Journal of Water Supply: Research and Technology—AQUA | 66.1 | 2017

Economic feasibility of rainwater harvesting systems: a systematic literature review

Gabriela C. R. Pacheco and Marcus A. S. Campos

ABSTRACT

Rainwater harvesting (RWH) systems are increasingly being used as an alternative source of water supply. However, their installation is not often financially feasible. The feasibility analysis of such investments is carried out by traditional techniques that have uncertainty limitations. Thus, the objective of this study is to describe how the studies concerning the economic feasibility of RWH systems have been conducted, thus identifying trends of current studies through a systematic review. We performed a literature search of published articles and, using defined inclusion criteria, 30 relevant articles were selected. We noted an increase in publications on this issue in recent years, and we demonstrate that the feasibility of the systems is frequently calculated by discounted cash flow methods. Several studies seek to incorporate uncertainties with an analysis of sensitivity, and only one study uses real options analysis. With these analyses, we provide recommendations for future studies and an overview of the current literature.

Key words | feasibility, rainwater harvesting, systematic literature review

Gabriela C. R. Pacheco
Marcus A. S. Campos (corresponding author)
School of Civil and Environmental Engineering,
Federal University of Goiás,
Goiania,
Brazil
E-mail: *marcussiqueira@gmail.com*;
marcusscampos@gmail.com

INTRODUCTION

Water conservation is an important issue in sustainable buildings and a basic strategy in facing current water shortages. It consists of demand and supply management (Sautchuk *et al.* 2006). Among several options for water conservation in buildings, rainwater harvesting (RWH) systems are very attractive (Özdemir *et al.* 2011; Domènech *et al.* 2013; Vargas-Parra *et al.* 2013) due to the simplicity of construction with regular materials, the use of simplified treatments and the different possible uses of this resource. This technique is also valuable for urban planning because it mitigates strain on the drainage system by reducing the volume of rainwater in the drainage network, decreasing rainwater disasters (Lixin *et al.* 2010).

RWH systems are becoming increasingly common in several locations around the world (Jones & Hunt 2010). The rediscovery of these systems was driven by the high values of water tariffs, the scarcity of this resource and the formation of national and international associations that helped to disseminate their implementation (Gouvello *et al.* 2014).

Thus, RWH systems have become common in many countries like Germany where it is estimated there were 1.5 million cisterns in 2010 (Sieker 2010) and in Australia where 26% of the households have a RWH system installed (Smith 2016). It is noticed that the number of implementations of these systems in the last two decades has increased. The reasons for this vary by country. In areas with water scarcity such as India (Shivakumar 2007), South Africa (Kahinda *et al.* 2007) and Brazil (Gomes *et al.* 2012), governmental programs encouraged RWH system deployment in rural areas. In other situations there has been establishment of financial support to intensify the implementation of RWH as in Japan (Sacadura 2011) and Australia (Rahman *et al.* 2012). Moreover, some countries required RWH system construction by law such as in the United States, India, Sri Lanka and some cities of Brazil (Gouvello *et al.* 2014).

Even if the environmental benefits are more valuable than the economical savings generated by these systems, the financial

doi: 10.2166/aqua.2016.048

feasibility remains the main item for decision making in the deployment of an RWH system, especially in developing countries where economical resources may be scarce. The financial feasibility of the implementation of this type of system should be conducted before construction, and the result of this analysis is the main obstacle to the use of RWH systems (Islam *et al.* 2010; Matos *et al.* 2010; Kim *et al.* 2014), as construction, maintenance and operation costs are normally uncertain.

To determine the feasibility of an RWH system, several aspects of information are essential, including the demand and supply of rainwater, the reservoir volume and its efficiency, total costs of the system, water tariffs and several economic variables such as the required rate of return, inflation and the adjustment of the water tariff. In addition, we must select an economic evaluation method of investment that values, in a rigorous way, a project through decision-making processes (Copeland & Antikarov 2001).

Investments in RWH systems are characterized by uncertainties that come from changes in the rainfall volume, the demand for rainwater and the readjustment of water rates. These values become more unpredictable with climate change and will directly affect the feasibility of these systems. Therefore, the methods used to calculate the financial index must be able to consider these uncertainties as well to value them during the economic feasibility analysis.

Thus, this paper seeks to describe how the studies concerning the economic feasibility of RWH systems have been conducted and published in international journals.

METHODOLOGY

We performed a systematic literature review (SLR) on the economic evaluation methods used to assess RWH systems' viability in order to obtain a better understanding of how these analyses are accomplished. SLR is a method used to identify and evaluate the available research information on a given research question. Therefore, it provides an overview of a specific area of knowledge, and it is possible to verify the existence of studies on a given topic as well as detect gaps in knowledge and areas for future studies (Petticrew & Roberts 2008; Kitchenham 2011).

Systematic review increases the methodological rigor, as its process of implementation must be replicable and transparent (Tranfield *et al.* 2003). The procedure adopted to perform the SLR was based on the Cochrane Handbook for Systematic Reviews of Interventions (Higgins & Green 2011) in addition to other literature (Tranfield et al. 2003; Brereton *et al.* 2007). This procedure consists of the stages shown in Figure 1 (Tranfield *et al.* 2003; Higgins & Green 2011).

First, we set the subject of research so that the following questions would be answered:

- What methods were used to analyze the feasibility of RWH systems?
- What considerations were adopted in these analyses?
- Are the RWH systems considered to be economically feasible?

We conducted the search for publications in the following databases: Engineering Village (Compendex), Science Direct, Scopus and Web of Science. It is noteworthy that only journal articles were part of the research. There are several technical reports, guidelines and standards that have been published with the purpose of mitigating the implementation of RWH systems in their respective region (Texas Water Development Board 2005; Thomas & Martinson 2007; Brazilian Association for Technical Standards

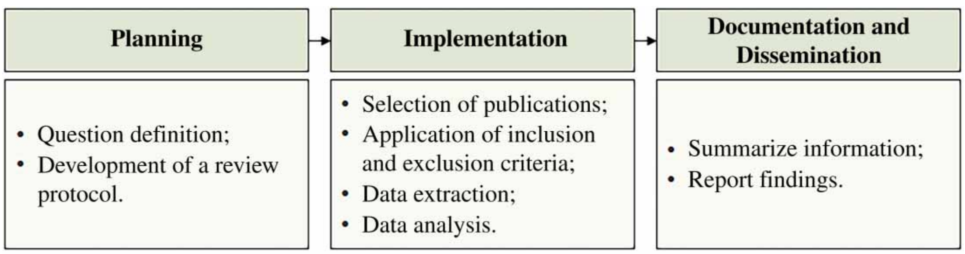

Figure 1 | Stages of SLR (Tranfield *et al.* 2003; Higgins & Green 2011).

(ABNT) 2007; Australian Government 2008; Government of Ontario 2010; Macomber 2010). Although important, they were not considered in this research.

The first step was to determine keywords to find publications related to the topic under study. From the initial analysis of certain relevant articles, we found that the majority of uses of the term 'RWH' were in relation to rainwater utilization systems. However, several articles used the term 'rainwater use' or only 'rainwater'; thus, we defined this term as one of the strings if it included either of these variations.

