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Rainfall data used for rainwater harvesting systems: a bibliometric and systematic literature review

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ABSTRACT

The demand for water has led to an increase in scarcity events in several urban regions. In an urban context, water consumption in buildings plays an important role and rainwater harvesting is one of the ways that consumption can be reduced. One of the input variables for the dimensioning of rainwater tanks is the pluviometric regime's characteristics in the region where the rainwater harvesting system (RWHS) is to be installed. In this study, a bibliometric and systematic literature review was carried out on the types of rainfall data used in the dimensioning of the elements of RWHS. Worldwide, the most-used data comes from meteorological stations, with a historical series size of 30 years, however, other types of data and different sizes of historical series are also used. From this study, it was possible to synthesise the regions where differentiation data can be collected, as well as their characteristics, enabling the researchers to quickly access the definition of separation data collection parameters.

Key words: rainfall, rainfall data, rainwater harvesting, systematic literature review

HIGHLIGHTS

- General understanding of the rainfall data used in research of reservoir sizing rainwater harvesting systems.
- Providing sources in different parts of the world to obtain rainfall data.
- The most used sizes of historical series of rainfall data are reported.
- The types of rainfall data found and their usage locations are presented.
- Knowledge gaps and scientific research trends are presented.

INTRODUCTION

The demand for water has led to an increase in scarcity events in several urban regions. Population growth, changing habits and climate change contribute to the availability of water for residential, commercial, agricultural and industrial activities. In an urban context, water consumption in buildings plays an important role. According to the National Brazilian Standards NBR 15527/2019, the adoption of water conservation plans in buildings must initially start with actions that allow the reduction of the demand for potable water through demand management and, only after contemplating these actions, the use of alternative sources (ABNT 2019).

The use of rainwater harvesting has been highlighted as a potential alternative water source. Rainwater harvesting systems (RWHSs) are not recent phenomena, however, they have been studied with greater intensity in recent times, especially in regions that are far from supply networks or in situations with chronic supply shortages (Liaw & Chiang 2014). Their functioning can be summarised as: the collection of rainwater from the catchment area, conducting it through the transport system, storing it and then distributing it (Mitchell 2007; Kim & Yoo 2009; Jones & Hunt 2010). For the proper sizing of an RWHS, the main data set needed is that of precipitation, as it characterises the region's rainfall patterns and results in the volume of usable rain collected by the RWHS for later use.

The adequate input of factors to determine the supply of rainwater is essential for the most careful dimensioning of the system (Mun & Han 2012). In order to obtain accurate precipitation data, it is necessary to have rainfall data from close to the place where the RWHS is supposed to be installed. Extensive monitoring history is not a reality for all regions of the world (Lúcio *et al.* 2020). There are places that only have recent precipitation measurements, as well there are places that do not have a monitoring network. In places where monitoring exists, access to historical series information can be performed through the databases of institutions present in the region.

In Brazil, obtaining rainfall data can be carried out at the Brazilian National Water and Sanitation Agency (ANA 2021) and at the Brazilian National Institute of Meteorology (INMET 2021). There are also public education institutions that carry out the monitoring. When the studies take part in different countries, it is necessary to search for the entities responsible for providing information, so that the data obtained can characterise the studied location well. Lack of knowledge of the sources used in different countries may result in the use of data that may not adequately characterise the region of implementation. By considering the lack of data from certain regions, those regions that have recent monitoring data, and global climate change, such considerations sharpen the search for understanding which rainfall data can be used for these purposes and where they can be collected for use in the sizing of storage tanks.

In this paper, a bibliometric and systematic literature review (BSLR) on the types of rainfall data used in the design of the elements of the building systems that use rainwater was carried out.

Based on the results obtained, it is expected that this article can help designers to obtain rainfall data in regions with greater or lesser monitoring input. In addition, it is also expected that the designer will increase the understanding of how these data are used worldwide in the design of RWHS elements.

