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Review

Rainwater Harvesting in Buildings in Brazil: A Literature Review

Andrea Teston *, Matheus Soares Geraldi, Barbara Müller Colasio and Enedir Ghisi

Laboratory of Energy Efficiency in Buildings, Department of Civil Engineering, Federal University of Santa Catarina, Florianópolis, SC 88040-900, Brazil; matheus.s.geraldi@gmail.com (M.S.G.); barbara.colasio@gmail.com (B.M.C.); enedir.ghisi@ufsc.br (E.G.)

* Correspondence: andreateston@yahoo.com.br; Tel.: +55-48-3721-5184

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Abstract: This article presents a literature review on rainwater usage in buildings in Brazil. It focuses on economic, environmental and social impacts. The legislation related to rainwater harvesting—including the cities that have made such a practice mandatory—was also assessed. The literature review was based on a search strategy that uses protocols to find and select studies about the main subject, i.e., rainwater harvesting in buildings. The protocols were defined as the site to be investigated (buildings), the intervention (rainwater harvesting), and the expected result (influence on the potable water consumption). Despite the variation of water availability in the country, it was concluded that there is a high potential for potable water savings when using rainwater in buildings in Brazil. Finally, it was observed the need for financial investments in experimental research and innovation technologies in order to improve rainwater management.

Keywords: rainwater usage; potable water savings; investment feasibility analysis; urban flood mitigation; sustainable urban water systems; public policy; water conservation; buildings; Brazil

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1. Introduction

For approximately two centuries, water management in cities followed the principles of control and domination, well represented by urban drainage, which is sized so that the urban environment is free of floods [1]. With the continuous urbanization process, larger drainage systems are required [2], which increasingly interferes with the natural cycle of water. The main impacts of urbanization on the water cycle are the increase in runoff and the anticipation of peak flows, the reduction of evapotranspiration and groundwater quantity supply, and the deterioration of surface water quality [3].

In addition, the concern about water shortage is a target for studies all over the world, in local level [4–6], mostly in regions that already suffer from lack of water, and in global level [7–10]. Kummu et al. [10] demonstrated that while water consumption increased fourfold in the 20th century, the population suffering from water scarcity rose from 0.24 billion (14% of the world population) in the 1900s to 3.8 billion (58%) in the 2000s. Vörösmarty et al. [9] pointed that almost 80% of the world population is exposed to high levels of threat to water safety.

Another issue is about the leakages from the piping systems in cities. Worldwide, the average water leakage is 35%, and in Brazil it is close to 40% [11]. According to the Brazilian Diagnosis of Water and Sewage Services of 2015, the national average water leakage is 36.7% [12], i.e., in addition to wasting potable water, this index represents a high waste of energy in urban distribution services. According to Gomes [13], the energy consumption of water and sewage service providers represents about 3% of the total energy consumption in the world. Stewart et al. [14] propose a web-based knowledge management system. It integrates smart metering, end-use water consumption data and information management systems in order to provide real-time information on how, when and where water is being consumed or wasted by means of leakages. Some types of smart systems, like the one proposed by Stewart et al. [14], have high potential to mitigate water losses and energy wastage.

From this perspective, there is a need to better control in the hydrological cycle in cities, hence the current model of water and sanitation urban services need to undergo changes [15]. The water industry has been seeking for alternatives for the sustainable planning of services provided [14,16,17]. Among such alternatives there is the use of smart meters, increase and maintenance of permeable areas and the use of decentralised water systems [18], such as rainwater harvesting systems.

The great climatic differences all over Brazil hinder the water management. Despite having high rainfall levels in almost all of its territory, which assures water to supply the cities, rainwater is considered to be a source of water only in regions where water is scarce, such as the Brazilian semi-arid region. In such region, social programmes encourage rainwater usage for surviving purposes. In other cities, rainwater harvesting is considered to be an advancement in technology and constructive methods [19]. Besides, the perception of the benefits of using rainwater in buildings is small when compared to its potential because legislations and incentives for rainwater harvesting in buildings are still few and recent [20].

Even though there are records of rainwater harvesting over thousands of years [21], new technologies for rainwater harvesting systems in buildings have been subject of research in many countries in the lasts decades. One of the main reasons for the adoption of rainwater harvesting systems in buildings is the potential for potable water saving by using rainwater for non-potable water. Besides that, it is necessary to considering other potential benefits associated to the rainwater harvesting in buildings [22].

Worldwide, some of the topics covered in the searches about rainwater harvesting are the quality of the rainwater collected from the roofs and their implication on population health, the design of the system and the potential for potable water savings, the impact of rainwater harvesting on stormwater management in cities, and climate change impact. However, a literature review performed by Campisano et al. [22] points that there is a need for high quality datasets associated with water saving, stormwater management, energy consumption and greenhouse gas emissions. Therefore, this research aims to seek data from the development of research on rainwater harvesting in Brazil.

This article presents a literature review of scientific studies that have been developed in Brazil regarding rainwater usage in buildings. The evolution of public policies on rainwater is also assessed. Thus, this paper presents the state of the art on rainwater harvesting and how it has evolved in Brazil, trends, future perspectives, and a comparison to studies developed worldwide.

2. Method

The literature review was based on a strategy that defined the main subject through the site to be investigated (buildings), the intervention made (the rainwater usage), and the expected result (the influence of intervention on the consumption of water). Through this strategy, the key question to be investigated was: "What is the potential for potable water savings through the installation of rainwater harvesting systems in buildings?".

First, a portfolio of studies related to rainwater use system was obtained from CAPES (an agency of the Brazilian government for postgraduate studies), which keeps a website with doctorate's theses and master's dissertations published in Brazil, covering a period of ten years (2007–2017). The studies were identified focusing on the subareas "environment", "engineering" and "earth sciences". In Brazil, the researches present different nomenclatures due to the synonyms of words such as "pluvial" and "rain". Therefore, the search protocols used were:

- Protocol 1: Utilization AND water AND (pluvial OR rain);
- Protocol 2: Utilization AND water AND (pluvial OR rain) AND (domest * OR residenc * OR edifica *); and
- Protocol 3: Utilization AND water AND (pluvial OR rain) AND (domest * OR residenc * OR edifica *) AND drinkable.

The studies on rainwater harvesting systems were identified, and the most relevant researches with possibility of comparison of results were selected. In addition, a search was made in national scientific journals and conferences related to water resources and sustainable constructions.

Papers published in international journals were also selected. Equivalent research protocols were used for researching in Portuguese and English, in order to allow an equivalent comparison. The purpose of this search was to compare the national scientific production with the international production in order to assess whether the national production follows the pace of the international studies, quantitatively and temporally.

After the selection of studies, they were reviewed from a meta-analysis, allowing a view of the general panorama. In the sequence, the works were filtered according to the topics of interest and allocated in each research topic.

3. Results

3.1. Brazilian Production

By searching theses and dissertations, Protocol 1 resulted in 151 works, i.e., 127 dissertations and 24 theses. However, many of these works were not related to the focus of our search. Protocol 2 presented more coherent results, showing 59 works (48 dissertations and eleven theses) and it was used to develop this search. Protocol 3 filtered the searches to make sure all works were consistent with the subject under investigation. Therefore, 34 works were found, being 29 dissertations and five theses.