We also found that there are numerous terms related to economic evaluation: 'economic feasibility', 'financial analysis', 'investment feasibility', 'payback period', 'net present value (NPV)' and 'sensitivity analysis'. After several tests, we verified that the word 'feasibility' was the most frequently used. We adopted the following search string: (Rainwater) AND (Feasibility). It should be noted that the terms searched were in the title, abstract and keywords of existing publications in the databases. We did not make any limitations related to the area of knowledge since we observed that several papers were in the multidisciplinary studies category. There was also no restriction on the publication's year or the type of publication. Therefore, we selected articles from both journals and conferences in the databases.

We excluded any repeated texts found using different databases. By reading the titles first followed by the abstract and complete text, we also discarded the irrelevant items for the defined issues. Articles in another language and those that did not have access to full text through the journals subscribed to by the university were also excluded.

We also excluded articles that analyzed the feasibility of rainwater use for agricultural purposes (Yuan *et al.* 2003; Ngigi *et al.* 2005; Wotessa *et al.* 2006). Studies on the influence of water quality in sustainable systems (Hammes *et al.* 2000; Jordan *et al.* 2008; Jain & Chundawat 2011), works related to the infiltration of rainwater (Alfakih *et al.* 1999), articles on the technical feasibility of rainwater systems (Han & Ki 2010; Lixin *et al.* 2010), urban rainwater management (Zeng *et al.* 2007), socioeconomic analysis of RWH systems deployment (Zhang *et al.* 2009b; Islam *et al.* 2011) and papers that were only concerned with the potential for water saving (Appan 2000; Matos *et al.* 2013) were also excluded.

After selecting the adherent articles, we extracted the following data: year of publication, research strategy, keywords used, impact factor of the journals, countries where the studies were realized, institutional affiliations of those who did the research, methods used to determine economic feasibility and the considerations adopted in each study. We conducted data evaluation to summarize the information and provide an overview of this research issue.

RESULTS

We performed the search in March 2015 and we updated it in August. We found 478 publications and, by the selection criteria chosen, 30 adherent publications to the research were selected, as illustrated in Table 1.

The distribution of publications in the databases is illustrated in Figure 2. In Science Direct, we found the smallest number of items in the initial search; however, almost one third of them proved to be adherent to the subject of this study, a much greater proportion than that found in other databases.

Among the selected papers, 25 articles were published in journals while the other five were conference publications. To assess the quality of the articles published in journals, we analyzed the impact factors of the journals as illustrated in Figure 3. We considered the 5-year impact factors reported by Journal Citation Reports (JCR) and the highest impact factor found was 6.279. The impact factor range for 60.87% of the articles found was between 2.831 and 3.598.

Table 1 | Application of selection criteria for papers

Papers previously selected	478
Duplicated papers	−221
Reading titles	−121
Reading abstracts	−84
Full papers not available	−12
Reading full papers	−19
Snowballing sampling	+9
Total adherent articles	**30**

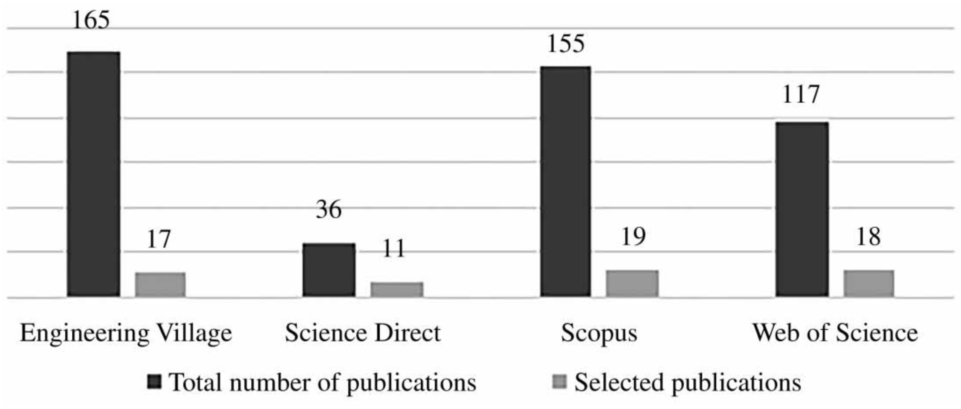

Figure 2 | Number of publications in each database.

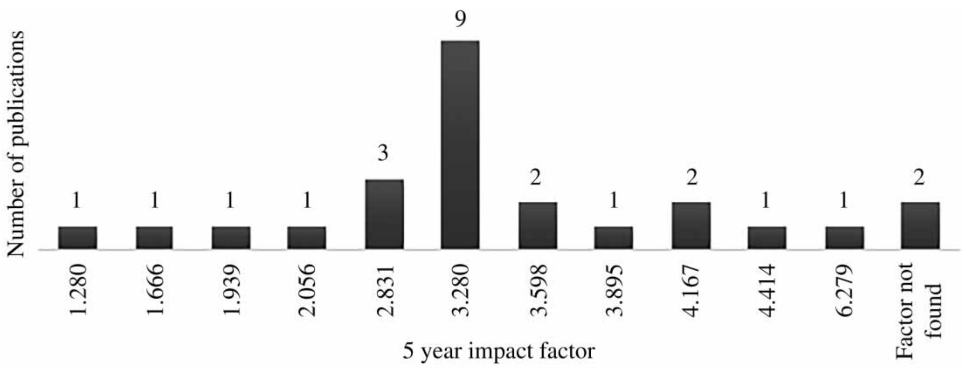

Figure 3 | JCR impact factors of the selected papers.

We evaluated the keywords used in each article, and we verified that there is no standardization of terms applied to articles for this research question. In total, we found 100 different keywords, and most were used only in one article. The keywords that could be applied more than once are reported in Figure 4. They were divided into terms related to rainwater utilization systems and terms of economic evaluation. Furthermore, most of the terms that are not in Figure 4 refer to the particularities of each study related to the place and climate where the search was conducted.

Figure 5 shows the distribution of publications by year. It is possible to see that the issue studied is recent. The first article was published in 2000 and we observe that 56.67% of all research was published in the last five years. This increase in publication is probably caused by water scarcity in many areas of the globe.

We analyzed the countries where each search was performed (Figure 6). We verified that Brazil is the country with the most studies related to the feasibility of RWH systems, followed by Australia and England.

Other analyses concerned the relationship between the country and year of occurrence of the study (Figure 7). The first two searches occurred in England, but it was not possible to establish a relationship among the variations for articles published from one country to another. In Brazil, for example, there has been constant publication since 2007, and the last full year (2014) had the highest number of publications.

