supply in regions further away from major urban centers, rainwater harvesting has been adopted to effectively alleviate the water problem for the local population, contributing to the development of local agriculture. (GUOZHEN *et al.*, 2011).

In Brazil, a study was conducted in 40 cities in the Amazon region with the aim of presenting the potential for saving potable water by substituting rainwater for some activities. The study observed a potable water savings, depending on demand, averaging 76%. It was endorsed that the implementation of a policy to replace potable water with rainwater would lead to a significant reduction in potable water use, thus preserving the region's water resources (LIMA *et al.*, 2011).

Therefore, this study aligns with international and national practices regarding the capture, storage, and use of rainwater for non-potable purposes. It reinforces the need for continued

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research on rainwater management in conjunction with architectural development, as it proves to be efficient and contributes to reducing the use of potable water.

5 CONCLUSION

This study estimated the potential savings of potable water achieved through the implementation of a rainwater harvesting system for non-potable purposes in a residence located in the historic district of Olinda, Pernambuco, Brazil, at 488 Rua do Sol, Carmo neighborhood.

Initially, data on the residents' water consumption was collected, measurements of the flow rates of existing sanitary appliances in the building were taken, and an analysis of the invoices from the Pernambuco Basic Sanitation Company (COMPESA) was conducted.

With the collected data, the values of the average total daily, monthly, and yearly consumption were estimated.

It was found that the appliances: kitchen sink faucet and bathroom 1 shower, despite their low flow rate, due to their poor condition, are the main consumers of potable water in the residence.

The daily consumption of potable water was analyzed, resulting in monthly and annual totals of potable water consumption of 33,717.56 and 404,610.72 liters, respectively. It was identified that the potential for saving potable water consumption reaches a total of 21% of the potable water destined for non-potable end uses (toilets, washing machine, irrigation, general cleaning, and car washing), corresponding to 236.02 liters/day, which can be replaced by rainwater, resulting in a savings of R$ 1.04 per day and R$ 31.22 per month, totaling R$ 374.67 annually.

Furthermore, an economic feasibility study was conducted for the implementation of the system, where prices of materials, equipment, as well as labor and electricity costs were obtained from the major civil construction material companies in the region. This resulted in a total implementation cost of R$ 2,240.70. with an estimated payback period of approximately 5 years and 10 months.

Therefore, this study has shown that the implementation of a rainwater harvesting system is economically viable as it provides savings in the consumption of potable water, resulting in a reduction of the water bill. It is also environmentally sustainable and contributes to the reduction of frequent flooding in the city, offering both financial and environmental benefits.

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