Thus, the reviewed theses and dissertations related to the topic, selected through Protocol 2, were developed on the subjects presented in Table 1. However, from the titles presented by the search protocol, eight were not found in their entirety and seven were inconsistent with the intended subject.

Table 1. Subjects covered by the theses and dissertations obtained from Protocol 2 and considered in our review.

Subject	References
Water quality and health risks	[23–37]
Social acceptance	[38]
System measurements and its variables	[25,26,30,35,39–47]
Potential for saving potable water	[31,33,45,48–51]
Economic viability	[38,48,52–57]
Environmental impact	[56,58]
Impact on drainage	[41,59,60]
Different typologies of surface runoff harvesting (quality and quantity of water collected)	[61–63]
Literature review	[64–66]

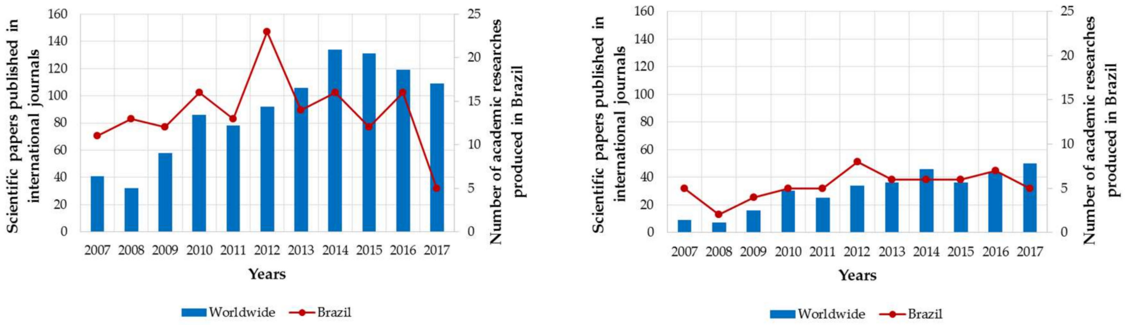
Although the theses and dissertations have been classified in these large groups, not all of them present results that can be compared, since there is a great variety of topics researched within these groups, such as the method used by them, for example. Most of the thesis and dissertations selected focus on water quality and health risks, the design of the system and its variables, the potential for potable water savings and economic viability.

Regarding water quality, however, there are no standard parameters investigated for potable and non-potable purposes. In this way, it is difficult to compare researches, since they analyse different parameters. Regarding the rainwater system, some studies that evaluated the influence of the sizing variables in the system [39,46], but most of them proposed different methods for rainwater tank sizing or compared the methods proposed by the Brazilian Standard for Rainwater Usage. The potential for potable water savings is influenced by the tank sizing method used in the research, which also makes it difficult to compare the results. The same is true for the economic viability. It is worth mentioning the research carried out by Leon [57], which was concerned with accounting for the sewage generated by the rainwater harvesting system, in the cost of disposal and treatment of sewage, which is generally not accounted for.

On the other subjects, such as drainage and environmental impact, few researches were found, which demonstrates the need for further studies in this area. According to Ghimire et al. [67], implementation of rainwater systems continues to be a challenge, mainly due to a lack of understanding of their environmental and human health impacts (material selection criteria and energy use) and partly due to a lack of worldwide regulations. To prove the effectiveness of the systems in minimising environmental impacts, it is necessary to use evaluation tools that analyse costs, impact on the life cycle of the systems and the urban water cycle.

Regarding the evolution of subjects over the years, it was not possible to establish a trend line of decrease or growth in the number of theses and dissertations. In the second search protocol, which was the most coherent for this review, the average number of studies developed each year was 5.4. The year that presented the highest number of works was 2012, i.e., seven dissertations and one thesis.

In order to analyse whether national production follows the pace of international studies, quantitatively and temporally, Figure 1 shows the number of academic researches published in Brazil and papers published worldwide over 2007-2017.



(**a**) (**b**)

Figure 1. Number of scientific publications in Brazil and worldwide found through the search protocols (**a**) Protocol 1: Utilization AND water AND (pluvial OR rain); and (**b**) Protocol 2: Utilization AND water AND (pluvial OR rain) AND (domest * OR residenc * OR edifica *). (**a**) Number of publication obtained from Protocol 1; (**b**) Number of publication obtained from Protocol 2.

There is a growth of international works in this area since 2009, and this growth is noticeable in national production related to buildings, which reveals that the Brazilian scientific scenario is worrying not only about the rainwater usage to mitigate extreme drought problems, but also as an alternative water source to be used in buildings to provide financial savings and reduce environmental impact.

There are papers written by Brazilian researchers that were published in international journals. These papers were classified as scientific papers published in international journals (worldwide). However, by reviewing the publications it was noticed that many researchers do not publish results obtained in their theses or dissertations in international journals; which results in low or no citation of their works.

3.2. Potential for Potable Water Savings

As for rainwater harvesting for non-potable purposes, many papers related to the potential for potable water savings [68–73] were found. The potential for potable water savings is closely related to the water end-uses. Thus, some researchers have been developing research on the water end-uses in residential buildings [58,74–81], schools [82,83], hotels [84], office buildings [85] and public administrative buildings [86]. The average, minimum and maximum non-potable uses are shown in Figure 2.

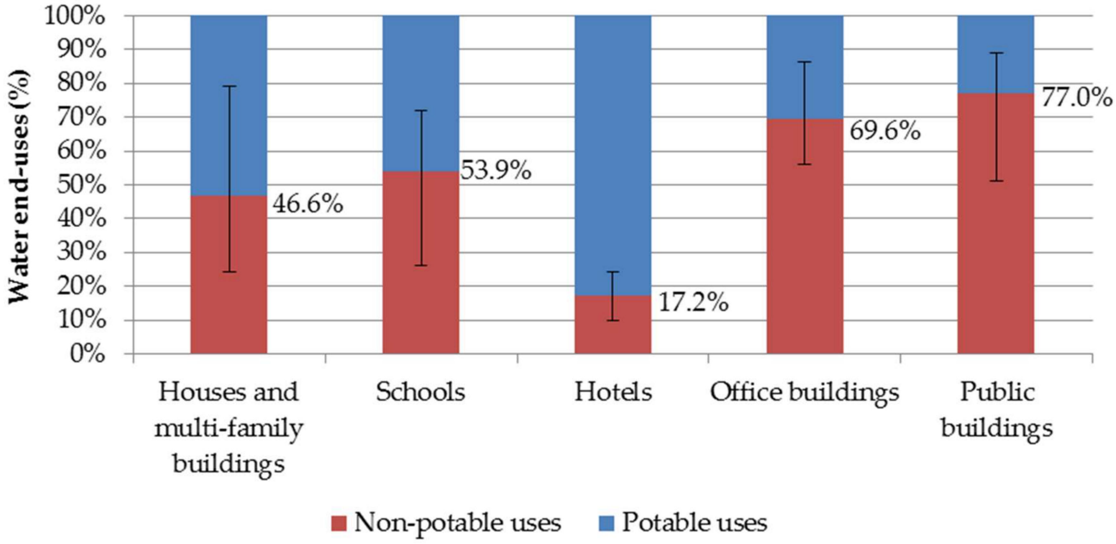


Figure 2. Potable and non-potable water end-uses in different types of buildings in Brazil.