METHODS

The procedure for performing the BSLR adopted in this study was proposed by Tranfield *et al.* (2003) and Higgins *et al.* (2022). According to these authors, the review is divided into:

- planning which questions are defined,
- developing the protocol,
- conducting the selection of publications, through the application of the inclusion and exclusion criteria,
- extracting and analysing the data,
- documenting and disseminating a summary of the information obtained, and
- presenting the findings.

The research questions were defined as:

1. What types of rainfall data are used for the RWHS tank sizing?
2. What are the sizes and temporal resolution of the historical series of rainfall data used for the sizing of the tanks?
3. From which sources are the data obtained?
4. Is it possible to verify the impact of the types of rainfall data on the results of the sizing of the tanks?
5. Is there any relationship between the type of sizing and the type of rainfall data?
6. Is there a relationship between the location of the study and the type of data considered?

The second action was the definition of the databases in which the searches were carried out. The selection was made by peer-reviewed journal papers indexed in the Engineering Village (Compendex), Science Direct, Scopus and Web of Science. It is understood that these papers already have proven quality attributed to the renowned journals in which they were published. For this reason, it was decided not to establish specific criteria for the analysis of the quality of the papers.

To perform the search in the scientific databases, it was necessary to define keywords that were related to the topic. This step was carried out through initial exploratory research and previous readings of the material considered to be relevant. It is noteworthy that, even though the papers were considered relevant, they did not sufficiently answer the proposed questions or guarantee that they would cover the entire subject. Through the readings performed, the keywords which would be synonymous were raised and analysed (see Table 1).

The definition of the string encompassed the raised words, but in a way that did not restrict or limit the search too much. This happened when using Boolean operators (AND, OR), the full and short form of RWHS, as well as the asterisk that works as a wildcard means that it will search for words that have the first letters 'harvest', as harvested, harvesting and others. Then,

Table 1 | Keywords raised and their corresponding synonyms

Keywords	Synonyms
Rainfall	Rainfall data Rainfall time series
Rainwater harvest*	Rainwater harvesting RWH

to support the search, some initial criteria were considered. The search was only performed for journal papers, to gather information only from publications that underwent peer review. Only papers from journals that were written in Portuguese or English were considered. There was no restriction on the period of publication, for the generation of the chronology of the development of the research on the subject.

The specific area of knowledge of the subject was not defined, considering the possibility of studies in other areas due to its multidisciplinary nature. Finally, the search terms (string) were in the title, abstract and keywords of the publications. Based on these definitions, the characteristic search instructions of each database and the filters considered, the strings used were as follows:

1. Engineering Village (Compendex): The searched string was [rainfall AND (data or time) AND (rainwater harvest* or rwh)]; the search was performed on (title, abstract, keywords).
2. Science Direct: The searched string was [rainfall AND (data or time) AND (rainwater harvest or rwh)]. The harvest asterisk was removed, as the database did not recognise the symbol and the search was performed in the main field; then the search filters were used, regarding the location of the string in the title, abstract and keywords.
3. Scopus: The searched string was [rainfall AND (data OR time) AND (rainwater AND harvest* OR rwh)]. The search was performed in the main field and then search filters were used regarding the location of the string in the title, abstract and keywords.
4. Web of Science: The searched string was [rainfall AND (data or time) AND (rainwater harvest* or rwh)]; the search was carried out in the Main Collection of the Web of Science and in the Topic that corresponds to 'Searches title, abstract, author keywords, and Keywords Plus'.

In the implementation stage, the papers were selected and downloaded according to the inclusion and/or exclusion criteria defined in the protocol. This process took place in three stages: in the reading of the titles, in the reading of the abstracts and in the complete reading of the texts. Thus, the criteria for inclusion or exclusion were established and these are listed in Table 2.

The selection of papers was performed using the tools available in Parsif.al (2021) and an electronic spreadsheet created in Microsoft Excel. Through them, it was possible to read the titles and abstracts, apply the inclusion and exclusion criteria and carry out data collection for each paper.

