

Article

Financial Feasibility Analysis of Residential Rainwater Harvesting in Maringá, Brazil

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Abstract: Rainwater harvesting (RWH) systems are key solutions to improve water resource management in cities, and financial feasibility is essential for their diffusion. Moreover, studies about rainwater often adopt diverse design approaches, leading to incompatible results for direct comparison. This study introduces a categorised item-by-item outlay procedure and evaluates indirect (gravity) and direct (pressuriser) rainwater distribution schemes. Computer simulations were used to design 54 generic RWH system scenarios in Maringá based on a range of design variables. For each scenario, a monthly cost–benefit balance was built, and discounted payback, net present value, and internal rate of return were obtained. Similar outlays were obtained for direct and indirect rainwater distribution schemes ($\Delta = \text{BRL } 21.81$) with an average of BRL 13,484.87 among all scenarios. Average operational costs were estimated at BRL 1.31/month.m³ of rainwater demand. On average, paybacks of 14.7 years and internal rates of return of 0.99% per month were obtained among feasible scenarios. Like in other studies, financial feasibility indicators presented significant correlations ($0.88 \leq R^2 \leq 0.94$) with rainwater demand. The initial outlay distribution proposed herein provides an objective reference for result comparison among similar studies. Similar results for both rainwater distribution schemes point towards investigating alternative technical solutions for RWH systems.

Keywords: economic feasibility; payback; internal rate of return; initial outlay; investment feasibility; computer simulation



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1. Introduction

The financial feasibility of rainwater harvesting (RWH) systems is indispensable for the large-scale promotion of such a technology. Nonetheless, most residential RWH systems are often deemed financially unfeasible due to high payback [1]. Moreover, studies that investigate the financial performance of RWH systems often employ significantly different building layout considerations [2], which makes it difficult to compare their results directly. In this perspective, Teston et al. [3] observed a wide variety of results regarding the financial feasibility of residential RWH systems in Brazil, which presented, more frequently, payback periods ranging from 20.1 to 25 years.

In general, residential users tend to neglect the necessity of financial analysis for RWH systems, producing a knowledge gap that leads to reluctance to implement such a solution [4]. The financial feasibility analysis presented herein objectively determines the costs and benefits of residential RWH systems in Maringá, aiming to elucidate to potential investors the probabilities of financial return. Financial indicators such as the net present value, internal rate of return, and payback are commonly used for this purpose [2,5] and also explored herein.

In Brazil, the technical standard NBR 15,527 specifies RWH requirements for roofs aimed at harvesting rainwater for non-potable uses. Such uses may include toilet flushing, garden irrigation, and floor and vehicle cleaning, as well as decorative applications [6]. According to NBR 15,527 [6], RWH system designs must include local characterisation,

precipitation regime, and the calculation of a suitable storage tank size to supply the rainwater demand.

Currently, many Brazilian cities undergo serious water availability problems. The metropolitan region of São Paulo, the most extensive urban area in the country, presents one of the most critical situations nationally regarding the supply of sufficiently treated water to the population [7]. An immediate need to improve the city's water utility system was pointed out by increasing centralised water storage capacity and making water resource management more efficient. Among other strategies, the role of RWH systems is highlighted in addressing this problem.

Ghisi and Schondermark [8] point out that the financial feasibility of residential RWH systems is directly associated with rainwater demand. Five cities in southern Brazil were analysed, and several design variables were investigated using computer simulations and financial analysis. Tank costs were surveyed locally, while costs of piping, drains, and connections were considered based on the work of Ghisi and Oliveira [9] per unit of the catchment area. The payback periods between 1.5 and 10 years indicated good financial feasibility in most simulated cases, especially those with high rainwater demands.

Ghisi and Ferreira [10] evaluated the financial feasibility of rainwater harvesting systems for three multi-storey residential buildings. The cost survey was based on the assumption that plumbing and connections correspond to 15% of the combined cost of the rainwater tank, pump, and labour. This highlights the diversity of budget considerations in different studies.

Severis et al. [11] pointed out RWH systems with basic water treatment and direct rainwater distribution as the most financially feasible among the three most common configurations (direct distribution, indirect distribution, and storage in a single rainwater tank). In Lages, southern Brazil, sensitivity analysis pointed to the initial outlay, the minimum acceptable rate of return, the water tariff scheme, and the rainwater demand as the most significant variables for the financial feasibility of domestic RWH systems. The study obtained internal rates of return equal to 6.85% per year for the most feasible systems, indicating that RWH systems can be profitable if cost-effective design solutions are adopted.

Berwanger and Ghisi [12] associated the financial feasibility of rainwater harvesting systems with the rainwater demand and the catchment area in the city of Itapiranga, southern Brazil. The water tariff policy adopted by the local utility, which charged a fixed fee for water consumption below 10 m³ per month, was detrimental to the financial feasibility of some scenarios.

Gómez and Teixeira [5] studied twelve houses with different construction standards in Belém, northern Brazil, and also associated the rainwater demand with the financial feasibility of RWH systems. Similarly, as observed by Berwanger and Ghisi [12], Gómez and Teixeira [5] found that the tariff structure practised by the local water utility is detrimental to the feasibility of some systems. This finding highlights the importance of revising the current local water tariff model to encourage potable water savings by providing financial benefits for users.

In this sense, Cureau and Ghisi [13] point out that water tariff schemes that charge a fixed fee for consumption below a certain threshold inhibit consumers from adopting solutions to save water. However, this model is prevalent in Brazil and practised in the city studied herein. In Maringá, the local utility charges a fixed monthly fee for water consumption below 5 m³ [14].

Most research approaches tend to be simplistic by not considering the totality of benefits provided by RWH systems [1]. For a more realistic analysis, it is essential to consider the indirect benefits of RWH systems when assessing their financial feasibility. Delaying the expansion of centralised water supply and improving runoff peak flow control bring along savings for public management [15]. Moreover, Cureau and Ghisi [13] demonstrated that reducing potable water consumption through RWH systems causes significant savings in centralised water supply facilities. Chiu et al. [16] point out that RWH

systems tend to be more feasible when a water–energy nexus is defined and both water and energy savings are considered. In this sense, to popularise the use of RWH systems, governmental support is essential through the employment of public policies and subsidies, conceived to comprise the social and environmental benefits of such systems at a broader scale [5,17,18].