In addition, the potential for potable water savings depends on rainfall, area and type of surface to collect rainwater, rainwater demand and potable water demand. Thus, a better way of sizing the rainwater tank is by means of computer simulation that takes into account daily rainfall and daily water demand [87]. Considering a great variability of the rainfall time series used in the researches, some researchers have evaluated the influence of the time series length on the rainwater harvesting systems sizing [70,88]. Geraldi and Ghisi [88] used a 30-year time series from Berlin, Germany, as a reference and then compared the results with those of shorter series. It was observed that the shortest rainfall time series length that satisfies the proposed criteria, which is to obtain potential for potable water savings and tank capacities significantly similar, was ten years.

Although the Brazilian standard on rainwater usage in buildings presents six methods for tank sizing, there are criticisms about them, such as the fact that the results presented by them are very different from each other [89]. According to Dornelles [41], the practical methods in the standard are those that present greater limitations since they adopt ratios of simple proportionality between rainfall and tank capacity, i.e., they do not take the seasonal pattern of rainfall into account. Thus, there are recommendations in the literature about the use of the computer programme Netuno [72,90–92], developed in the Laboratory of Energy Efficiency in Buildings of the Federal University of Santa Catarina. Netuno performs daily water balances to estimate the volume of rainfall that can be used, the volume of rainwater available in the tank before consumption, the volume of rainwater consumed, and indicates the ideal tank capacity through a predetermined interval between tank capacities (m^3). Thereby, it is possible to obtain the potential for potable water savings [93].

Other parameters can also be evaluated to determine the system performance, such as reliability and efficiency. As per Bezerra et al. [89], reliability is the relationship between the period in which demand is met with rainwater and the total investigated period, and efficiency is the relationship between the volume of harvested rainwater and the volume of rainwater that did not overflow from the tank. Therefore, reliability is related to the verification of the service to the demand, and efficiency is related the impact of the rainwater harvesting system on runoff.

Teston et al. [87] compiled nine national researches on the potential for potable water savings through the use of rainwater in residential buildings and obtained results for 158 cases. Using this compilation, when it comes to residential buildings, Figure shows the frequency of (a) rainwater demand; (b) potable water savings; and (c) system reliability.

Through Figure 3, obtained from [68,69,74–76,80,81,94,95], it is possible to notice that most of the surveys considered rainwater demand from 27.5 to 60.5%, due to the non-potable water end-uses. Only about 5% of the investigated cases adopted rainwater demand of 93.5 to 100%; of these, only 1% met such a demand. More than 55% of the cases obtained potential for potable water savings from 26.1 to 48.1%. Marinoski et al. [96] obtained similar results when evaluating twenty houses in southern Brazil. Non-potable uses accounted for, on average, 33% of the total water consumed. By using rainwater, considering a 3000-L rainwater tank estimated by Neptune, the potential for potable water savings was 30% (Reliability of 90%). Using a 10,000-L tank, this potential would reach 33%, that is, it would have 100% reliability, taking into account all the demand.

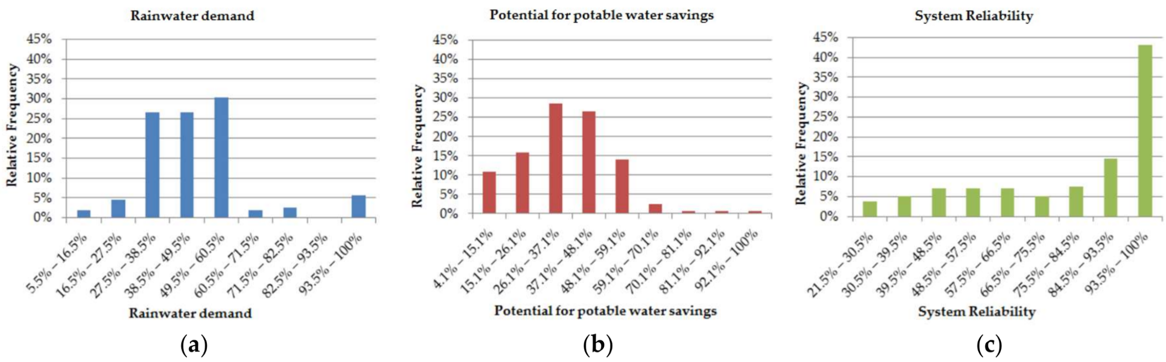


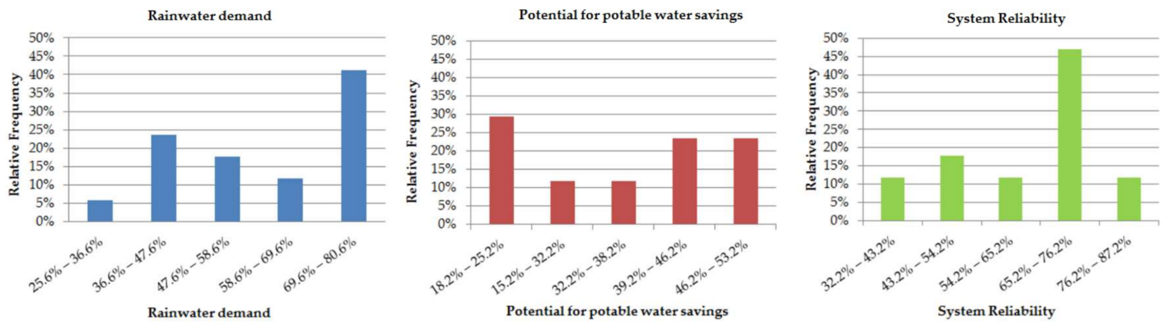
Figure 3. Histograms of (**a**) rainwater demand; (**b**) potential for potable water savings; and (**c**) system reliability, resulting from research data on rainwater harvesting in residential buildings obtained from [68,69,74–76,80,81,94,95]. (**a**) Rainwater demand, (**b**) Potential for potable water savings and (**c**) System reliability.

In Figure 3, it is also observed that more than 40% of the investigated cases obtained reliability from 93.5 to 100%, and reliability remained above 75% in about 65% of cases. Considering the variability of the data used in the research (varying rainfall, roof area and water demand), it can be concluded that the systems meet the demand for rainwater in residential buildings satisfactorily.

Marinoski and Ghisi [82], Fasola et al. [83] and Salla et al. [97] evaluated the impact of rainwater harvesting on potable water consumption in schools. Marinoski and Ghisi [82] evaluated a school in Florianópolis and considered rainwater demand ranging from 48.5 to 78.5%. Fasola et al. [83] considered two case studies, being a municipal school and a state school. Salla et al. [97] evaluated several results in a university, considering different number of students and rainwater demands. Considering the results obtained by the authors, Figure 4 shows the frequencies of rainwater demand (a); potable water savings (b) and reliability (c).

It is noted that, although more than 40% of the data adopted rainfall demand in the range of 69.6 to 80.6%, the highest potential for potable water savings was 53.2%. When analysing the reliability of the system, it is observed that demand is met more than 65% of the time with a frequency of approximately 60%. However, only 11% of the data showed reliability above 76%. This is mainly due to the high demand for rainwater. The monthly rainwater demand in the buildings analysed by the authors varied from around 33,000 L per month to around 338,000 L per month. The reliability of the system with the lowest monthly rainwater demand is 87.7%, while reliability is only 31.5% for the building with the highest rainwater demand.