With the selected papers in hand, the analysis of the set of adherent papers was carried out. At first, the analyses covered the bibliometric criteria within the information collected, with respect to the following data: author(s); institution of each

Table 2 | Inclusion and exclusion criteria

ABBREVIATION	**Inclusion criteria**
CI-01	Effect of climate change and/or historical series size on the RWHS tank sizing
CI-02	RWHS tank sizing
ABBREVIATION	**Exclusion criteria**
CE-01	It is not a journal paper
CE-02	It is not an RWHS system urban and building
CE-03	Quality of rainwater in urban and building cases
CE-04	It is not in English/Portuguese

author; country of institution of each author; country where the research was carried out; year of publication; keywords; journal and journal's Journal Citation Reports (JCR).

In the second step, the papers were classified into six categories based on the objectives of the papers. The following information was used: the type of rainfall data used to determine the supply of rainwater (e.g. meteorological station, grid); the temporal resolution of the rainfall data considered for the RWHS tank sizing (minute, hourly, daily, monthly, annual); the size of the historical series of rainfall data; and the database or location where the data was collected. The elaborated protocol is presented in Supplementary Material A.

RESULTS AND DISCUSSION

The data search was carried out on January 18, 2021 and resulted in 1,024 papers. Even with the initial criteria adopted, the search yielded some works that were not of the journal paper type and others that were written in a language other than the established ones (English and Portuguese). This made it necessary to insert filters among the exclusion criteria.

The selection was initially performed by reading all of the titles and applying the criteria. The abstracts of papers selected by reading the titles were read and those selected went to the full-text reading step. Table 3 lists the number excluded at each stage and the total number of papers that conformed to the required criteria. The list of studies is presented in Supplementary Material B.

In Figure 1, through Venn diagrams, the quantities obtained in each of the databases used, as well as the quantity of adherent papers, are shown. It can be seen that Science Direct had the largest number of papers that were not made available in any of the other three databases; the same occurs in relation to the adherent papers. In contrast, Engineering Village only offered three papers that were not in the other three databases and they were not adherent, so the database did not have any unique adherent paper. Of the 32 papers in the four databases, more than half adhered to the inclusion criteria There was a high occurrence of papers in the Web of Science, Scopus and Engineering Village and a weak relation of occurrence between Science Direct and the other three databases, when analysing by pairs or trios.

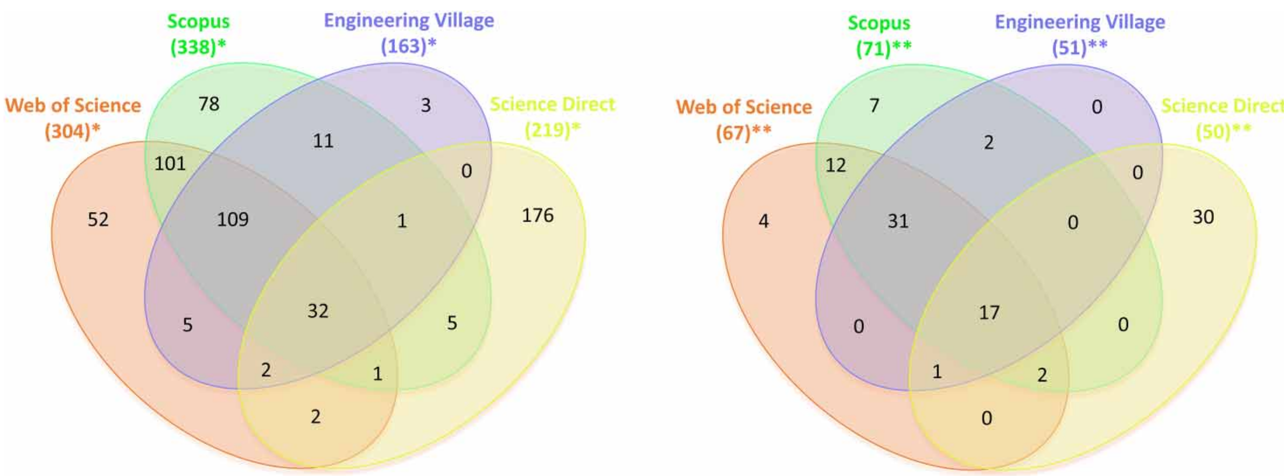
The first result of the survey analysed was in relation to the year of publication of the papers. The first publication took place in 2007 (Mitchell 2007) and until the year 2011 there was no significant increase in research. Since 2012, the publications related to the topic have increased considerably, suggesting the increasing interest from researchers related to the topic addressed. This increase in interest coincides with the United Nations Conference on Sustainable Development (Rio+20) held in 2012. Preparatory meetings started in 2010 and nation states, international organisations and civil society sent their contributions to the United Nations. The two themes addressed at the conference were 'Green economy in the context of sustainable development and poverty eradication' and 'Institutional framework for sustainable development'. In both themes, the use of RWHS improved the situations at the time, which justified increased academic interest in researching the subject (RIO20 2012).