In addition to assessing the country where the research was developed, we evaluated the institutions from whence the studies occurred, as shown in Figure 8. By this evaluation, we verified that 39 institutions researched the feasibility of RWH systems, and among these institutions, 23 were universities. We verified that the institutions often held studies together, even in different countries. Thus, there are several countries where

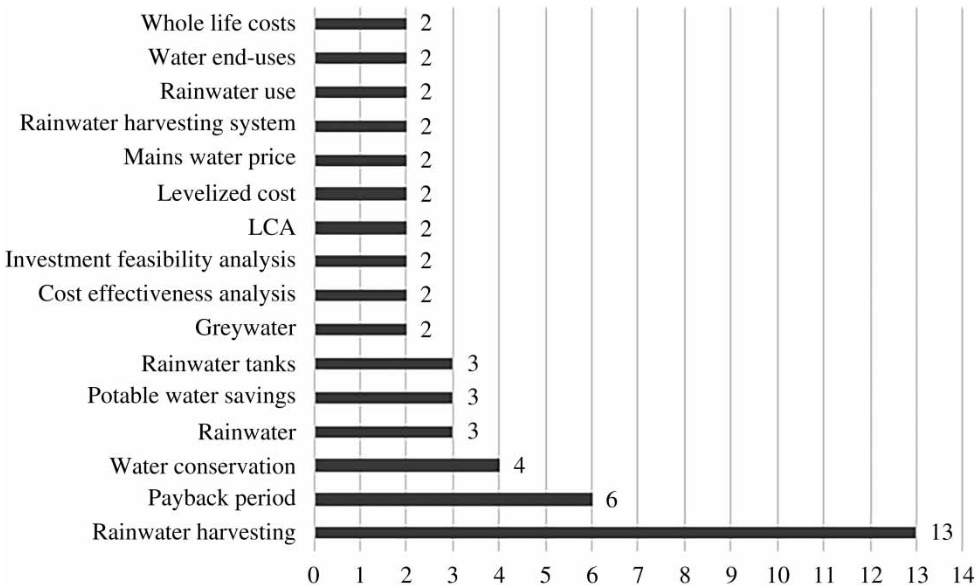

Figure 4 | Frequency of the most important keywords found.

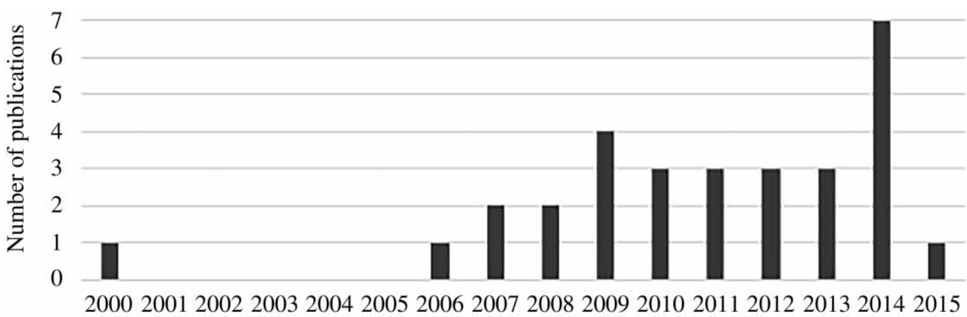

Figure 5 | Distribution of publications per year.

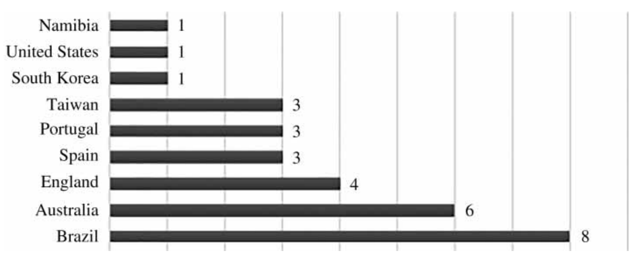

Figure 6 | Distribution of publications per country.

RWH feasibility has not yet been studied, such as China, Colombia and Switzerland. However, several of their institutions are studying this subject elsewhere. In addition, Namibia has been the subject of a study, but it does not have any institution that has studied the research issue. The United Kingdom and Brazil stand out as countries with the largest number of institutions researching this subject.

We also examined the approach of each publication, as identified in Table 2. The most relevant articles for this research were case studies that verified the feasibility of a specific RWH system, or of several RWH systems with different locations or different buildings from a single location. One case studied assesses the feasibility of a system in use compared with the value set in design.

Publications that compare the methods for sizing the reservoir by calculating the viability of each system were also selected. Several studies researched which water conservation technique is the most viable. Others proposed a

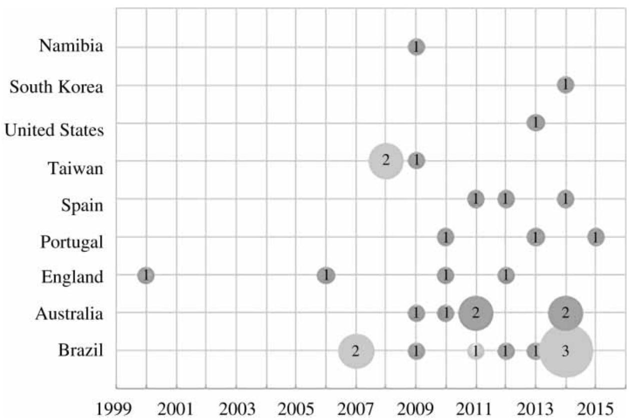

Figure 7 | Number of articles published per year in each country.

procedure for determining the viability based on the evaluation methods already mentioned.

The analyzed articles included different uses of rainwater and they considered different types of buildings, including public, residential and commercial, as illustrated in Figure 9. Most of the papers performed studies in residential buildings; thus, the main use of water was toilet flushing, followed by irrigation and laundry. It must be noted that the water demand for irrigation is variable, and it is higher in periods when the amount of rain is reduced. Thus, rainwater would be more appropriate for uses with constant demand that lead to a smaller rainwater tank and greater economic benefits (Farreny *et al.* 2011).

We could not verify which typologies were more viable, even using different tariffs that are usually charged. Only in domestic and small systems, which normally have low demand, is it expected that the economic benefits are insignificant (Ghisi & Schondermark 2013; Santos & Taveira-Pinto 2013).

One way to increase the RWH system viability is the design of collective systems, such as, for example, at the neighborhood level. Usually, in this type of system, the economic viability is higher than in the case of single buildings (Farreny *et al.* 2011; Santos *et al.* 2011; Morales-Pinzón *et al.* 2012). The time of construction also interferes with the feasibility, as systems deployed during building construction are more feasible than retrofit actions (Farreny *et al.* 2011).

Other information we collected from the selected papers included the economic evaluation method used in each study, as identified in Figure 10. It is worth noting that the number of times that the methods were employed does not match the total of items considered relevant because many studies used more than one technique.

We confirm that, usually, the feasibility of RWH systems is determined by the use of traditional methods based on discounted cash flow (DCF) analysis; the payback approach is the technique most used. This usage is due to the simplicity of its application. However, the use of this indicator to determine the feasibility may present some flaws, as it does not consider the period after the recovery of the initial investment and has difficulty in defining the length of time for which the investment is regarded as feasible. Moreover, this technique is not considered appropriate when it has to compare more than one investment option; however, it is this analysis that is made in many articles. However,

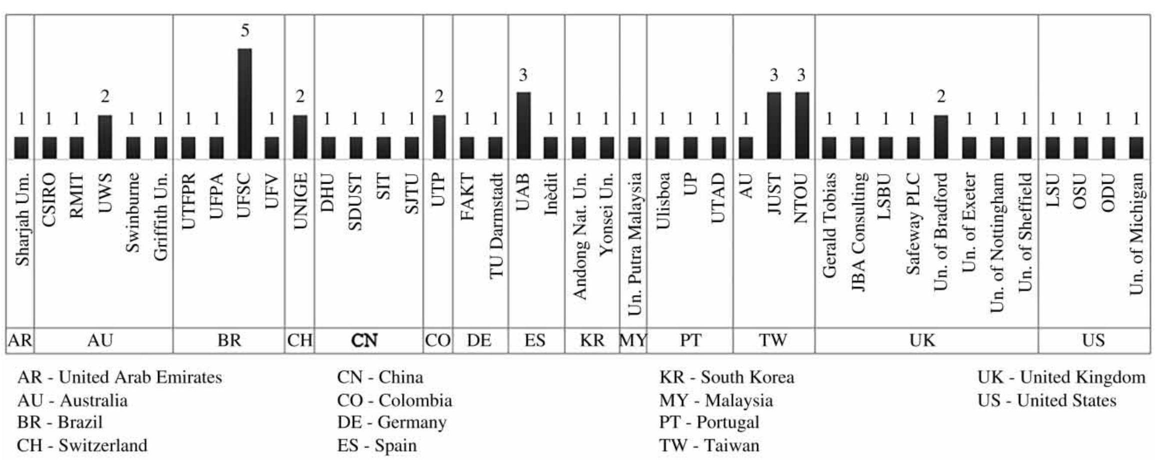

Figure 8 | Distribution of publications by institution and country.