It is not possible to obtain, through these case studies, a simplified relationship between system reliability and rainwater demand because the potential for potable water savings is influenced by other variables, such as rainfall and roof area. Silva and Ghisi [98] performed a sensitivity analysis of design variables and an analysis of uncertainties of daily potable water demand in the performance of rainwater harvesting systems. The dependent variables analysed were the potential for potable water savings and the design of the underground tank capacity for some cities with different rainfall levels. In general, design variables such as daily potable water demand, rainwater demand and roof area were the most influential in assessing the ideal underground tank capacity and potential for potable water savings. Rainwater demand was the most influential variable on the potential for potable water savings for most cities analysed. The use of an average value of potable water demand for performance evaluation of rainwater harvesting systems will always generate uncertainties; however, it can be overlooked because most of the uncertainties had a low probability of occurrence.



(**a**) (**b**) (**c**)

Figure 4. Histograms of (**a**) rainwater demand; (**b**) potential for potable water savings; and (**c**) system reliability, resulting from research data on rainwater harvesting in schools obtained from [82,83,97]. (**a**) Rainwater demand; (**b**) Potential for potable water savings; (**c**) System reliability.

Lopes et al. [73] evaluated the potential for potable water saving in residential buildings in 60 cities of Santa Catarina state, varying the roof area, the potable water demand, the rainwater demand and the number of inhabitants per house. They obtained some conclusions: the larger the roof area and the daily rainwater demand, the greater the potable water savings and the ideal rainwater tank capacity; for small roof areas, the relationship between the increase in the daily rainwater demand and the ideal rainwater tank capacity is not linear; cities and regions with higher rainfall tend to require lower rainwater tank capacity and result in greater potable water savings; and cities with high rainfall variation throughout the year tend to need a larger ideal rainwater tank capacity, while cities with more uniform rainfall tend to require smaller rainwater tank capacity.

Ghisi et al. [90] assessed the potential for potable water savings through the rainwater usage for vehicle washing. For this, they varied the roof area, water demand, and tank capacity, obtaining potential for potable water savings between 9.2% and 57.2% of. When assessing the same purpose, Lage [99] concluded that it is possible to obtain potential for potable water savings between 9.7% and 26.8%. The difference between the two studies was that Ghisi et al. [90] varied the data from the case study, with the intention of obtaining a relationship between the variables and Lage [99] simulated the design for the buildings of six case studies, without varying data such as roof area or demand.

It is noticed that, through the studies presented, there is significant potential for potable water savings through the rainwater harvesting for non-potable purposes in buildings and also for washing vehicles.

3.3. Rainwater Quality

According to Teston et al. [87] in Brazil, research on the quality of rainwater harvesting is being developed for potable and non-potable purposes in Brazil. There is no single Brazilian standard for determination of all water quality parameters required for each water end-use in buildings. The Ministry of Health Ordinance No. 2914/2011 addresses water quality standards for potable water and NBR 15527 presents quality parameters for rainwater collected from roofs for non-potable purposes. In addition, the National Environment Council defines water quality parameters for rivers that may or may not serve as a source of drinking water.

Due to this lack of standardisation, the studies do not present a pattern of parameters analysed. Thus, there is a great variability of parameters analysed in theses, dissertations and articles, and thus it is difficult to compare them. However, it is worth mentioning some studies. For the improvement of water quality, some techniques are recommended, such as discarding the first few millimetres of precipitation known as first flush. Jaques [100], Annecchini [101] and Salla et al. [97,100,101] have shown that water quality can be improved by increasing the amount of rainwater to be discarded in the first flush. On the Annecchini [101] search, the total coliforms are 360 NMP/100 mL, 150 NMP/100 mL and 47 NMP/100 mL for first flush equal to 0.5 mm, 1.0 mm and 1.5 mm, respectively. NBR 15527 recommends a first flush equal to 2.0 mm.

Annecchini [101] and Silva et al. [102] pointed out that promoting the simplified treatment (by means of first flush), water quality is compatible with Class 1 rivers, according to the resolution of the National Environment Council. Class 1 represents good quality water and only disinfection is required to be suitable for human consumption as potable water. Besides, in Brazilian semi-arid region rainwater is consumed for drinking purposes considering only the first flush with no treatment.

In the Brazilian semi-arid region, the studies are focused on the impact of rainwater harvesting on the health of the population, mainly checking the presence of contaminants such as *Escherichia coli*. Souza et al. [103], for example, evaluated seven houses with rainwater tanks (with a 1.0 mm first flush) for potable purposes and found that only one of them did not present *Escherichia coli*. Such house was the only one that had a pump to collect rainwater from the tank. The collection of the water from the tanks in the other houses was done by means of buckets. Thus, although the rainwater collected from the roof presents good quality, if the management of the system is inadequate the rainwater can be contaminated.

3.4. Economic Feasibility and Other Benefits

The economic feasibility of a rainwater harvesting system is one of the determining factors for the implementation of this system. The analysis should be performed to allow for decision making [104]. In view of this, many studies assess this viability through the payback on investment.

In the study done by Ghisi and Ferreira [74], applied in a multi-family building composed of three blocks in Florianópolis, Santa Catarina, the authors estimated the payback when implementing three scenarios with different systems: one of rainwater use, one of greywater reuse, and one considering both systems for rainwater usage and greywater reuse together. For the analysis, variables were considered as the monthly cost of water in each block, the average cost of water for each flat and the number of flats for each block. In addition, they considered the potential for potable water savings, water demand per flat and per block and the monthly savings obtained in each block. For the rainwater harvesting system, block A presented a payback equivalent to 2.4 years; block B 5 years; and for block C the payback was not estimated because the water consumption was less than 10 m^3. This 10 m^3 is equivalent to the minimum water tariff to be charged by the water utility. This means that even if the water consumption is less than 10 m^3, there will be no reduction in the tariff charged for water consumption.

Ghisi and Oliveira [105] estimated the payback when considering the rainwater usage and the greywater reuse in two single-family houses in Palhoça, Santa Catarina. For the economic analysis, the potable water costs (based on the water consumption), the costs of all material and equipment needed for the rainwater system, the electricity costs, and the potable water savings were considered. The payback for the rainwater harvesting system for house A was 21 years and 5 months, and for house B it was 67 years and 4 months. The water tariffs considered in the study varied according to water consumption. Thus, for water consumption between 0 and 10 m^3, the tariff was R$ 1.7050 per m^3; between 11 and 25 m^3, R$ 2.9750 per m^3; and for consumption greater than 26 m^3, R$ 4.0640 per m^3. The paybacks were recalculated considering the method of net value with interest rates of 1%, 5% and

10% per year, increasing to 25 years (house A and rate of 1% per year) and 116 years (house B and rate of 1% per year). For rates of 5% and 10% a year, both houses had a payback greater than 250 years. Thus, the implantation of a rainwater harvesting system in this study was economically infeasible.