In order to analyse all of the co-authorship relationships, in Figure 2, all authors who were linked in at least one paper were considered, thus obtaining a group of 271 authors working in co-authorship, with the main co-authors being identified in the graph.

The network of co-authors in this study comprised 61 clusters, the six largest having a variation in their composition from 10 to 16 members who have been carrying out research since 2012. The authors Monzur Alam Imteaz (from Swinburne

Table 3 | Results after applying the criteria

Step	Quantity
Search results	+1,024
Duplicate papers	−455
Reading titles	−266
Reading abstracts	−114
Reading full papers	−74
Full papers not available	−9
Total adherent papers	+106



* Quantity of articles obtained in each of the databases.
**Quantity of adherent papers in each of the databases.

Figure 1 | Venn diagram on the left shows the list of papers per database along with the duplication ratio; Venn diagram on the right shows the list of papers adhered to by the database and their occurrences in the databases. Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/aqua.2022.034.

University of Technology in Australia), Enedir Ghisi (from the Federal University of Santa Catarina, Brazil) and Ataur Rahman (from Western Sydney University in Australia) were the authors who presented the most publications: 10, 8 and 7 papers, respectively. This is also evidenced in the size of the nodes of their clusters, which are the common points corresponding to each of the co-authors involved.

Another point to note is that several smaller clusters were formed by authors who carried out research between 2016 and 2020. This shows that the topic is still being studied and that larger clusters of co-authors can probably be formed in the coming years with the advance of the surveys.

The number of publications per journal and the JCR type qualifier were related. Of the 43 journals, 31 included JCR, while the rest of the journals did not have this indicator. The highest JCR was 8.424, for the journal 'Water Research,' and the lowest

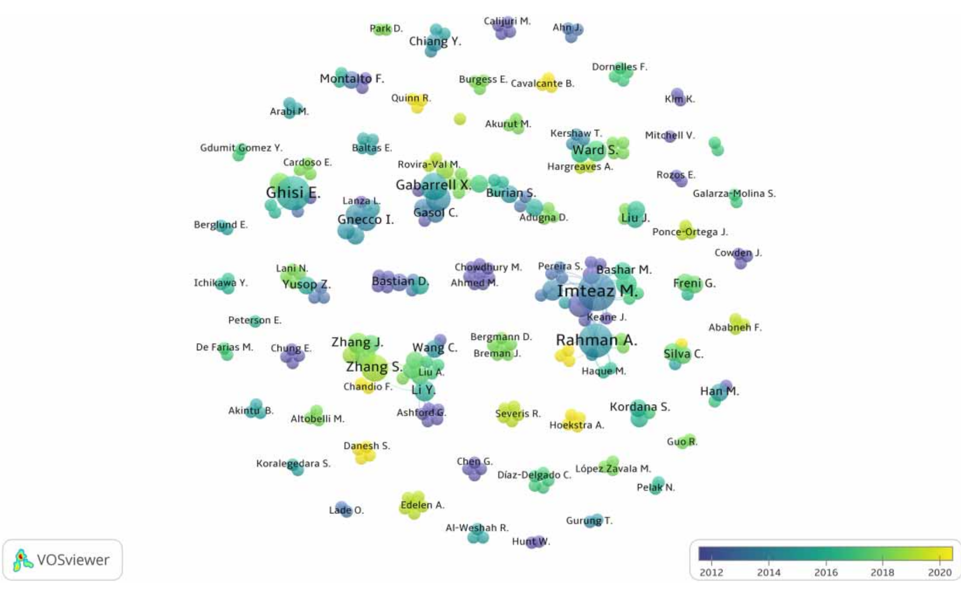


Figure 2 | Graph showing the co-authorship relationship with at least one occurrence. Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/aqua.2022.034.