Despite recent advancements, Teston et al. [3] point out that Brazilian legislation regarding RWH systems is still in its initial stage, limited to a few cities. Most public policies related to RWH systems in Brazil are municipal laws, which depend on the city government's supervision to be put into practice. In this sense, it is essential to produce more knowledge about RWH systems, considering their importance in addressing water scarcity and promoting rational use of water [3].

Reliable information regarding the local costs involving the installation, operation, and maintenance of RWH systems is essential for developing accurate public policies to promote rainwater harvesting. Conversely, most research about rainwater employs varying cost survey approaches and construction layouts, often lacking the detail needed to define public policies assertively. Considering the low concentration of technical information regarding the financial feasibility of residential RWH systems in the literature [15] and for Maringá, this study aims to determine the conditions under which such systems are financially feasible in the city. The paper compares two rainwater distribution schemes and introduces a thorough item-by-item outlay procedure to serve as a reference for future studies or other locations.

2. Materials and Methods

A range of generic RWH systems was designed based on daily representative rainfall data obtained for Maringá, southern Brazil. Relevant indicators oriented to RWH system design were extracted from the rainfall time series. Simulations were carried out using the Netuno computer programme, version 4 [19]. Different catchment areas, number of occupants, potable water demands, and rainwater demands were evaluated. Additionally, rainwater systems with indirect (gravity) and direct (pressuriser) rainwater distribution were compared. Initial outlays were obtained in the local market for each scenario analysed. Utility tariffs and additional costs were also surveyed locally.

A monthly cost–benefit balance was built for each scenario considering all relevant costs and benefits related to the RWH systems. Finally, the financial feasibility of the systems was assessed using three indicators: discounted payback (months), net present value (BRL), and internal rate of return (%). The research aimed to verify under which conditions RWH systems are financially feasible in Maringá while introducing a comprehensive item-by-item outlay procedure to serve as a reference for similar studies.

2.1. Study Area

The study area is Maringá, located in the north of Paraná, southern Brazil. The city is located at latitude $-23^{\circ}25'31''$ and longitude $-51^{\circ}56'19''$. According to the Brazilian Institute of Geography and Statistics [20], Maringá has an area of 487.012 km² and an estimated population of 430,157 people. The climate is classified as Aw according to the Köppen–Geiger classification, which means an equatorial climate with dry winter [21]. Figure 1 shows the location of the city.

Precipitation data were obtained via the National Institute of Meteorology [22] and characterised through indicators considered important for the design of RWH systems. Such indicators were chosen because other researchers commonly use them when evaluating rainfall time series for RWH system design.



Figure 1. Map of Brazil indicating the location of Paraná and the city of Maringá [23].

Initially, according to Geraldi and Ghisi [24], three indicators were considered: average annual precipitation, the average number of dry days (without rain) per year, and the seasonality index. The average annual precipitation was calculated using Equation (1).

$$R = \frac{\sum_{i=1}^n (T_i)}{n} \quad (1)$$

where: R is the average annual precipitation (mm), T_i is the total precipitation for each year i (mm/year), and n is the historical time series duration (years).

The average number of dry days per year was calculated using Equation (2).

$$D = \frac{\sum_{i=1}^n (d_i)}{n} \quad (2)$$

where: D is the average number of dry days per year (days), d_i is the total number of dry days for each year i (mm/year), and n is the historical time series duration (years).

The seasonality index is calculated using Equation (3) [25]. It describes the seasonal variation in precipitation in a given location, and the higher its value, the greater the seasonal rainfall variation.

$$S = \frac{1}{A_i} * \sum_{i=1}^{12} \left| M_i - \frac{A_i}{12} \right| \quad (3)$$

where: S is the seasonality index (non-dimensional), A_i is the yearly precipitation (mm), and M_i is the average monthly precipitation (mm).

In addition to the three indicators presented above, four statistical indicators for dry periods were also considered herein, as used by Silva and Ghisi [26]. Such indicators were obtained through MS Excel functions applied to the precipitation series.

First, each dry period in the precipitation series was identified. Any day with no precipitation record preceded by a day with a precipitation record was regarded as the beginning of a dry period. For each dry period, the number of consecutive days with no precipitation was obtained. From this list, the average duration, standard deviation, coefficient of variation, and maximum duration of dry periods were obtained for each rainfall time series.

2.2. RWH Systems Simulation

Computer simulations were used to design RWH systems. Netuno computer programme, version 4, was used to perform the simulations [19]. A daily water balance model considered building features related to rainwater harvesting (catchment area, first-flush

discharge, and runoff coefficient) and water demand information (total water demand, number of occupants, and rainwater demand as a percentage of total water demand).

This research considered design parameters suitable to the city studied. The fixed design parameters were: catchment area, runoff coefficient, number of occupants, water demand (per capita), first flush discharge, and rainwater tank size. The variable parameters were: precipitation time series and rainwater demand. The total water demands were determined based on the average water consumption for Maringá [27]. According to Silva and Ghisi [26], seasonal changes in rainwater consumption do not significantly affect the simulation results evaluated in this research and therefore were not considered herein. The runoff coefficient was adopted as 0.8 to favour safety and allow compatibility with similar studies that involved simulating generic residential RWH systems [24,26,28,29]. First-flush discharge was defined as 2 mm according to the previous version of the Brazilian technical standard NBR 15,527 [30]. Additional definitions were adopted based on the Brazilian standard NBR 15,527 [6].

Two rainwater distribution schemes were compared within each simulation scenario. The first contemplates indirect rainwater distribution (via gravity from an upper tank, which requires previous pumping from the lower tank). In this case, the upper tank volume was considered equal to the daily rainwater demand. The second scheme considers direct rainwater distribution (via a pressuriser directly from the lower tank). Figure 2 shows the schematics of the two rainwater distribution schemes. Table 1 presents the input parameters used in the computer simulations.

Table 1. Input data for the computer simulations.

Parameter	Unit	Input Value
Rainwater distribution	-	Indirect ¹ ; Direct ²
Runoff coefficient	%	80
Roof area	m ²	100, 200 and 300
Number of dwellers	inhabitant	2, 4 and 6
Total water demand	L/inhab.day	150
Rainwater demand (% of total water demand)	%	30, 50 and 70
First-flush discharge	mm	2
Upper tank size	L	¹ Variable, ² zero
Lower tank size	L	1000–50,000 (at intervals of 1000)

¹ Indirect rainwater distribution, ² Direct rainwater distribution.