Table 2 | Approach of publications

RWH systems viability	**22**
Case study of a single RWH system	10
Chilton *et al.* (2000), Chiu *et al.* (2008), Chiu et al. (2009a), Ghisi *et al.* (2009), Sturm *et al.* (2009), Matos *et al.* (2010); Moreira Neto *et al.* (2012), Shah *et al.* (2013), Yoshino *et al.* (2013), Kim *et al.* (2014).	
Case study of several RWH systems	11
Zhang *et al.* (2009a), Roebuck *et al.* (2010), Tam *et al.* (2010), Farreny *et al.* (2011), Khastagir & Jayasuriya (2011), Morales-Pinzón *et al.* (2012), Ghisi & Schondermark (2013), Gurung & Sharma (2014), Hajani & Rahman (2014), Morales-Pinzón *et al.* (2014), Silva *et al.* (2015).	
Case study of an existing system	1
Ward *et al.* (2012).	
Economic feasibility to aid in decision-making	**6**
Comparison of sizing methods	2
Imteaz *et al.* (2011), Santos & Taveira-Pinto (2013).	
Comparison of water conservation techniques	4
Ghisi & Ferreira (2007), Ghisi & de Oliveira (2007), Ghisi *et al.* (2014), Gois *et al.* (2014).	
Technical proposal to assess the feasibility of RWH systems	**2**
Roebuck & Ashley (2007), Chiu & Liaw (2008).	2

according to Table 3, we can confirm that most of the selected publications used more than one method of economic evaluation in their studies.

Only one study in South Korea used real options analysis (ROA) as an economic evaluation method for RWH systems (Kim *et al.* 2014). This technique creates option pricing by establishing a value for managerial flexibility, thus enabling the adjustment of the future actions of a company according to the changes that may occur during its lifetime (Dias 2014). Then, an investment that had no economic return when assessed by traditional methods can become viable.

This lack of analysis indicates a potential topic for future studies. As this study is the only method found that assesses uncertainties and administrative flexibility, ROA would be the most appropriate technique for such assessments.

Through the results of the studies, we were able to verify that more than one scenario is used to determine the feasibility. In the attempt to clarify how the different variables can change the economic viability of a system, the researchers created scenarios varying values of demand, water price, discount rate, volume of rainwater tanks and even the system configuration (Zhang *et al.* 2009a; Matos *et al.* 2010; Roebuck *et al.* 2010; Farreny *et al.* 2011; Khastagir & Jayasuriya 2011; Santos & Taveira-Pinto 2013; Morales-Pinzón *et al.* 2014). Then, variations of economic indicators are obtained instead of a single value, similarly to a sensitivity analysis. However, in many articles that reported variable results, it was not mentioned that they performed this sensitivity analysis (Farreny *et al.* 2011; Khastagir & Jayasuriya 2011; Santos & Taveira-Pinto 2013).

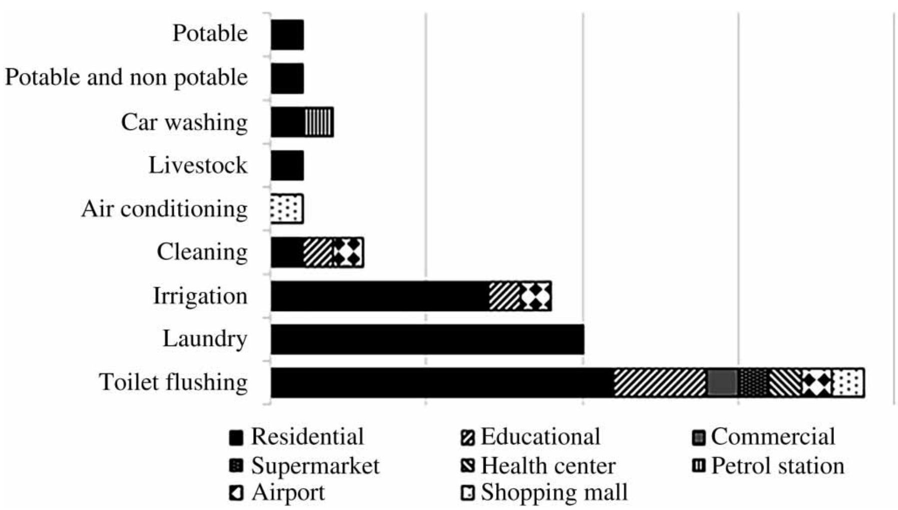

Figure 9 | Water use per building.

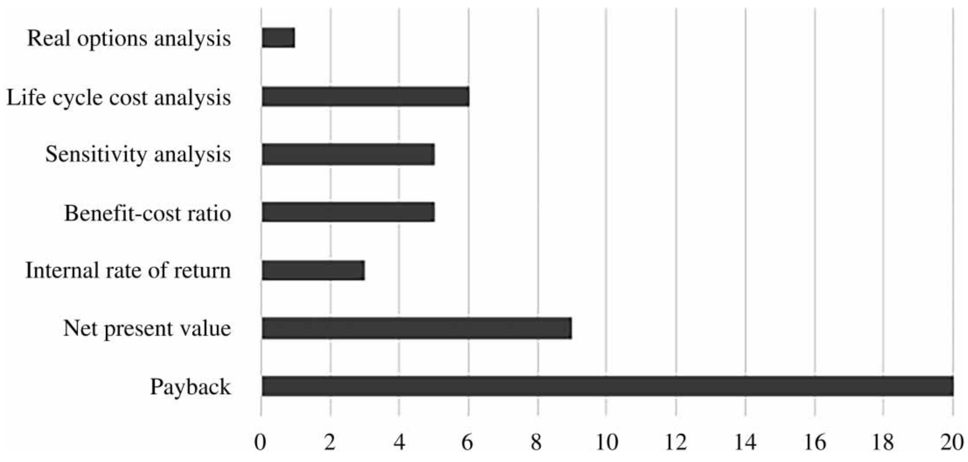

Figure 10 | Economic evaluation methods.

Despite the flaws already mentioned, the payback method is still used. Several studies in recent years verify the feasibility using only this technique (Shah *et al.* 2013; Gois *et al.* 2014; Silva *et al.* 2015). However, more recent work uses the payback period associated with other economic evaluation methods (Yoshino *et al.* 2013; Ghisi *et al.* 2014; Morales-Pinzón *et al.* 2014).

Table 3 also illustrates how parameters such as lifetime and discount rate may vary in the verified studies. The appropriate discount rate must be chosen carefully, as it represents the relationship between the money now and in the future and defines the project risk (Suttinon & Nasu 2010). Its value directly affects the viability of the system (Khastagir & Jayasuriya 2011).