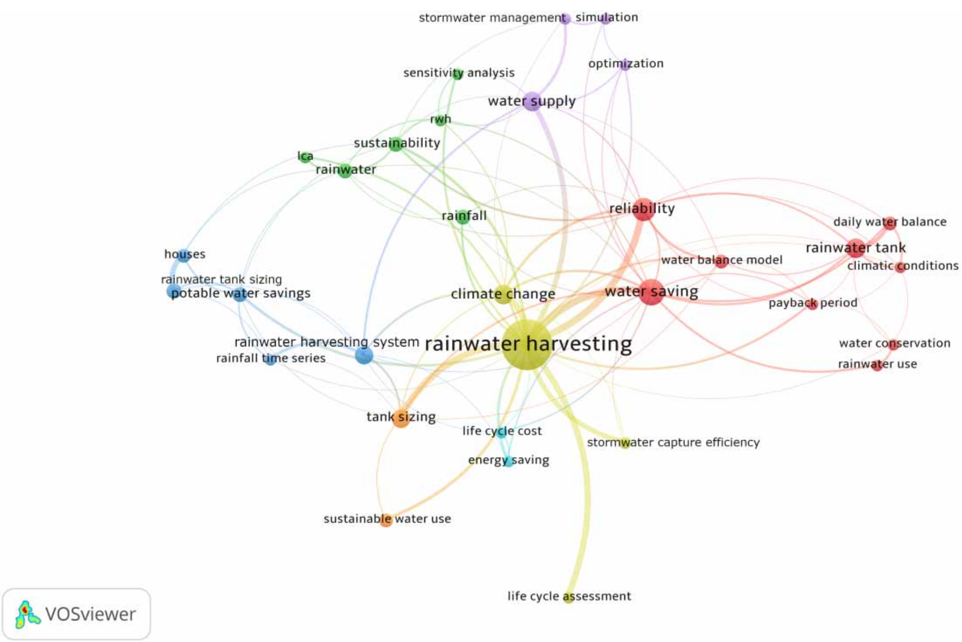


Figure 3 | Graph with the correlation of keywords used by authors in their studies. Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/aqua.2022.034.

was 0.725, for the 'American Water Works Association'. The average of the journals that had JCR was found to be 4.784, with a standard deviation of 2.064. There was a high dispersion among the surveyed JCRs, as the calculated amplitude was 7.699. It should also be noted that 90.4% of the papers were in journals where JCR greater than 4.[1]

Another analysis was performed on the keywords used by the authors in their research. Those that appeared in at least three papers were considered and this criterion was established so that the most recurrent correlations could be analysed. After applying the parameter, seven clusters were formed (Figure 3). Through each cluster, it is possible to perceive the approach contained in a large part of that group's research. For example, the cluster symbolised in red suggests the approaches related to reliability through financial analysis in the implementation of the RWHS and, in most of the papers that used these keywords, the authors chose to use the daily water balance for the RWHS tank sizing (Youn *et al.* 2012; Lo & Koralegedara 2015; Kisakye *et al.* 2018; Li *et al.* 2018; Musayev *et al.* 2018; Toosi *et al.* 2020). The cluster depicted in light blue, on the other hand, conveys an approach related to the RWHS' life cycle (Lash *et al.* 2014; Wurthmann 2019; Dijk *et al.* 2020).

Another factor that was considered was the relationship of the content to the publications, as well as the description of the data and the information contained in each paper. The works were classified, considering six categories, and the one that grouped most of the research was 'technical feasibility', corresponding to 47.2% of the studies. The second largest number of studies was the RWHS element sizing category, corresponding to 21.7% of the studies. The third category was environmental analysis, comprising 16% of the participating surveys. As a fourth category, economic feasibility was considered, accounting for 10.4% of the papers. The fifth category was the influence of the size of the historical series of rainfall data, representing 2.8% of surveys. Finally, the sixth category was the use of decision support systems, comprising 1.9% of the works. The classification of each adhering paper, in terms of category and/or subcategory, can be seen in Table 4.