The combination of the input parameters shown in Table 1 results in 54 simulation scenarios. The major simulation output is the potential for potable water savings for each of the lower tank sizes tested. Tank size is considered insufficient (under storage) when the increase in storage capacity results in a great increase in the potential for potable water savings. On the other hand, tank size is considered excessive (over storage) when the increase in capacity corresponds to a low or no increase in the potential for potable water savings. The ideal tank size, namely a size between those two undesirable situations, was set to be chosen when the potential for potable water savings varies 2.00%/m³ or less for a 1000 litre increase in tank capacity. Additional details, such as the complete simulation algorithm used in the Netuno 4 computer programme, can be found in the software's user manual [31]. Ideal tank sizes and potential for potable water savings were the outputs used as a reference to compare simulation results.

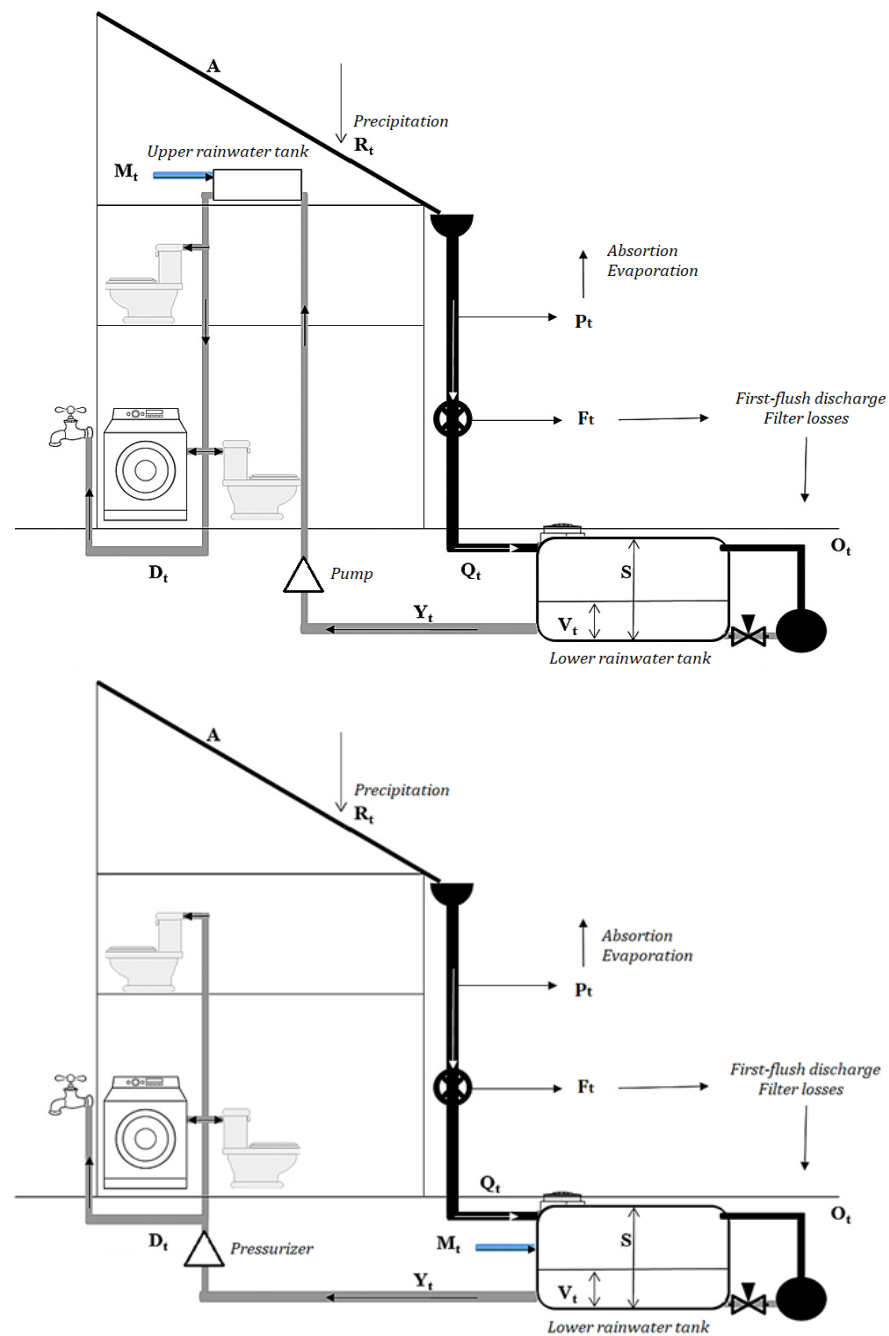


Figure 2. Components of an RWH system with direct distribution. Arrows indicate water flow. Source: Adapted from Melville-Shreeve, Ward, and Butler [32]. A (m^2) is the impermeable catchment area; R_t (mm) is precipitation; P_t (m^3) are water losses on the roof; F_t (m^3) is the deviated outflow; Q_t (m^3/day) is the collected rainwater flow; O_t (m^3) is the overflow volume; V_t (m^3) is the stored volume; S_t (m^3) is the rainwater tank capacity; Y_t (m^3) is the rainwater volume yielded in the tank; M_t (m^3) is the water volume provided by the utility; D_t (m^3/day) is the water demand; and subscription t indicates variables associated with the time interval of the computer simulation (day).

2.3. Financial Feasibility Analysis

2.3.1. Initial Outlay

Single-family RWH systems were designed following the recommendations from the Brazilian standard NBR 15,227 [6], which contemplates the minimum requirements for RWH systems in Brazil. Ideal tank sizes obtained in the computer simulations were used in the analysis. Two rainwater distribution schemes, namely indirect and direct, were also

compared. Table S1 in the supplementary data summarises the construction conventions used to elaborate the system designs used in this research. The designs determined the material quantities necessary to implement a residential RWH system in new buildings.

This research introduces a thorough item-by-item outlay procedure to evaluate the financial feasibility of RWH systems in the city of Maringá. Each analysed scenario's initial outlay was determined considering all its variations regarding tank size, catchment area, and rainwater distribution scheme. An item-by-item list of materials and labour was considered according to representative compositions obtained from Brazil's national prices and indexes system for civil construction (SINAPI) [33]. From the materials list, tank costs were surveyed at local suppliers via phone, e-mail, and digital messaging. A minimum of three suppliers were contacted for each item, and the lowest market price was considered. Other costs were obtained from the SINAPI [33] database corresponding to the study area.