Júnior et al. [106] considered three types of houses with distinct socioeconomic levels in João Pessoa, Paraíba, in their study about the economic feasibility of rainwater harvesting system implementation. The types of houses considered were: low-cost, with four inhabitants, water consumption equal to 130.0 L/inhab.day and rainwater catchment area equal to 60 m^2; average standard, with five inhabitants, water consumption equal to 162.0 L/inhab.day and rainwater catchment area equal to 120 m^2; and high standard, with six inhabitants, water consumption equal to 192.8 L/inhab.day and rainwater catchment area equal to 300 m^2. For the economic analysis, the net present value and the benefit/cost ratio were calculated. However, due to the low water tariff for the low-cost and average standard houses, this system proved to be infeasible in these cases. As for high standard houses, a positive economic feasibility was achieved for the implementation of the system, with payback periods ranging from 8.2 to 10.2 years. When considering future scenarios with an increase in water tariff for low-cost and average standard houses, the installation of the rainwater harvesting system may become economically feasible.

Carvalho [107] estimated the economic feasibility of the rainwater harvesting system implantation in residential buildings in Londrina, Paraná. A house of 200 m^2 with four inhabitants and water consumption of R$ 5.40 m^3/month was considered. For the economic analysis, a cost/benefit ratio was calculated, considering the total value spent on the implantation of the rainwater system (including materials and labour) and the amount of water saved per year. The savings obtained by using rainwater would be R$ 59.40 per month, and the payback of the investment equivalent to 5 years and 3 months, which makes the implementation of the system economically feasible.

Ghisi and Schondermark [108] evaluated the economic feasibility of the implantation of rainwater harvesting systems in houses of five cities in Santa Catarina. For the economic analysis, the estimated costs of installation and maintenance of the system and the financial savings deriving from the reduction of potable water consumption were considered. In most of the cases analysed, paybacks between 1.5 and 10 years were obtained. However, in some cases, the paybacks ranged from 10 to more than 30 years.

Berwanger and Ghisi [109] carried out an economic feasibility analysis of the use of rainwater in the residential sector of Itapiranga, Santa Catarina. The authors performed simulations considering four houses and twelve variables for each house. For the economic analysis, the potential for potable water savings, monthly financial savings, and costs of materials and labour were considered. There was a high variation of the payback for the cases studied (from 8 years to periods greater than 20 years). Therefore, only cases that remained between 8 and 20 years were considered feasible, and cases with payback above 20 years were considered economically infeasible.

Cruz and Blanco [110] evaluated the rainwater usage for non-potable purposes in a single-family house in Rio Branco, Acre. For the economic analysis, the total cost of the system (tank, pipes, electrical material and labour) and the economy of the system were considered. When considering eight inhabitants in the house, the payback was 24 years, and when considering five inhabitants, the payback was 27.1 years. However, when comparing with the city of Belém, Pará, changing the value of the water tariff from R$ 1.99 to R$ 2.68, the payback decreased to 17.9 years for eight inhabitants and 20.1 years for five inhabitants. The system proved to be infeasible due to the high payback.

Table 2 shows the paybacks found in the studies presented, as well as the characteristics of the residential buildings and the economic feasibility of the systems analysed.

According to Table 2, the payback periods of the studies presented ranged from 2.4 years to over 250 years. It was observed that systems with a payback up to approximately 10 years were considered feasible. Among the factors that influence the economic feasibility of a rainwater harvesting system, the demand for non-potable water is directly related, since there is a minimum water tariff charged for a volume of 10 m^3. That is, even if the consumption of potable water is less than 10 m^3, there will be no reduction in the tariff charged for water consumption. Therefore, in houses where water consumption is less than this value, the implantation of a rainwater harvesting system is economically infeasible [74,105,108,109]. The water tariff charged also influences the economic feasibility of the system. The higher the tariff, the lower the payback period [105,110].

In addition to studies on residential buildings, studies that analysed the economic feasibility of installing rainwater harvesting systems in commercial and public buildings have also been found. Fernandes at al. [111] applied their feasibility study at the Federal University of Rio Grande do Norte, in Natal, Rio Grande do Norte. The economic feasibility of the system was defined by the net present value method. The authors found that the scenario with rainwater harvesting system was more feasible over the 20 years analysed compared to the potable water scenario of the public system.

Table 2. Paybacks for the implantation of rainwater harvesting systems in residential buildings.

Reference	Feature	Payback (Years)	Economic Feasibility
[74]	Multi-family building block A Multi-family building block B Multi-family building block C	2.4 5 -	Feasible system There is no saving
[105]	Residence A with three inhabitants Residence A with three inhabitants and 1% yearly rate Residence A with three inhabitants and 5% and 10% yearly rates Residence B with two inhabitants Residence B with two inhabitants and 1% yearly rate Residence B with two inhabitants and 5% and 10% yearly rates	21.4 25 >250 67.3 116 >250	Infeasible system
[106]	Popular residence with water tariff of R$ 1.99 Medium standard residence with water tariff of R$ 2.62 High standard residence with water tariff of R$ 3.53	>20 >20 8.2–10.2	Infeasible system Feasible system
[107]	Residence of 200 m^2 with four inhabitants	5.3	Feasible system
[108]	Minimum payback period Maximum payback period	1.5 30	Feasible system in most cases
[110]	Single-family residence with eight inhabitants (Rio Branco, Acre) Single-family residence with five inhabitants (Rio Branco, Acre) Single-family residence with eight inhabitants (Belém, Pará) Single-family residence with five inhabitants (Belém, Pará)	24 27.1 17.9 20.1	Infeasible system

Marinoski and Ghisi [82] applied their study in an educational institution, Technology Center in Automation and Computing, in Florianópolis, Santa Catarina. The building has two floors and a total built area equal to 5199.45 m^2. For the economic analysis, the costs of implantation of the rainwater system, labour costs, operation costs of the rainwater system, the costs of potable water and the potable water savings were considered. The payback period of a rainwater harvesting system installation was 4 years and 10 months, which characterized the system as economically feasible.

Lage [99] evaluated the implementation of a rainwater harvesting system to wash vehicles at six car dealers in Belo Horizonte, Minas Gerais. For the economic analysis, the system implementation and operating costs were considered. The payback for the system ranged from 75 to 143 months, equivalent to 6.3 and 11.9 years, respectively. As the lifespan considered was 15 years, the systems were considered economically feasible.

Mello et al. [112] studied the economic feasibility of installing a rainwater harvesting system at the Paulo de Tarso Educational Institute, in Campos dos Goytacazes, Rio de Janeiro. The minimum attractiveness rate, the net present value, the internal rate of return, the simple payback, and the discounted payback were calculated. Two alternatives were considered: one with investments in the rainwater harvesting system (alternative 1) and the other remaining the potable water use project of the building and applying the investment value of the rainwater harvesting system in a savings account (alternative 2). In alternative 1, cash flow with and without financing was also considered for calculations of economic feasibility. The results showed that only alternative 1 without financing was economically feasible, with 9 years and 11 months for simple payback and 17 years and 8 months for discounted payback. Alternative 1 with financing was considered infeasible because it presented negative net present value and internal rate of return lower than the minimum attractiveness rate.

Alternative 2 also had negative net present value, and simple payback and discounted payback values were greater than 25 years.