Other analyses performed were the temporal resolution of precipitation data, considering its use in RWHS tank sizing. Figure 4 shows that most papers used daily data. Mitchell (2007) emphasised that the large-scale use of precipitation with daily resolution is related to the large number of places that are monitored by rain gauges. The difficulty in using data

[1] Year of reference 2021.

Table 4 | Classification of papers according to the subject covered

Category/Subcategory	Quantity
1.0 – Technical feasibility	50
1.1 – Case studies with various residential typologies Ghisi (2010), Farreny *et al.* (2011), Imteaz *et al.* (2011a), Imteaz *et al.* (2012a), Rahman *et al.* (2012), Souza & Ghisi (2012), Steffen *et al.* (2013), Hajani & Rahman (2014), Chiu *et al.* (2015), Karim *et al.* (2015), Lopes *et al.* (2016), Peterson (2016), Rostad *et al.* (2016), Gómez & Teixeira (2017), Palla *et al.* (2017), Santos & Farias (2017), Xu *et al.* (2018), Abu-Zreig *et al.* (2019), Hargreaves *et al.* (2019)	19
1.2 – Case studies with single-family residential typology Alam *et al.* (2012), Imteaz *et al.* (2012b), Palla *et al.* (2012), Fulton *et al.* (2013), Lade & Oloke (2013), Rahmat *et al.* (2020), Ali *et al.* (2021), Quinn *et al.* (2021)	8
1.3 – Case studies in condominiums with different residential types Teston *et al.* (2018), Freni & Liuzzo (2019)	2
1.4 – Case study in a residential complex with the same typology Rozos & Makropoulos (2012)	1
1.5 – Case studies in residential apartment buildings Jing *et al.* (2017), Bashar *et al.* (2018)	2
1.6 – Case studies in university buildings Imteaz *et al.* (2011b), Cardoso *et al.* (2020)	2
1.7 – Case studies in commercial buildings Matos *et al.* (2013), Lani *et al.* (2018)	2
1.8 – Case study in a transport logistics company Zavala *et al.* (2018)	1
1.9 – Case study in various types of hospitals Fulton (2018)	1
1.10 – Airport case study Neto *et al.* (2012)	1
1.11 – Case study with several residential and one commercial typology Lopes *et al.* (2017)	1
1.12 – Case studies with varied typologies (such as residential, commercial and educational) Kim & Yoo (2009), Jones & Hunt (2010), Sample & Liu (2014), Petit-Boix *et al.* (2018), Pérez-Uresti *et al.* (2019), Dijk *et al.* (2020)	6
1.13 – It was not possible to identify the typology Zhang *et al.* (2012), Campisano *et al.* (2013), Vuong *et al.* (2016), Khan *et al.* (2021)	4
2.0 – RWHS element sizing	23
2.1 – RWHS sizing Basinger *et al.* (2010), Mun & Han (2012), Hashim *et al.* (2013), Gurung & Sharma (2014), Liaw & Chiang (2014), Okoye *et al.* (2015), Wallace *et al.* (2015), Campisano & Modica (2016), Pelak & Porporato (2016), Galarza-Molina & Torres (2017), Nguyen & Han (2017), Cipolla *et al.* (2018), Guo & Guo (2018), Park & Um (2018), Lúcio *et al.* (2020)	15
2.2 – Comparisons between sizing methods Mitchell (2007), Cowden *et al.* (2008), Santos & Taveira-Pinto (2013), Imteaz *et al.* (2015), Londra *et al.* (2015), Rezende & Tecedor (2017)	6
2.3 – Development of methodology for sizing, economic and environmental assessment of RWHS Morales-Pinzón *et al.* (2015)	1
2.4 – Development of methodology to synthetically generate daily precipitation, water supply and irrigation demand for RWHS sizing Wurthmann (2019)	1
3.0 – Environmental analysis	17
3.1 – Effect of climate change on RWHS Youn *et al.* (2012), Seo *et al.* (2013), Giacomoni & Berglund (2015), Lo & Koralegedara (2015), Haque *et al.* (2016),	12