2.3.2. Operation and Maintenance

Operation and maintenance costs were considered aiming for a comprehensive description of the expenses expected for a typical RWH system. According to the local power supplier [34], the electricity tariff was considered BRL 0.76/kWh. Electricity consumption is related to the operation of the pump or pressuriser to distribute rainwater to the building. According to the literature surveyed by Vieira et al. [35], the median energy consumption for the operation of RWH systems among theoretical and empirical studies lies between 0.20 kWh/m³ and 1.40 kWh/m³ of rainwater use, respectively. Therefore, 0.80 kWh/m³ was used as a reference for the RWH systems with indirect rainwater distribution. RWH systems with direct distribution reduce energy consumption due to the higher sophistication embedded in the pressuriser compared with the motor pump [35]. Thus, an electricity cost reduction of 25% (resulting in 0.60 kWh/m³) was assumed for all direct RWH systems to account for such a lower power consumption.

Maintenance costs were assumed as 1.00% of the initial outlay yearly, which meets the recommended practice [10]. Disinfection costs were also considered. It was assumed that 1 L of sodium hypochlorite 12% (NaClO) treats up to 60 cubic meters of water [10] at BRL 3.19 per litre of disinfectant.

2.3.3. Financial Benefit

The systems' benefit was calculated monthly by subtracting the water tariff obtained after implementing the RWH system from the original water utility bill or the price that would be paid if the building did not use any RWH system. Water tariffs were surveyed at the local utility supplier [13] and can be found in Table S2 in the Supplementary Material. Sewage charges, as practised by the company, were also included. The monthly water consumption used to obtain the original monthly water tariff was determined for each case according to Equation (4).

$$W_0 = n * Q * d \quad (4)$$

where: W_0 is the original monthly water consumption (litres/month), n is the number of dwellers (people), Q is the potable water demand (litres/dweller/day), and d is the number of days at any given month (days).

Similarly, the monthly water consumption used to obtain the water tariff after implementing the RWH system in the building was calculated using Equations (5) and (6).

$$W_r = W_0 * P_{ws} \quad (5)$$

where: W_r is the monthly rainwater consumption (litres/month), W_0 is the original monthly water consumption (litres/month), and P_{ws} is the potential for potable water savings obtained in the computer simulation (%).

$$W_1 = W_0 - W_r \quad (6)$$

where: W_1 is the monthly water consumption after the implementation of the RWH system (litres/month), W_0 is the original monthly water consumption (litres/month), and W_r is the monthly rainwater consumption (litres/month).

2.3.4. Lifespan

The lifespan of the RWH systems was considered to be 30 years, according to Sant'Ana et al. [36]. This period corresponds to the total duration of the feasibility analysis. The inflation index was considered 0.40% per month based on reports issued by the Central Bank of Brazil [37]. The system's costs and benefits were adjusted every twelve months according to such an index.

2.3.5. Feasibility Indicators

Three indicators were used to evaluate the financial feasibility of all scenarios simulated. The Netuno computer programme [19] was used to perform such analysis via its built-in calculator.

The first feasibility indicator calculated was the discounted payback. It indicates the time required so that the investment generates enough financial benefit to pay for itself. Investments are more feasible as shorter paybacks are observed, and paybacks longer than the system's lifespan of 30 years are unfeasible [36]. The discounted payback considers the cash flow of each month with the respective discount rate and adds it to all the previous cash flows with their respective discount rate, accumulating its net present value. When the sum is equal or greater than the initial investment, this is the month of the discounted payback period. Discounted payback periods were calculated using Equation (7).

$$\sum_{t=1}^{360} \frac{B_t - C_t}{(1+i)^t} \geq K \quad (7)$$

where: B_t is the total benefit in the month of analysis (BRL), C_t is the total cost at the month of analysis (BRL), i is the interest rate (% per month), t is the time step count (months), and K is the initial cost of the investment (BRL).

Net present value was used to calculate the total financial benefit generated by the RWH system for 30 years, or 360 months. The net present value was calculated using Equation (8).

$$NPV = -K + \sum_{t=1}^{360} \frac{B_t - C_t}{(1+i)^t} \quad (8)$$

where: NPV is the net present value (BRL), K is the initial cost of the investment (BRL), B_t is the total benefit at month t (BRL/month), C_t is the total cost at month t (BRL/month), i is the interest rate (% per month), and t is the time step count (months).

According to Ghisi and Cordova [32], the internal rate of return is the rate that equals the present value of total benefits and costs at a certain point in time. The minimum acceptable rate of return was defined as 0.50% per month, commonly found in Brazil's fixed-income investments. The internal rate of return is the value that satisfies Equation (9).

$$NPV = 0 = -K + \sum_{t=1}^{360} \frac{B_t - C_t}{(1+IRR)^t} \quad (9)$$

where: NPV is the net present value (BRL), K is the initial cost of the investment (BRL), B_t is the total benefit at month t (BRL/month), C_t is the total cost at month t (BRL/month), IRR is the internal rate of return (% per month), and t is the time step count (months).

3. Results

3.1. Rainfall Data

Continuous daily rainfall data for Maringá were obtained between 2006 and 2018, sourced from Brazil's National Meteorology Institute [23]. According to Ghisi, Cardoso,

and Rupp [38] and Geraldi and Ghisi [24], thirteen years of continuous rainfall records produce consistent results.

In this period, average daily and monthly rainfall were 4.95 mm/day and 150.4 mm/month, respectively. The average annual rainfall was 1805 mm/year. Following the method suggested by Geraldi and Ghisi [24], rainfall characterisation indexes for this city can be found in Tables S3 and S4 in the Supplementary Material. Figure 3 shows the average monthly rainfall in Maringá within the observed period.

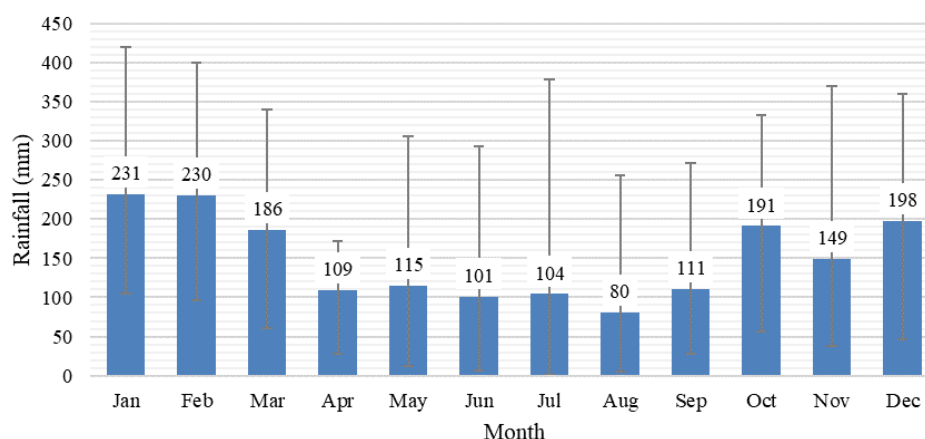


Figure 3. Average, minimum and maximum monthly rainfall in Maringá (2006–2018).