Sánchez [113] analysed the economic feasibility of installing a rainwater harvesting system at the Polytechnic School of the Federal University of Bahia, in Salvador. In this study, the cost/benefit ratio, the internal rate of return and the payback were calculated, considering a scenario in which 60% of the water demand will be served by the rainwater harvesting system and another scenario with 100%. The paybacks were 14 months for the scenario with 60% and 6 months for the scenario with 100%.

To evaluate the economic feasibility of a rainwater harvesting system at Severino Sombra University, in Vassouras, Rio de Janeiro, Souza et al. [114] considered different tank capacities and rainwater demands. For the economic analysis, the implementation costs, including materials, and operating and maintenance costs of the system were considered. Thereby, the authors obtained paybacks ranging from 3.8 to 7.8 years. Table 3 shows the paybacks found in the studies presented, as well as the economic feasibility of the systems analysed. Figure 5 shows the paybacks found in the studies presented, as well as the characteristics of commercial and public buildings and the economic feasibility of the systems analysed. It can be seen that the paybacks ranged from 0.5 years to over 25 years. Compared with the results presented in Table 2, there is a greater economic feasibility in the implantation of rainwater harvesting systems in commercial and public buildings, which may be justified by the higher demand for non-potable water. Other factors that may influence the difference are the rainwater catchment area and the method used to size the tanks. The intensity and distribution of rain can also influence, since the residential building studies were carried out predominantly in the South region of the country, and the studies on commercial and public buildings were carried out predominantly in the Northeast and Southeast regions. Figure 5 shows the percentage frequencies of the investment return periods for the implantation of a rainwater harvesting system in the different typologies of buildings.

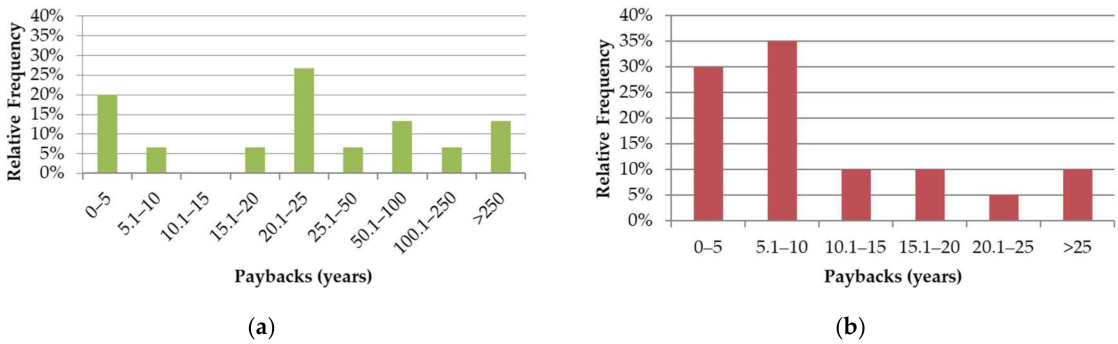


Figure 5. Percentage frequencies of the paybacks in (**a**) residential and (**b**) commercial and public buildings. (**a**) Residential Buildings; (**b**) Commercial and public buildings.

Table 3. Paybacks for the implantation of rainwater harvesting systems in commercial and public buildings.

Reference	Feature	Payback (Years)	Economic Feasibility
[82]	Educational institution	4.8	Feasible system
[99]	Carbel Car Dealership	6.3	Feasible system
	Garra Car Dealership	7.7	
	Catalão Car Dealership	11.1	
	Misaki Car Dealership	9.3	
	Valence Car Dealership	6.8	
	Reauto Car Dealership	11.9	
[112]	Educational institution, alternative 1, unfunded cash flow and simple payback	9.9	Feasible system
	Educational institution, alternative 1, unfunded cash flow and discounted payback	17.7	Feasible system
	Institution of education, alternative 1, cash flow with financing and simple payback	16.3	Infeasible system
	Educational institution, alternative 1, cash flow with financing and discounted payback	21	Infeasible system
	Educational institution, alternative 2 and simple payback	>25	Infeasible system
	Educational institution, alternative 2 and discounted payback	>25	Infeasible system
[113]	Educational institution with replacement of 60% of the water demand for rainwater	1.2	Feasible system
	Educational institution with 100% substitution of water demand for rainwater	0.5	
[114]	System with reservoir of 71 m^3 and percentage of use of 10%	7.8	Feasible system
	System with reservoir of 142 m^3 and percentage of use of 20%	5.3	
	System with reservoir of 215 m^3 and percentage of use of 30%	4.5	
	System with reservoir of 285 m^3 and percentage of use of 40%	4	
	System with reservoir of 355 m^3 and percentage of use of 50%	3.8	

In addition to economic feasibility, the rainwater usage has also environmental benefits. With the implementation of a rainwater harvesting system, the problems of urban drainage are reduced, since the system retains a significant part of the water that would flow through the streets and drains. It would also reduce the use of potable water for non-potable uses, such as garden watering, car washing and sidewalk washing [107,110].

Rainwater usage must also aim at preserving water resources, ensuring water security and encouraging environmentally sustainable actions [109,114]. Sánchez [113] also observed positive impacts on the drainage system, such as flood wave attenuation, the use of reservoirs as retention basins and the improvement of the quality of rainwater in the hydrographic basin. Rainwater retention aims to store the flow temporarily and then release this water in a controlled manner. However, the rainwater reservoir offers a retention capacity of the flow as long as the amount of rainfall does not exceed the available capacity in the reservoir. The greatest benefit observed by the author refers to the control of rainwater quality through the detention of contaminant particles deposited on the urban surface. According to Marinoski et al. [96], the environmental benefits obtained through potable water savings strategies are also influenced by the selection of the components of the system, since most of the energy incorporated in the strategies are related to the production of these components.

Through the studies presented in this section, it was observed that there is no standard for the criteria and variables used in the economic analyses. This assessment is limited by subsidies on water tariffs, energy subsidies and the development of new infrastructures. These costs may render the economic analysis incomplete or unrealistic, as they may present values that are incompatible with reality. Because of this, it is considered necessary to carry out a life cycle cost analysis of the systems, which covers an evaluation of the whole lifespan of the system.

However, in none of the studies presented in this section a comparison between the investment in the implementation of a rainwater utilization system and investment in improving existing systems to reduce water losses was carried out. This comparison could enrich the studies and improve the analysis of the systems to be implemented. In addition to decreasing investments this could also increase savings of water that would be lost in the failure of existing systems.

3.5. Pulic Policies

3.5.1. Brazilian Scenario

Considering the Brazilian government scenario, rainwater harvesting is encouraged by legislation in several cities, either because it is a sustainable strategy or because it is a policy of access to water in semi-arid cities. Those are two different approaches. Brazil has a semi-arid area in the northeast region (highlighted in Figure 6), and the first approach is about how the public policies are related to rainwater harvesting in order to promote water access in such area.

In Brazil, the "National Water Resources Plan" is the instrument that regulates and guides investments and actions related to water management in the country [115]. In this plan, the water management programmes are detailed with a target up to 2020. Related to rainwater, the document only mentions the "One Million Cisterns" programme, which is a federal government investment launched in 2001 to provide access to water for families in the Brazilian semi-arid region by encouraging the construction of cisterns. Gomes et al. [19] evaluated the impact of the programme that installed, up to the time of this publication, 372 thousand cisterns. Another government programme is "One Land Two Waters" (P1 + 2) [116], also aimed at articulating the growth of the Brazilian semi-arid region and complementing the One Million Cisterns Programme. In this social programme, families of farmers receive technologies and training to capture and store rainwater for agricultural purposes, complementing the supply for human consumption purposes that are promoted by the One Million Cisterns Programme.