The lifetime values established in Brazil are lower than in other countries in which this parameter varies from 25 to 60 years. Brazilian studies adopted values from 15 to a maximum of 30 years.

Water tariffs cannot be compared because they are in a different currency and they highlight local conditions. However, from the low values found, we can assume there is a tendency for water to be subsidized in the countries where the studies were conducted. The value of the water tariff tends to increase at a higher rate than inflation (Silva *et al.* 2015) and the consideration of these changes in the publications is very variable.

Several articles assume a single inflation rate for water, energy and other costs (Matos *et al.* 2010; Khastagir & Jayasuriya 2011; Moreira Neto *et al.* 2012; Ghisi *et al.* 2014; Morales-Pinzón *et al.* 2014) whereas others consider that the rate of return has already incorporated this inflation into water supply systems (Chiu & Liaw 2008; Sturm *et al.* 2009; Zhang *et al.* 2009a; Silva *et al.* 2015). Adjustment is also adopted in other jobs (Kim *et al.* 2014). The selection of such values can influence the results of the feasibility analysis due to the value of water interfering with the economic evaluation, wherein as the cost of water increases, so does the viability of the system (Khastagir & Jayasuriya 2011).

Several analyses simplify some costs. Most articles disregard indirect costs such as operational and capital costs of traditional water supply and the resultant cost of reduction in flood damage. To capture the externalities is a challenge for economic evaluation and when these externalities are not taken into account the decision making can be incorrect (Sharma *et al.* 2015).

Reduced energy consumption achieved by the installation of an RWH system is also disregarded but, when considered, can result in better economic indicators (Chiu *et al.* 2009b; Olmos & Loge 2013). The energy must be considered in the construction, operation and maintenance phases of RWH systems, and this consideration is a decisive item in the decision to deploy these systems (Vieira *et al.* 2014).

Through the analysis of the various items used in the economic evaluations of RWH systems, we perceived that many studies simplify this analysis, ignoring or adopting values that do not correspond to the reality of each study, failing to include items such as inflation, increase in the

Table 3 | Review of the papers on the economic feasibility of RWH systems

Reference	Location	Method	Results	Water savings (%)	Uses	Discount rate	Lifetime (years)	Price of water	Increase of water price
Chilton *et al.* (2000)	Greenwich, England	Payback	4 to 12 years	18.5 to 23.7	Toilet flushing			0.94 £/m^3	
Chiu & Liaw (2008)	Taipei, Taiwan	BCR	0.86 to 1.22		Toilet flushing	3% per year	25	17 NT$/m^3	
Ghisi *et al.* (2009)	Brasília, Brazil	NPV Payback	−4,155.45 to 24,744.64 R$ 31 to 165 months	7.4 to 57.2	Washing vehicles	1% per month	15		
Zhang *et al.* (2009a)	4 cities, Australia	Payback	8.6 to 21.9 years	7 to 32.3	Non-potable uses	6.5% per year		0.81 $AU/m^3	
Farreny *et al.* (2011)	Granollers, Spain	NPV Payback	−868.304 to 447.599 € 27 to more than 60 years	35.7 to 43.9	Laundry	0 and 3% per year	60	1.12 and 4 €/m^3	
Khastagir & Jayasuriya (2011)	Greater Melbourne, Australia	Payback	14 to 46 years		Toilet flushing, laundry and irrigation	5 to 10% per year	40	0.9 to 1.4 $/m^3	
Moreira Neto *et al.* (2012)	Confins, Brazil	NPV Payback	−1,057,200.24 to 1,022,141.17 US$ 1.4 to >30 years	66 to 100	Toilet flushing, cleaning and irrigation	1% per month	30	2.36 US$/m^3	6% per year
Yoshino *et al.* (2013)	Belém, Brazil	NPV Payback	−39,096.14 to −36,526.13 R$ more than 20 years	16.53 and 30.88	Toilet flushing	13.28% per year	20		
Morales-Pinzón *et al.* (2014)	16 cities, Spain	NPV BCR Payback	−2,370.6 to 612.1 € 0.1 to 3.1 5.5 to 204 years	8 to 96	Laundry	5% per year	50	0.85 to 2.65 €/m^3	3% per year
Kim *et al.* (2014)	Jeonju South Korea	ROA	Option value: US$998,000		Toilet flushing	5.14% per year	35	$ 1.26	5.09% per year
Silva *et al.* (2015)	Porto and Almada, Portugal	Payback	14.137 to 27.035 years	17 to 95	Toilet flushing, laundry and irrigation		50		

NPV, net present value; BCR, benefit-cost ratio; ROA, real options analysis.

price of water, energy consumption, water tariff level and discount rate. Inadequate consideration of these items can overvalue or undervalue the economic advantages of deploying these systems. The suitable choice of values for these parameters, coupled with the use of a calculation method, is essential for obtaining economic indicators that are closer to reality.

DISCUSSION AND CONCLUSIONS

According to the analysis of data obtained in this SLR, we found that most of the techniques used were based on DCF such as: NPV, internal rate of return and benefit-cost ratio (BCR). These investment valuation methods express the net result of the sum of inputs and outputs provided during the lifetime of a project (Abensur 2012).

Often, these techniques do not lead to better strategic decisions (Yoshimura 2008) since they evaluate the uncertainty using a discount rate that is set arbitrarily, and they do not consider administrative flexibility.

Thus, several studies have begun to perform sensitivity analyses to determine the impact of different variables that affect the viability of an investment in RWH systems (Chiu *et al.* 2009a, 2009b; Morales-Pinzón *et al.* 2014; Silva *et al.* 2015).

However, by evaluating the sensitivity to different design parameters, we are not able to consider the managerial flexibility that can transform the uncertainties into strategic opportunities in the decision-making process during construction. The flexibility maximizes the opportunity of a worthwhile investment as it increases the potential gains and limits losses from the management of initial expectations (Minardi 2000).

In an attempt to correct these flaws presented by the traditional methods, one alternative approach would be ROA. This approach is a modern method of investment analysis applied to real or tangible assets under technical uncertainty and market conditions (Dias 2014).

Many applications of this method have been observed in various fields, especially in those with high volatility and general water supply systems show considerable volatility. ROA is already used to determine the feasibility of large supply systems (Suttinon & Nasu 2010; Park *et al.* 2014) and can be used for smaller systems, such as a RWH system.

In the economic evaluation of water supply systems uncertainties in the water tariff (Michailidis & Mattas 2007), demand (Jie *et al.* 2009; Suttinon & Nasu 2010) or precipitation (Kim *et al.* 2014; Park *et al.* 2014) are considered, and to deal with them, different deployment strategies have been created such as the option to extend, postpone or even abandon the investment. Thus, through a pricing model of options, such as the binomial method, the Black Scholes model or Monte Carlo simulation, the value of the option and the economic indicator can be calculated.

RWH systems are subject simultaneously to uncertainties due to the unpredictability of rainfall patterns, demand values and water tariffs. Therefore, there is a need for the development of research on the applicability of this technique to RWH systems, defining what kind of uncertainty must be employed in each case, and determining which options valuation method is most suitable for these studies. The use of ROA can be a more appropriate method for analysis of investments with these kinds of uncertainties. This method is not usually employed because its analysis is more complex and there is not a standardized method that can be applied for any investment analysis.