3.2. RWH Systems Simulation

From the simulation of RWH systems, 54 scenarios were considered according to the input parameters shown in Table 1. Ideal tank sizes and potential for potable water savings were obtained for each scenario. No significant differences were obtained in this analysis between indirect and direct rainwater distribution schemes.

The average tank size obtained for systems with indirect rainwater distribution was 6629 L compared with 6741 L obtained for directly distributed rainwater. The percentage difference between such capacities is 1.68%. Exact median tank sizes of 7000 L were obtained for both rainwater distribution schemes. As for the potential for potable water savings, averages of 43.7% and 43.2% were obtained for systems with both indirect and direct rainwater distribution, respectively. This is coherent to what was observed by Teston et al. [3], who compiled Brazilian research studies about rainwater harvesting and showed that most cases (>55%) yielded potential for potable water savings between 26.1% and 48.1%. Complete results can be found in Tables S5 and S6 and Figures S1–S4 in the Supplementary Material.

3.3. Financial Feasibility Analysis

3.3.1. Initial Outlay

In this study, all costs correspond to January 2021 and include labour costs. Costs for systems with indirect rainwater distribution were BRL 21.81 higher when compared with direct rainwater distribution in all scenarios. Such a difference is insignificant, corresponding to only 0.16% of the average initial outlay of all scenarios. In this study, the higher cost of the pressuriser equipment is equivalent to the savings obtained by not using an upper tank and the components required for its operation.

Table 2 shows the initial outlays obtained for RWH systems with indirect rainwater distribution. In this case, initial outlays ranged from BRL 9696.27 to 17,057.71, depending on the catchment area and tank size.

All costs obtained by other studies were corrected to January 2021 according to Brazil's national construction cost index [39] to compare results obtained herein with other studies. Ghisi and Oliveira [9] evaluated the costs of RWH systems for two single-storey houses in Palhoça, southern Brazil. Rainwater tanks with 5000 L were considered to provide

potable water savings of around 50% at two houses with catchment areas of approximately 200 m². Initial outlays of BRL 6027.68 and BRL 7512.70 were obtained for both houses, corresponding to 48.6% and 60.6% of the corresponding costs obtained in this research. Carvalho [40] estimated an initial outlay of BRL 7199.29 for a single-family house with four residents, a catchment area of 200 m², and a tank size of 5000 L. This cost corresponds to 58.02% of the cost obtained in this research.

Table 2. Initial outlays for RWH systems with indirect rainwater distribution.

Tank Size (L)	Catchment Area		
	100 m ²	200 m ²	300 m ²
3000	BRL 9696.27	BRL 10,663.95	BRL 11,412.88
4000	BRL 10,539.29	BRL 11,506.97	BRL 12,255.90
5000	BRL 11,439.27	BRL 12,406.95	BRL 13,155.88
6000	BRL 12,339.35	BRL 13,307.03	BRL 14,055.96
7000	BRL 13,289.68	BRL 14,257.36	BRL 15,006.29
8000	BRL 14,290.26	BRL 15,257.94	BRL 16,006.87
9000	BRL 15,341.09	BRL 16,308.77	BRL 17,057.71

Note: On 1 August 2022 BRL 1.00 = USD 0.194 = GBP 0.159 = EUR 0.190.

Severis et al. [10], on the other hand, obtained an initial outlay of BRL 14,372.72 for a dual-tank RWH system with a roof area of 139.20 m² and a tank size of 12,000 L. This cost corresponds to 93.68% of the cost obtained in this research for a system with 100 m² of catchment area and a 9000 L tank. Such similarity is due to the fact that Severis et al. [10] adopted an item-by-item approach when listing materials and surveying costs for RWH systems, as similarly performed herein.

Although most studies claim that all materials and labour are considered in their research, different layouts and construction conventions are often adopted, thus significantly impacting costs for the RWH systems. In this sense, this research obtained initial outlays higher than what is commonly found in the literature [10,39,40], thus indicating a higher detailing level.

In order to provide reference for further studies about financial analysis of rainwater harvesting, this study proposed a division of initial outlays based in categories representing different component groups of typical RWH systems. Table 3 shows the average initial outlay distribution obtained for RWH systems with indirect rainwater distribution depending on the building's catchment area. Full results can be found in Tables S7 and S8 in the Supplementary Material.

Table 3. Initial outlays for RWH systems with indirect rainwater distribution.

Catchment Area (m ²)	Tanks (%)	Plumbing (%)	Civil Works (%)	Rain Collection (%)	Electrical System (%)
100	26.18	22.68	20.94	18.84	11.35
200	24.32	20.97	19.41	24.79	10.50
300	23.06	19.82	18.37	28.82	9.92

In all scenarios, bigger tank sizes resulted in increasingly higher tank costs relative to the total outlay. The results obtained herein differ from what was observed by Severis et al. [10] in terms of cost distribution. It was observed that tanks corresponded to 43% and 42% of the initial outlays for indirect and direct RWH systems. However, costs included in the initial outlays were not specified, whereas the construction conventions adopted in this study can be consulted in Table S1 in the Supplementary Material.

Sant'Ana [41] also surveyed the initial outlay of an RWH system in a house in Brasília. The author obtained an initial outlay of BRL 53,206.59, corrected for the current date. This cost corresponds to an RWH system with indirect rainwater distribution, a catchment area of 483 m², and a 30,000 L main rainwater tank. Majoring coefficients were applied to the cost distribution observed in this research for a 200 m² catchment area and 9000 L rainwater tank (i.e., 3.33 for tanks and civil works based on tank capacity ratio and 2.00 for the remaining items based on catchment area ratio), resulting in an initial outlay of BRL 44,486.67. Such cost corresponds to 83% of the cost observed by Sant'Ana [41] and is herein corrected to the current date. This indicates that such a method can estimate the costs of larger RWH systems with limited but satisfactory accuracy.

Table 4 shows the average initial outlay distribution obtained for RWH systems with direct rainwater distribution depending on the building's catchment area.

Table 4. Initial outlays for RWH systems with direct rainwater distribution.