The "National Water Resources Plan" also mentions that the use of rainwater should be intensified, along with an increase in urban areas with vegetation cover in order to prevent floods in cities. However, any goals or programmes to promote such actions were not quoted.

On the other hand, the second approach is about using rainwater in order to reduce potable water demand, which concerns the rest of the country.

Despite the encouragement and regulation in some cities, Brazil is still taking the first steps in this direction. The NBR 15527 provides guidelines for designing rainwater harvesting systems from the roof of buildings for use in non-potable purposes. Besides being outdated, since it does not provide guidelines for designing the system in a more modern way, the Brazilian standard does not cover guidelines for the safe use of rainwater in potable uses. This would be important since the country has a semi-arid area where rainwater is the main water source in great part of the year, and is used not only for toilet flushing and cleaning but also for cooking, shower and personal hygiene. Besides, the sizing methods, parameters and procedures are much outdated in relation to the international practices.

In July 1999, the Brazilian Association for Catchment, Management and Utilization of Rainwater was founded. The objective of this association is to promote actions aimed at the rational and efficient use of rainwater in Brazil. Since its foundation, it has promoted symposiums and brought together researchers and professionals of the field to discuss the theme. It also has provided books and educational material, spreading information and concepts about the theme. Among the autarchies and institutions researched, it is considered the main Brazilian reference in the theme.

Also in the national scope, in May 2015, a bill was proposed in the Federal Congress House that intends to make mandatory the implantation of rainwater use in buildings larger than 200 m^2 (Federal Law Project # 1750 of 2015). However, this legislation depends on the approval by political leaders to come into force.

However, municipal legislation is more restrictive in this regard, and some cities require implementation by their own legislation. Thus, a survey of the municipal legislations in the country that make the use of rainwater an obligatory practice, or that have some policy for rational use of water in buildings, was carried out. This demonstrates a concern of part of the cities regarding water governance. The result of this survey is shown in Figure 6.

It is possible to notice that many cities are concerned with the issue, and most are not located in semi-arid-Brazilian regions, which indicates an initiative related to sustainable development. Although there is legislation in some of the major cities, as São Paulo, Rio de Janeiro, Brasília and Porto

Alegre, it is still a small number compared to the all national territory. In addition, it is necessary to emphasize that the observed legislation is restricted to the dimensions of the buildings, for example, Florianópolis legislation requires the use in buildings with more than 200 m^2, while Blumenau requires the use in buildings with more than 700 m^2.

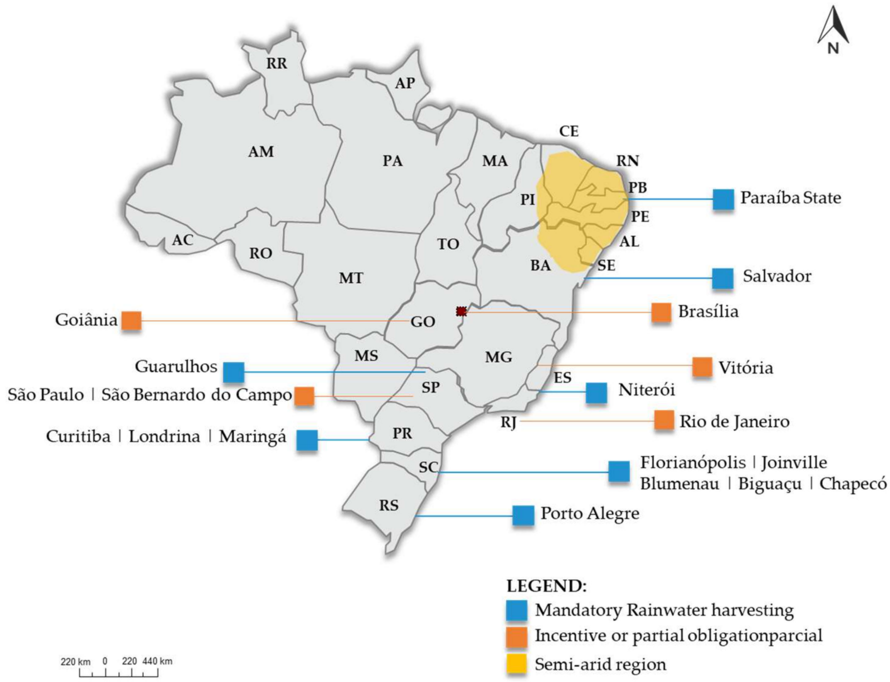


Figure 6. Map identifying cities with own legislation related to rainwater harvesting or water management.

Some other types of legislation related to the use of rainwater have also been observed, as the legislations that improve sustainable practices in buildings and give bonuses, as increase the maximum built area allowed or apply discounts on the Urban Building and Land Tax, commonly called Green Tax (in Portuguese, "IPTU Verde"). It is a reality in some cities, as example of Florianópolis, Santa Catarina (Municipal Decree # 12608 of 2014), Camboriú, Santa Catarina (Municipal law # 2544 of 2013) and Salvador, Bahia (Municipal Law # 8474 of 2013).

Among the legislations observed, the most important are the programmes implemented, particularly the cities of Curitiba-PR (Municipal Law # 10,855 of 2003), São Paulo (Municipal Law # 14,018 of 2005), Campinas (Municipal Law # 12,474 of 2006). The programmes of these cities, called "Programme for Conservation and Rational Use of Water in Buildings", are more specific in relation to the subject and have several measures to instigate the reduction of water consumption and adoption of new water sources, as the use of rainwater. In these programmes, actions to improve the rational use of water are quoted, and for sure, rainwater harvesting is one of the most important practices cited and turned mandatory for every building greater than 200 m^2.

Therefore, it is noted that the Brazilian legislation and public policies related to rainwater harvesting in Brazil are still in an initial phase, and require more intensification by the authorities and leaderships. Most of the initiatives are intended to promote progress in the semi-arid region and supply families. Table 4 presents the list of legislations consulted.

Table 4. List of legislations consulted.