We also verified that the variables used for economic evaluation, such as inflation, increase of the water price rate, water tariff level and discount rate, vary between the different research studies and they must be chosen carefully since these inputs may overvalue or undervalue the economic gains from the implementation of a system.

Likewise, the scaling parameters of the RWH system, such as precipitation, demand and runoff coefficients, may affect the viability of the system since they determine the volume of the reservoir and the water volume saved. Therefore, we should adopt appropriate values of all these parameters, according to each specific case, to have an economic evaluation that approximates reality and ensures the right decision is made about the deployment of such systems.

It must be noted that the search for articles was limited due to keywords definition and the 30 selected papers cannot represent all the studies on this topic. The chosen research string could have provided a more comprehensive search. For example, we could mention the names of economic evaluation techniques as strings, combined with the word 'Feasibility'.

However, an increasing tendency for research in this area reflects the current concern about water conservation and it demonstrates an effort to show that, beyond environmental gains, RWH can generate economic benefits.

ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the Coordination for the Improvement of Higher Education Personnel (CAPES) Foundation for the master research scholarship.

REFERENCES

ABNT Associação Brasileira De Normas Técnicas (Brazilian Association for Technical Standards) 2007 *NBR 15527: Água de chuva – Aproveitamento de coberturas em áreas urbanas para fins não potáveis – Requisitos (Requirements of Rainwater Harvesting of Surface Area in Urban Areas for non-Potable Uses).* Rio de Janeiro.

Abensur, E. O. 2012 Um modelo multiobjetivo de otimização aplicado ao processo de orçamento de capital (A multi-objective optimization model applied to the capital budget process). *Gestão & Produção, São Carlos* **19** (4), 747–758.

Alfakih, E., Barraud, S. & Martinelli, I. 1999 A study of stormwater infiltration system feasibility and design. *Water Science and Technology* **39**, 225–231. doi: 10.1016/S0273-1223(99)00034-7.

Appan, A. 2000 A dual-mode system for harnessing roofwater for non-potable uses. *Urban Water* **1**, 317–321. doi:10.1016/S1462-0758(00)00025-X.

Australian Government 2008 *Rainwater Tank Design and Installation Handbook*. Arris Pty Ltd, Sydney, Australia. p. 111.

Brereto, P., Kitchenham, B. A., Budgen, D., Turner, M. & Khalil, M. 2007 Lessons from applying the systematic literature review process within the software engineering domain. *Journal of Systems and Software, Software Performance 5th International Workshop on Software and Performance*. **80**, 571–583. doi: 10.1016/S0273-1223(99)00034-7.

Chilton, J. C., Maidment, G. G., Marriott, D., Francis, A. & Tobias, G. 2000 Case study of a rainwater recovery system in a commercial building with a large roof. *Urban Water* **1**, 345–354. doi:10.1016/S1462-0758(00)00032-7.

Chiu, Y. R. & Liaw, C. H. 2008 Designing rainwater harvesting systems for large-scale potable water saving using spatial information system. In: *Computer Supported Cooperative Work in Design IV, Lecture Notes in Computer Science*. Springer, Berlin, Heidelberg, pp. 653–663.

Chiu, Y. R., Liaw, C. H. & Chang, H. H. 2008 GIS-based decision supporting system in hydraulic simulation and economic analysis for rainwater harvesting design. In: *12th International Conference on Computer Supported Cooperative Work in Design – CSCWD*, pp. 1133–1138. doi:10.1109/CSCWD.2008.4537139.

Chiu, Y. R., Liaw, C. H., Hu, C. Y., Tsai, Y. L. & Chang, H. H. 2009a Applying GIS-based rainwater harvesting design system in the water-energy conservation scheme for large cities. In: *13th International Conference on Computer Supported Cooperative Work in Design – CSCWD*, pp. 722–727. doi:10.1109/CSCWD.2009.4968144.

Chiu, Y. R., Liaw, C. H. & Chen, L. C. 2009b Optimizing rainwater harvesting systems as an innovative approach to saving energy in hilly communities. *Renewable Energy* **34**, 492–498. doi: 10.1016/j.renene.2008.06.016.

Copeland, T. & Antikarov, V. 2001 *Opções Reais: Um novo paradigma para reinventar a avaliação de investimentos (Real Options: A New Paradigm for Reinventing the Valuation of Investments)*. Campus, Rio de Janeiro.

Dias, M. A. G. 2014 *Análise de investimentos com opções reais – teoria e prática com aplicações em petróleo e em outros setores (Investment Analysis with Real Options – Theory and Practice with Applications in Oil and other Sectors*). Interciência, Rio de Janeiro.

Domènech, L., March, H. & Saurí, D. 2013 Degrowth initiatives in the urban water sector? A social multi-criteria evaluation of non-conventional water alternatives in Metropolitan Barcelona. *Journal of Cleaner Production* **38**, 44–55. doi: 10.1016/j.jclepro.2011.09.020.

Farreny, R., Gabarrell, X. & Rieradevall, J. 2011 Cost-efficiency of rainwater harvesting strategies in dense Mediterranean neighbourhoods. *Resources, Conservation and Recycling* **55** (7), 686–694. doi:10.1016/j.resconrec.2011.01.008.

Ghisi, E. & de Oliveira, S. O. 2007 Potential for potable water savings by combining the use of rainwater and greywater in houses in southern Brazil. *Building and Environment* **42**, 1731–1742. doi:10.1016/j.buildenv.2006.02.001.

Ghisi, E. & Ferreira, D. F. 2007 Potential for potable water savings by using rainwater and greywater in a multi-storey residential building in southern Brazil. *Building and Environment* **42**, 2512–2522. doi:10.1016/j.buildenv.2006.07.019.

Ghisi, E. & Schondermark, P. N. 2013 Investment feasibility analysis of rainwater use in residences. *Water Resources Management* **27** (7), 2555–2576. doi:10.1007/s11269-013-0303-6.

Ghisi, E., da Tavares, D. F. & Rocha, V. L. 2009 Rainwater harvesting in petrol stations in Brasília: potential for potable water savings and investment feasibility analysis. *Resources, Conservation and Recycling* **54** (2), 79–85. doi:10.1016/j.resconrec.2009.06.010.

Ghisi, E., Rupp, R. F. & Triska, Y. 2014 Comparing indicators to rank strategies to save potable water in buildings. *Resources, Conservation and Recycling* **87**, 137–144. doi: 10.1016/j.resconrec.2014.04.001.

Gois, E. H. B., Rios, C. A. S. & Costanzi, R. N. 2014 Evaluation of water conservation and reuse: a case study of a shopping mall in southern Brazil. *Journal of Cleaner Production* **96**, 263–271. doi:10.1016/j.jclepro.2014.08.097.

Gomes, U. A. F., Heller, L. & Pena, J. L. 2012 A national program for large scale rainwater harvesting: an individual or public responsibility? *Water Resources Management* **26**, 2703–2714. doi:10.1007/s11269-012-00041-1.

Gouvello, B., Geroli, A. & Le Nouveau, N. 2014 Rainwater harvesting in urban areas: how can foreign experiences enhance the French approach? *Water, Science & Technology: Water Supply* **14** (4), 569–576. doi:10.2166/ws.2014.029.

Government of Ontario 2010 *Ontario Guidelines for Residential Rainwater Harvesting Systems–Handbook* (C. Leidl & K. Farahbakhsh, eds). Guelph, Ontario. p. 133.