Catchment Area (m ²)	Tanks (%)	Plumbing (%)	Civil Works (%)	Rain Collection (%)	Electrical System (%)
100	24.58	20.98	21.36	14.21	18.87
200	22.84	19.44	19.75	13.14	24.83
300	21.66	18.40	18.66	12.42	28.87

Despite having similar initial outlays, the cost distribution showed to be different from what was obtained from RWH systems with indirect rainwater distribution. Although pressure-distributed RWH systems require less money for tanks, the electrical cost is greater due to the significant price difference between the motor pump (BRL 496.35) and the pressuriser (BRL 1395.00). Severis et al. [10] also evaluated direct and indirect RWH systems and confirmed that they present similar initial outlays (USD 2293.79 and 2377.34, respectively). In this sense, it is important to investigate new technical solutions for RWH aimed at significantly reducing installation costs and thus improving financial performance.

3.3.2. Operational Cost

Total operational costs were analysed for each scenario. According to Severis et al. [10], operational costs do not significantly impact the financial indicators of RWH systems, especially in projects with domestic purposes. In this study, average operational costs were estimated at BRL 1.31/month/m³ of rainwater demand among all scenarios. The higher the rainwater demand, the lower the monthly operational cost per m³ of rainwater used. Larger tank sizes demanded lower operational costs than what was observed for smaller systems. RWH systems with direct rainwater distribution resulted in operational costs averaging 97.27% of the costs observed for systems with indirect rainwater distribution. This slight difference is due to the smaller initial outlay of systems with direct water distribution, which served as a reference to calculate the monthly maintenance costs. Figure 4 presents the total monthly operational costs for all rainwater tank sizes as a function of rainwater demand.

3.3.3. Feasibility Indicators

Overall, the greater the rainwater demand in the building, the greater the financial feasibility. Berwanger and Ghisi [11] observed the same trend for residential RWH systems simulated in Itapiranga, southern Brazil. Figure 5 shows the discounted paybacks observed for indirectly distributed RWH systems in Maringá.

The average payback observed for all feasible indirectly distributed RWH systems is 14.89 years, ranging from 8.75 to 23.75 years. Due to smaller initial outlays, directly distributed RWH systems resulted in paybacks averaging 14.40 years, ranging from 8.50 to 22.92 years. The higher the rainwater demand, the lower the payback period. Coefficients

of determination ranged from 0.80 to 0.88, which indicates a strong correlation between rainwater demand and discounted payback.

It is important to note that, although the feasibility criteria for this indicator was defined as a payback shorter than the system's lifespan of 30 years [36], this may not be adequate for some users. From the 54 scenarios simulated, only 6 presented payback lower than 10 years. Such scenarios were the same for both rainwater distribution schemes. Similarly, 24 scenarios presented payback from 10–20 years, and 6 presented payback between 20 and 30 years.

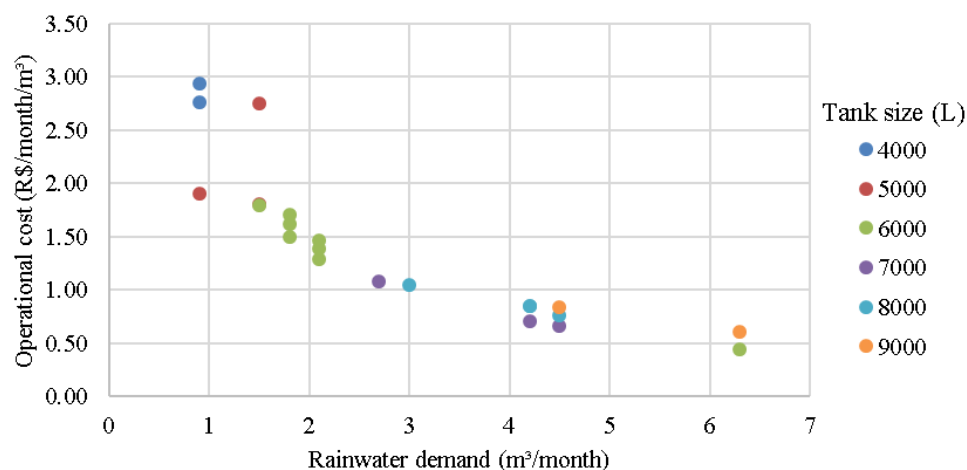


Figure 4. Total monthly operational cost as a function of rainwater demand for residential systems in Maringá.

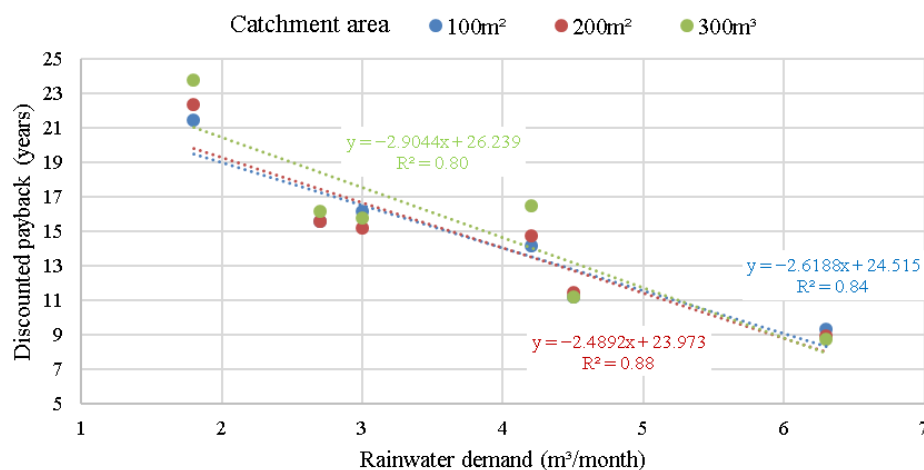


Figure 5. Discounted payback as a function of rainwater demand for financially feasible RWH systems in Maringá (R^2 stands for the coefficient of determination; y represents the discounted payback; and x represents the rainwater demand).

Berwanger and Ghisi [11] analysed smaller residential systems. Feasible cases resulted in paybacks ranging from 8 to 20 years and coefficients of correlation ranging from 0.54 to 0.66, which are significantly smaller than those observed in this research.

Figure 6 shows the correlation between internal rate of return and rainwater demand for all cases financially feasible. The minimum acceptable rate of return was taken as 0.50% per month.