City	State	Type of Legislation	Law Number	Year
Paraíba	PB	State law	N° 9130	2010
Campinas	SP	Municipal law	N° 12,474	2006

Table 4. *Cont.*

City	State	Type of Legislation	Law Number	Year
São Paulo	SP	Municipal law	N° 14,018	2005
Curitiba	PR	Municipal law	N° 10,785	2003
Florianópolis	SC	Municipal law	N° 482	2014
Camboriú	SC	Municipal law	N° 2544	2013
Salvador	BA	Municipal law	N° 8474	2013
Florianópolis	SC	Municipal Decree	N° 12,608	2014
Distrito Federal	DF	Municipal law	N° 3677	2005
Goiânia	GO	Municipal law	N° 17,128	2010
Rio de Janeiro	RJ	Municipal law	N° 3899	2005
Rio de Janeiro	RJ	Municipal Decree	N° 23,940	2004
Rio de Janeiro	RJ	Municipal law	N° 5279	2011
Porto Alegre	RS	Municipal Decree	N° 16,305	2009
Manaus	AM	Municipal law	N° 1192	2007
João Pessoa	PB	Municipal law	N° 12,515	2013
Londrina	PR	Municipal law	N° 11,381	2011
Maringá	PR	Municipal law	N° 910	2008
Vitória	ES	Municipal law	N° 7073	2007
Joinville	SC	Municipal law	N° 220	2006
Blumenau	SC	Municipal law	N° 691	2008
Chapecó	SC	Municipal law	N° 324	2008

Table 4 shows that most of the legislation is municipal law, which depends on the city government to be put into practice. This implies that rainwater practice will depend on the people of the city. The only exception is for the state of Paraíba, a semi-arid area where rainwater is used to assure water access for the people. It is possible to note that most of the cities with legislation on rainwater are from the same state, reinforcing the influence that nearby cities have on each other. It is possible to note that, although Brazil has 27 states, most of them with rainy seasons, only eleven have any city with legislation on rainwater, and most of them are state-capital cities. Besides, the concerning about regulation and legislation on rainwater practices started in the 2000s, i.e., rainwater legislation is very recent in the country.

3.5.2. International Scenario

In the international scenario, it can be noticed that several countries have laws and policies regulating the use and best practices of rainwater harvesting.

In the USA, each state defines its own policies as incentives or mandatory practices. According to NCSL (2018) [117], there are 18 states with legislation related to the theme: Arizona, Arkansas, California, Colorado, Hawaii, Illinois, Nevada, New Jersey, North Carolina, Ohio, Oklahoma, Oregon, Rhode Island, Texas, Utah, Virginia, Washington, U.S. Virgin Islands. As an example, since 2009, Colorado has legislation that creates a pilot project about rainwater harvesting (HOUSE BILL 1129, 2009), and in 2015 the guidelines of this pilot project were adapted (HOUSE BILL 1016), and in 2016 the practice was authorized for non-potable use in houses (HOUSE BILL 16-2005). Since 1964, the facilities built in U.S. Virgin Islands must have at least one support water supply system for reducing the potable water demand, such as a rainwater harvesting system (U.S. Virgin Island Code Title 29 §308). It can be noted that the legislation in the USA is always changing, adapting to the social reality [117].

In the European Union, a report commissioned by The European Parliament and The Council addressing the challenge of water scarcity and droughts in Europe reported that rainwater harvesting is a practice to be considered important in order to improve the water performance in buildings, jointly with water reuse. In the same report, it was stated that Germany has supported rainwater harvesting in at least 1/5 of the cities with legislation and incentives [118].

In the UK, the practice has been supported since ancient years. In 2006 a governmental document that encourages sustainable practices in residential buildings was added to the Code for Sustainable Homes, and was in force until 2015 [119]. The UK has the standard BS 8515:2009 Rainwater Harvesting Systems-Code of Practice that outlines guidelines to develop projects and installation for rainwater systems, and the regulation of Water Supply (Water Supply—Water Fittings—Regulations 1999) that outlines parameters for the water quality.

In Australia, the government launched a document in 2004 that compiles guidelines for rainwater harvesting practices [120]. In this Guidance document, it was mentioned that a great number of Australian cities have legislation of incentives related to rainwater harvesting, including Sydney. The regions of Queensland and Northern Territory have a specific regulation related to mosquito control.

Given the above, it is possible to note that regulating rainwater harvesting practices is a global concern. Basically, it is impossible to summarise all the world legislation about rainwater harvesting, mostly because the legislations showed to be inherent to the municipal scope. It was possible to note, by comparing the international with the Brazilian legislation, that Brazilian legislation is focused in turning the practices mandatory while a great amount of the international legislation is focused in establishing financial incentives and guidelines to the appropriate implementation of the systems.

4. Conclusions

This article aimed to present the state of the art on rainwater harvesting in Brazil. The theme was analysed from the perspective of the Brazilian scientific production, and studies were used to analyse the potential for potable water savings due to rainwater usage, the economic feasibility of the system and the scope of public policies. Based on the evaluation developed in this article, the main conclusions are as follows:

- Regarding the scientific production, it can be concluded that it follows the international pace. In both spheres, national and international, there was an expressive increasing on the number of studies on rainwater in the past five years.
- Most national searches on rainwater harvesting were developed based on the benefits of the system (potential for potable water savings, flood minimisation), social acceptability, economic viability, environmental impacts, and system design. No search on the use of future rainfall data has been addressed.
- The studies that focused on potable water savings show that the potential for potable water savings is related to the type and use of the building, varying for each case. On a global view, the results of the reviewed works showed an average potential for potable water savings equal to 53% of the total water demand.
- Rainwater harvesting systems for non-potable purposes result in high potential for potable water savings. However, they will perform better when taking into account the control of leakages and losses caused by carelessness or poor maintenance in buildings (mainly institutional buildings).
- Researches on water quality have shown that rainwater presents good quality for non-potable uses. For drinking purposes, disinfection is recommended. Nevertheless, in the semi-arid region rainwater is used for potable purposes considering only first flush equal to 1.0 mm. In addition, despite the national "One Land Two Waters" programme, the incorrect use of the systems still causes water degradation. In this sense, there is a lack of research on system maintenance and performance.
- The studies that focused on economic feasibility analysed the payback and showed that it varies according to the type/use of the building, if compared to other variables. The major investment occurs in the installation phase, and the tank represents the major cost. In general, the payback was more attractive for commercial buildings if compared with residential buildings. Of course, other parameters also influence the system feasibility, as climate variability and human interaction.

- The public policies about rainwater focused on the rainwater harvesting to provide water supply for the semi-arid region. On the other hand, there are laws turning rainwater harvesting mandatory in some cities and other laws that promote the practice, and both types show an environmental concern by the municipal administrations. Despite the existence of legislation about rational water use in some cities, it is not present in great part of the country.
- The effort to take rainwater harvesting systems into account by institutions and the general public is valid when considering the overall benefits they can provide. However, it is not a suitable solution for all types of buildings and all locations. Thus, instead of a mandatory use of rainwater harvesting (through laws), the environmental impacts of large-scale deployment should be evaluated and compared with centralised supply systems and other types of decentralised systems.
- As a general conclusion it is noted that both the potential for potable water savings and the economic feasibility were greater in offices and public buildings in Brazil, but, there is no legislation about rainwater use in these buildings. Thus, public policies should improve and intensify the rainwater harvesting in such buildings. Despite the economic benefits for public administration, rainwater harvesting in public buildings will serve as an example for society, educating people and acting in the social dimension of sustainability. However, a detailed analysis is always recommended in order to produce a good reliability system and assure the economic and environmental feasibility.
- It was observed that there are few studies that used the experimental process and/or innovative approach related to rainwater harvesting practice. This is probably due to the lack of investments for research.

Future works:

- Climate change is an important issue and very impacting on rainwater harvesting, but studies on how this impacts rainwater harvesting in Brazil were not found. Therefore, it is recommended that studies on the influence of the climate change on rainwater practices in Brazil be carried out. The IPCC weather scenarios could be used for this purpose.
- Studies about technologies and practices to improve rainwater harvesting are also encouraged. It is also recommended that actual rainwater systems be analysed in order to improve and update regulations and laws.

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