Gurung, T. R. & Sharma, A. 2014 Communal rainwater tank systems design and economies of scale. *Journal of Cleaner Production* **67**, 26–36. doi:10.1016/j.jclepro.2013.12.020.

Hajani, E. & Rahman, A. 2014 Rainwater utilization from roof catchments in arid regions: a case study for Australia. *Journal of Arid Environments* **111**, 35–41. doi:10.1016/j.jaridenv.2014.07.007.

Hammes, F., Kalogo, Y. & Verstraete, W. 2000 Anaerobic digestion technologies for closing the domestic water, carbon and nutrient cycles. *Water Science and Technology* **41** (3), 203–211.

Han, M. & Ki, J. 2010 Establishment of sustainable water supply system in small islands through rainwater harvesting (RWH): case study of Guja-do. *Water Science and Technology* **62** (1), 148–153. doi:10.2166/wst.2010.299.

Higgins, J. P. T. & Green, S. 2011 *Cochrane Handbook for Systematic Reviews of Interventions*. Version 5.1.0, Updated March 2011, The Cochrane Collaboration.

Imteaz, M. A., Shanableh, A., Rahman, A. & Ahsan, A. 2011 Optimisation of rainwater tank design from large roofs: a case study in Melbourne, Australia. *Resources, Conservation and Recycling* **55**, 1022–1029. doi:10.1016/j.resconrec.2011.05.013.

Islam, M. M., Chou, F. N. & Kabir, M. R. 2010 Acceptability of the rainwater harvesting system to the slum dwellers of Dhaka City. *Water Science and Technology* **61** (6), 1515–1523. doi:10.2166/wst.2010.049.

Islam, M. M., Chou, F. N. F. & Kabir, M. R. 2011 Feasibility and acceptability study of rainwater use to the acute water shortage areas in Dhaka City. *Natural Hazards* **56** (1), 93–111. doi: 10.1007/s11069-010-9551-4.

Jain, S. K. & Chundawat, D. S. 2011 Artificial Recharge & Storm Water Management in Hero Honda Motors Ltd for Haridwar & Dharuhera plants, Haryana State, India. In: *6th WSEAS International Conference on Water Resources, Hydraulics & Hydrology*. Recent Researches in Hydrology, Geology and Continuum Mechanics, WSEAS Press, Cambridge, UK.

Jie, Z., Lianfen, Y. & Jigan, W. 2009 The study on the real option decision-making model for investment value of water project. In: *International Conference on Engineering Computation*, pp. 110–113.

Jones, M. P. & Hunt, W. F. 2010 Performance of rainwater harvesting systems in the southeastern United States. *Resources, Conservation and Recycling* **54**, 623–629. doi:10.1016/j.resconrec.2009.11.002.

Jordan, F. L., Seaman, R., Riley, J. J. & Yoklic, M. R. 2008 Effective removal of microbial contamination from harvested rainwater using a simple point of use filtration and UV-disinfection device. *Urban Water Journal* **5** (3), 209–218.

Kahinda, J. M., Taigbenu, A. E. & Boroto, J. R. 2007 Domestic rainwater harvesting to improve water supply in rural South Africa. *Physics and Chemistry of the Earth* **32**, 1050–1057. doi:10.1016/j.pce.2007.07.2007.

Khastagir, A. & Jayasuriya, N. 2011 Investment evaluation of rainwater tanks. *Water Resources Management* **25** (14), 3769–3784. doi:10.1007/s11269-011-9883-1.

Kim, B., Anderson, K., Lee, S. & Kim, H. 2014 A real option perspective to value the multi-stage construction of rainwater harvesting systems reusing septic tank. *Water Resources Management* **28** (8), 2279–2291. doi:10.1007/s11269-014-0613-3.

Kitchenham, B. 2011 *Procedures for Performing Systematic Reviews*. Technical report. Keele University, Keele, UK.

Lixin, H. E., Xiaoqiang, J. I. A. & Lina, W. A. N. G. 2010 Feasibility of rainwater utilization of Handan city. In: *Proceedings of 3rd WSEAS International Conference on Urban Planning and Transportation*. Latest Trends on Urban Planning and Transportation, WSEAS Press, Greece, pp. 147–152.

Macomber, P. S. H. 2010 *Guidelines on Rainwater Catchment Systems for Hawaii*. College of Tropical Agriculture and Human Resources, University of Hawaii. Manoa, Publication no RM-12, 52 pp.

Matos, C., Lourenço, J., Ramos, L., Pinto, T. & Bentes, I. 2010 Economic feasibility of a rainwater recovery system. Case study for a residential area in Portugal. In: *Proceedings of 3rd WSEAS International Conference on Urban Planning and Transportation*. Latest Trends on Urban Planning and Transportation, WSEAS Press, Greece, pp. 17–20.

Matos, C., Santos, C., Pereira, S., Bentes, I. & Imteaz, M. 2013 Rainwater storage tank sizing: case study of a commercial building. *International Journal of Sustainable Built Environment* **2**, 109–118. doi:10.1016/j.ijsbe.2014.04.004.

Michailidis, A. & Mattas, K. 2007 Using real options theory to irrigation dam investment analysis: an application of binomial option pricing model. *Water Resources Management* **21** (10), 1717–1733.

Minardi, A. M. A. F. 2000 Teoria de Opções Reais aplicada a Projetos de Investimento (Real options theory applied to investment projects). *Revista de Administração de Empresas – RAE* **40** (2), 74–79.

Morales-Pinzón, T., Lurueña, R., Rieradevall, J., Gasol, C. M. & Gabarrell, X. 2012 Financial feasibility and environmental analysis of potential rainwater harvesting systems: a case study in Spain. *Resources, Conservation and Recycling* **69**, 130–140. doi:10.1016/j.resconrec.2012.09.014.

Morales-Pinzón, T., Lurueña, R., Gabarrell, X., Gasol, C. M. & Rieradevall, J. 2014 Financial and environmental modelling of water hardness – implications for utilising harvested rainwater in washing machines. *Science of the Total Environment* **470–471**, 1257–1271. doi:10.1016/j.scitotenv.2013.10.101.

Moreira Neto, R. F., de Carvalho, I. C., Calijuri, M. L. & da Santiago, A. F. 2012 Rainwater use in airports: a case study in Brazil. *Resources, Conservation and Recycling* **68**, 36–43. doi:10.1016/j.resconrec.2012.08.005.

Ngigi, S. N., Savenije, H. H. G., Thome, J. N., Rockström, J. & Vries, F. W. T. P. 2005 Agro-hydrological evaluation of on-farm rainwater storage systems for supplemental irrigation in Laikipia district, Kenya. *Agricultural Water Management* **73** (1), 21–41.

Olmos, K. C. & Loge, F. J. 2013 Offsetting water conservation costs to achieve net-zero water use. *Journal – American Water Works Association* **105**, E62–E72. doi:10.5942/jawwa.2013.105.0002.

Özdemir, S., Elliott, M., Brown, J., Nam, P. K., Hien, V. T. & Sobsey, M. D. 2011 Rainwater harvesting practices and attitudes in the Mekong Delta of Vietnam. *Journal of Water Sanitation and Hygiene for Development* **1** (3), 171–177.