Internal rates of return varied from 0.62% to 1.40%, with an average of 0.97% per month for feasible indirectly distributed RWH systems. Directly distributed RWH systems rendered monthly internal rates of return from 0.65% to 1.43%, with an average of 1.00% per month. Coefficients of correlation from 0.87 to 0.94 indicate a good correlation between

rainwater demand and internal rate of return. For smaller residential systems, Berwanger and Ghisi [11] obtained internal rates of return from 0.50% to 1.30% per month and coefficients of correlation between 0.54 and 0.66 among feasible cases. In this analysis, it is also noted that the financial feasibility increases for higher rainwater demands. Figure 7 shows the correlation between rainwater demand and net present value for indirectly distributed RWH systems.

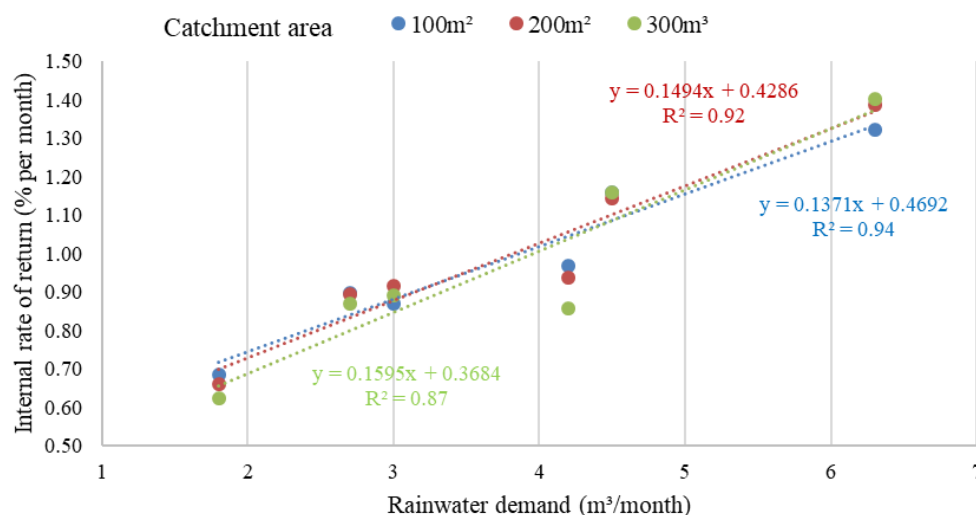


Figure 6. Internal rate of return as a function of rainwater demand for financially feasible indirectly distributed RWH systems in Maringá. (R^2 stands for the coefficient of determination; y represents the internal rate of return; and x represents the rainwater demand).

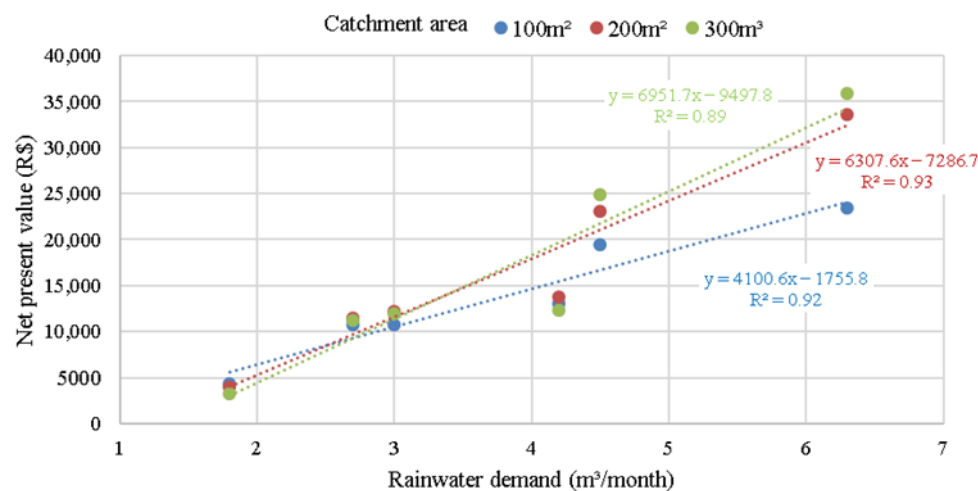


Figure 7. Net present value as a function of rainwater demand for financially feasible indirectly distributed RWH systems in Maringá. (R^2 stands for the coefficient of determination; y represents the net present value; and x represents the rainwater demand).

Eighteen cases (33%) were deemed unfeasible from the 54 scenarios analysed. Unfeasible cases were the same for both rainwater distribution schemes. All scenarios with rainwater demands lower than 6.3 m³/month generated unfeasible RWH systems, with the exception of three cases, with rainwater demand of 5.4 m³/month that yielded paybacks of 22 years. The complete summary of feasibility indicators can be found in Tables 5 and 6.

Table 5. Summary of feasibility indicators for indirectly distributed RWH systems in Maringá.

Rainwater Demand (m ³ /Month)	Tank Size (L)	Potential for Potable Water Savings (%)	Discounted Payback (Months)	Net Present Value (BRL)	Internal Rate of Return (% Monthly)	Monthly Operational Cost (BRL)
2.7	5000	29.81	-	−11,419.39	−0.743	2.75
4.5	6000	47.69	-	−11,706.92	−0.533	1.79
6.3	6000	62.70	-	−12,867.35	−0.602	1.29
5.4	6000	27.69	257	4353.07	0.685	1.50
9.0	8000	42.42	194	10,750.24	0.871	1.05
12.6	7000	50.04	170	12,998.64	0.967	0.70
8.1	7000	25.76	187	10,797.61	0.897	1.08
13.5	7000	34.40	134	19,418.89	1.159	0.66
18.9	6000	37.34	112	23,410.29	1.322	0.44
2.7	4000	29.67	-	−11,258.46	−0.646	2.76
4.5	5000	48.17	-	−11,764.25	−0.531	1.80
6.3	6000	65.91	-	−12,915.10	−0.611	1.39
5.4	6000	28.82	268	3996.48	0.659	1.61
9.0	7000	45.05	182	12,168.13	0.915	1.10
12.6	8000	59.31	177	13,792.46	0.936	0.85
8.1	7000	27.56	187	11,507.62	0.895	1.16
13.5	8000	41.52	137	23,084.25	1.143	0.76
18.9	9000	53.02	107	33,650.63	1.386	0.58
2.7	4000	29.69	-	−12,351.61	−0.801	2.94
4.5	5000	48.48	-	−12,606.90	−0.566	1.91
6.3	6000	66.63	-	−13,770.22	−0.649	1.46
5.4	6000	29.01	285	3274.30	0.624	1.70
9.0	7000	46.14	189	11,944.54	0.890	1.10
12.6	8000	61.65	198	12,269.93	0.856	0.85
8.1	7000	28.12	194	11,213.78	0.869	1.22
13.5	9000	44.15	134	24,843.90	1.160	0.84
18.9	9000	56.44	105	35,879.60	1.401	0.61

Note: On 1 August 2022 BRL 1.00 = USD 0.194 = GBP 0.159 = EUR 0.190.

Table 6. Summary of feasibility indicators for directly distributed RWH systems in Maringá.

Rainwater Demand (m ³ /Month)	Tank Size (L)	Potential for Potable Water Savings (%)	Discounted Payback (Months)	Net Present Value (BRL)	Internal Rate of Return (% Monthly)	Monthly Operational Cost (BRL)
2.7	6000	29.81	-	−10,949.11	−0.716	2.65
4.5	6000	47.65	-	−11,236.65	−0.512	1.73
6.3	7000	63.72	-	−12,397.08	−0.581	1.25
5.4	9000	27.64	247	4823.35	0.710	1.45
9.0	8000	42.29	187	11,220.52	0.895	1.02

Table 6. *Cont.*

Rainwater Demand (m ³ /Month)	Tank Size (L)	Potential for Potable Water Savings (%)	Discounted Payback (Months)	Net Present Value (BRL)	Internal Rate of Return (% Monthly)	Monthly Operational Cost (BRL)
12.6	7000	49.83	164	13,468.91	0.995	0.68
8.1	9000	25.68	180	11,267.89	0.924	1.05
13.5	9000	34.25	130	19,889.16	1.191	0.64
18.9	6000	36.95	109	23,880.56	1.361	0.43
2.7	5000	29.66	-	-10,788.19	-0.622	2.67
4.5	5000	48.10	-	-11,293.98	-0.511	1.74
6.3	6000	65.80	-	-12,444.82	-0.590	1.35
5.4	7000	28.77	258	4466.75	0.682	1.56
9.0	7000	44.94	176	12,638.41	0.940	1.07
12.6	8000	59.08	172	14,262.73	0.960	0.83
8.1	9000	27.50	181	11,977.89	0.920	1.13
13.5	9000	42.18	133	23,554.52	1.169	0.74
18.9	7000	52.70	104	34,120.91	1.416	0.57
2.7	4000	29.68	-	-11,881.33	-0.773	2.84
4.5	4000	48.41	-	-12,136.63	-0.546	1.85
6.3	5000	66.53	-	-13,299.95	-0.629	1.42
5.4	6000	28.97	275	3744.57	0.646	1.65
9.0	6000	46.01	183	12,414.81	0.914	1.07
12.6	6000	62.53	192	12,740.20	0.877	0.83
8.1	7000	28.06	188	11,684.05	0.892	1.19
13.5	7000	43.97	131	25,314.18	1.185	0.82
18.9	7000	56.08	102	36,349.87	1.430	0.60

Note: On the 1 August 2022 BRL 1.00 = USD 0.194 = GBP 0.159 = EUR 0.190.

4. Conclusions

The research aimed to evaluate the financial feasibility conditions of RWH in Maringá, southern Brazil, while introducing a thorough item-by-item outlay procedure as a reference for similar studies. A range of generic RWH systems was designed for the studied area, and variations in design variables were evaluated. A monthly cost–benefit balance was built for each scenario to verify the discounted payback, net present value and internal rate of return. Additionally, the costs and performance of indirect and directly distributed rainwater systems were compared.

From 54 scenarios, 66% were deemed financially feasible according to the criteria established herein. A direct comparison of results obtained by similar studies indicates that the list of materials and labour considered in this paper is more thorough than commonly found in the literature due to the item-by-item approach adopted. Systems with indirect and direct rainwater distribution did not show significant differences in initial costs, thus resulting in similar paybacks. Only 16% of feasible scenarios presented paybacks lower than 10 years, 66% presented paybacks from 10–20 years, and 16% presented paybacks between 20 and 30 years. All financial feasibility indicators presented significant correlation with rainwater demand, suggesting that RWH systems with higher rainwater consumption tend to be more feasible.

The initial outlay was divided into categories suitable for reference for further studies (tanks, plumbing, labour, rain collection, and electrical systems). Considering the significant diversity observed in building layout [2], the categorisation presented herein may contribute to establishing a common ground for result comparison. Applying suitable coefficients to the costs obtained herein resulted in figures similar to what was found in other studies, indicating that the results from this study can be used to estimate costs of differently sized RWH systems with limited but satisfactory accuracy.

This study obtained financial feasibility results coherent with what was found by other researchers. As such, the information generated herein can contribute with reliable information regarding the local costs involving the installation, operation, and maintenance of RWH systems in Maringá. Moreover, the proposed initial outlay categorisation helps orient direct comparisons between studies while also serving as a reference for future studies or other locations. Considering the importance of financial feasibility and accurate public policies to promote the adoption of RWH systems at a grander scale, the information generated herein is suitable for both consumers and policymakers.

An investigation of other technical solutions for RWH aimed at lower initial outlays and favourable for the feasibility of smaller systems is suggested as a development suggestion. Since the initial outlay of direct and indirect RWH systems obtained herein presented no significant difference, it is suggested that design alternatives with more substantial differences are evaluated. Moreover, further investigation is recommended regarding the influence of water tariff schemes on the financial feasibility of RWH systems since it has been mentioned by several studies [3,11,13] as a significant parameter.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su141912859/s1>, Table S1: Construction conventions used in the system's designs; Table S2: Water tariff scheme used in this research; Table S3: Main rainfall characterisation indexes obtained for Maringá; Table S4: Characterisation indexes for dry periods obtained for Maringá; Table S5: Simulation results for indirectly distributed RWH systems in Maringá; Table S6: Simulation results for directly distributed RWH systems in Maringá; Table S7: Initial outlays for RWH systems with indirect rainwater distribution; Table S8: Initial outlays for RWH systems with direct rainwater distribution; Figure S1: Ideal tank size as a function of rainwater demand for indirectly distributed RWH systems in Maringá; Figure S2: Potential for potable water savings as a function of rainwater demand for indirectly distributed RWH systems in Maringá; Figure S3: Ideal tank size as a function of rainwater demand for directly distributed RWH systems in Maringá; Figure S4: Potential for potable water savings as a function of rainwater demand for directly distributed RWH systems in Maringá.

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