Park, T., Kim, C. & Kim, H. 2014 Valuation of drainage infrastructure improvement under climate change using real options. *Water Resources Management* **28** (2), 445–457. doi:10.1007/s11269-013-0492-z.

Petticrew, M. & Roberts, H. 2008 *Systematic Reviews in the Social Sciences: A Practical Guide,* 2nd edn. Blackwell Publishing Ltd, Oxford, UK.

Rahman, A., Keane, J. & Imteaz, M. A. 2012 Rainwater harvesting in greater Sydney: water savings, reliability and economic benefits. *Resources, Conservation and Recycling* **61**, 16–21. doi:10.1016/j.resconrec.2011.12.002.

Roebuck, R. M. & Ashley, R. M. 2007 Predicting the hydraulic and life-cycle cost performance of rainwater harvesting systems using a computer based modelling tool. *Water Practice & Technology* **2** (2), 699–706. doi:10.2166/WPT.2007046.

Roebuck, R. M., Oltean-Dumbrava, C. & Tait, S. 2010 Whole life cost performance of domestic rainwater harvesting systems in the United Kingdom. *Water and Environment Journal* **25**, 355–365. doi:10.1111/j.1747-6593.2010.00230.x.

Sacadura, F. O. M. O. 2011 *Análise de sistemas de aproveitamento de água pluvial em edifícios (Analysis of rainwater harvesting systems in buildings)*. Master thesis, Faculdade de Ciências Tecnologia da Universidade Nova de Lisboa.

Santos, C. & Taveira-Pinto, F. 2013 Analysis of different criteria to size rainwater storage tanks using detailed methods. *Resources, Conservation and Recycling* **71**, 1–6. doi:10.1016/j.resconrec.2012.11.004.

Santos, C., Taveira-Pinto, F., Cheng, C. Y. & Leite, D. 2011 Optimizing water consumption in buildings – A study on the alternatives to potable water supply. In: *Proceedings of 2011 Symposium CIBW062, Aveiro, Portugal*, pp. 34–42.

Sautchuk, C., Farina, H., Hespanhol, I., Oliveira, L. H., Costi, L. O., Ilha, M. S. O., Conçalves, O. M., May, S., Boni, S. N. S. & Schmidt, W. 2006 *Conservação e Reuso da Água em Edificações (Conservation and Reuse of Water in Buildings)*. Prol Editora Gráfica, São Paulo.

Shah, D., Patel, P., Kudo, P., Steinberg, A. & Herold, W. 2013 Feasibility of rainwater harvesting on Scott Laboratory. In: *Proceedings of IEEE Global Humanitarian Technology Conference (GHTC)*, pp. 361–364. doi:10.1109/GHTC.2013.6713712.

Sharma, A. K., Begbie, D. & Gardner, T. 2015 *Rainwater Tank Systems for Urban Water Supply*. IWA Publishing, London, UK, 372 pp.

Shivakumar, K. 2007 World's largest rainwater harvesting project in Karnataka. *Current Science* **92** (2), 161–163.

Sieker, H. 2010 Stormwater reuse options. Switch pilot training Johannesburg May 2010: Managing stormwater in the city of the future.

Silva, C. M., Sousa, V. & Carvalho, N. V. 2015 Evaluation of rainwater harvesting in Portugal: application to single-family residences. *Resources, Conservation and Recycling* **94**, 21–34. doi:10.1016/j.resconrec.2014.11.004.

Smith, M. 2016 Rainwater harvesting 2016: Resilience and Independence. In: *ARMO Conference*.

Sturm, M., Zimmermann, M., Schütz, K., Urban, W. & Hartung, H. 2009 Rainwater harvesting as an alternative water resource in rural sites in central northern Namibia. *Physics and Chemistry of the Earth* **34**, 776–785. doi:10.1016/j.pce.2009.07.004.

Suttinon, P. & Nasu, S. 2010 Real options for increasing value in industrial water infrastructure. *Water Resources Management* **24** (12), 2881–2892. doi: 10.1007/s11269-010-9585-0.

Tam, V. W. Y., Tam, L. & Zeng, S. X. 2010 Cost effectiveness and tradeoff on the use of rainwater tank: an empirical study in Australian residential decision-making. *Resources, Conservation and Recycling* **54**, 178–186. doi:10.1016/j.resconrec.2009.07.014.

Texas Water Development Board 2005 *The Texas Manual on Rainwater Harvesting,* 3rd edn. Texas Water Development Board, Austin, TX. p. 88.

Thomas, T. H. & Martinson, D. B. 2007 *Roofwater Harvesting: A Handbook for Practitioners.* IRC International Water and Sanitation Centre, Delft, The Netherlands, p. 160.

Tranfield, D., Denyer, D. & Smart, P. 2003 Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management* **14**, 207–222.

Vargas-Parra, M. V., Villalba, G. & Gabarrell, X. 2013 Applying exergy analysis to rainwater harvesting systems to assess resource efficiency. *Resources, Conservation and Recycling* **72**, 50–59. doi:10.1016/j.resconrec.2012.12.008.

Vieira, A. S., Beal, C. D., Ghisi, E. & Stewart, R. A. 2014 Energy intensity of rainwater harvesting systems: a review. *Renewable and Sustainable Energy Reviews* **34**, 225–242. doi: 10.1016/j.rser.2014.03.012.

Ward, S., Memon, F. A. & Butler, D. 2012 Performance of a large building rainwater harvesting system. *Water Research* **46**, 5127–5134. doi:10.1016/j.watres.2012.06.043.

Wotessa, Y. E., Hensley, M. & Van Rensburg, L. D. 2006 Catchment management in semi-arid area of central South Africa: Strategy for improving water productivity. In: *Conference proceedings of the biennial conference held in Durban*. Conducted by the Water Institute of South Africa (WISA).

Yoshimura, E. K. 2008 *Opções reais aplicadas na análise da qualidade de investimentos na construção civil (Real options applied in the analysis of the quality of investments in civil construction)*. Master thesis, Faculdade de Engenharia Civil, Arquitetura e Urbanismo, Universidade Estadual de Campinas.

Yoshino, G. H., Fernandes, L. L., Ishihara, J. H. & Silva, A. I. M. 2013 Use of rainwater for non-potable purposes in the Amazon. *Environment, Development and Sustainability* **16** (2), 431–442. doi:10.1007/s10668-013-9485-6.

Yuan, T., Fengmin, L. & Puhai, L. 2003 Economic analysis of rainwater harvesting and irrigation methods, with an example from China. *Agricultural Water Management* **60**, 217–226. doi: 10.1016/S0378-3774(02)00171-3.

Zeng, B., Tan, H. & Wu, L. 2007 A new approach to urban rainwater management. *Journal of China University of Mining and Technology* **17**, 82–84. doi:10.1016/S1006-1266(07)60018-2.

Zhang, Y., Chen, D., Chen, L. & Ashbolt, S. 2009a Potential for rainwater use in high-rise buildings in Australian cities. *Journal of Environmental Management* **91** (1), 222–226. doi:10.1016/j.jenvman.2009.08.008.

Zhang, Y., Chen, D., Chen, L., Grant, A. & Sharma, A. 2009b Assessing non-traditional water resources for high-rise buildings in Australian cities. In: *3rd International Conference on Bioinformatics and Biomedical Engineering*. ICBBE, pp. 1–4. doi:10.1109/ICBBE.2009.5162412.

First received 12 May 2016; accepted in revised form 11 October 2016. Available online 8 December 2016