(*Continued.*)

Table 4 | Continued

Category/Subcategory	Quantity
Tavakol-Davani *et al.* (2016), Alamdari *et al.* (2018), Kisakye *et al.* (2018), Musayev *et al.* (2018), Zhang *et al.* (2018, 2019), Toosi *et al.* (2020)	
3.2 – RWH system life cycle assessments Li *et al.* (2018), Ghimire *et al.* (2019), Vargas-Parra *et al.* (2019)	3
3.3 – Development of methodologies for sizing the RWHS considering climate change Warrick *et al.* (2012); Lash *et al.* (2014)	2
4.0 – Economic feasibility	11
4.1 – Development of methodology for economic analysis of RWHS Morales-Pinzón *et al.* (2012), Ghisi & Schondermark (2013), Silva *et al.* (2015), Imteaz *et al.* (2017), Amos *et al.* (2018), Oviedo-Ocaña *et al.* (2018)	6
4.2 – RWHS deployment risk assessments Wang & Blackmore (2012), Severis *et al.* (2019)	2
4.3 – Development of methodology to assist in decision making for the implementation of RWHS Liuzzo *et al.* (2016)	1
4.4 – Financial feasibility comparisons for water and energy conservation Stec *et al.* (2017)	1
4.5 – Financial feasibility comparisons for water conservation Stec & Kordana (2015)	1
5.0 – Influence of the size of the historical series of rainfall data Geraldi & Ghisi (2017, 2018, 2019)	3
6.0 – Decision support systems Fonseca *et al.* (2017), Li *et al.* (2017)	2

with a minute or hourly resolution may be related to the scarcity of records, since the amount of rain gauges which provide hourly data are considerably fewer than pluviometers, which offer daily data.

A likely reason for the greater use of sizing through daily water balance, as can be seen in Figure 4, is related to what Mitchell (2007) also concluded in his study, i.e. the possibility of using a more simplified model (e.g. an electronic spreadsheet) that

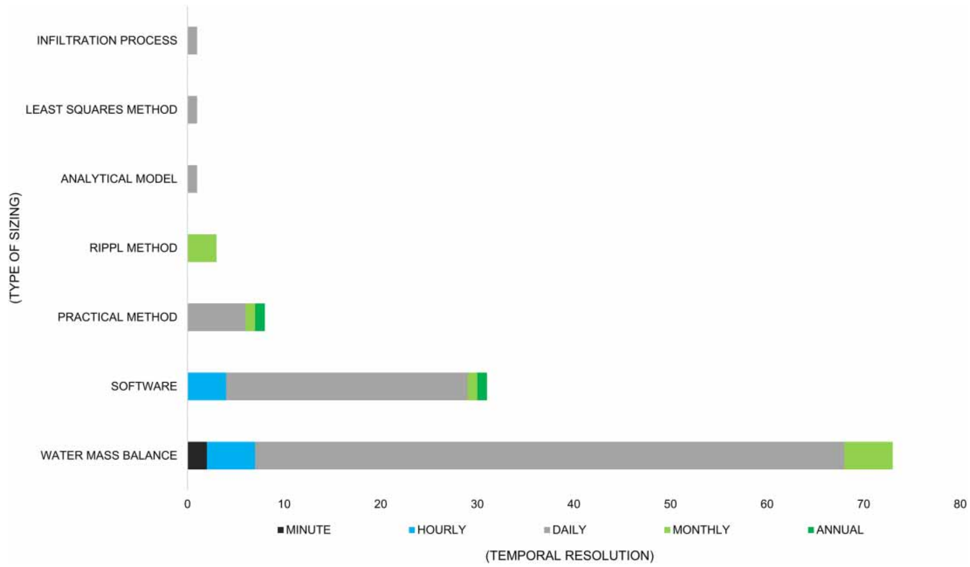


Figure 4 | Types of sizing and temporal resolution used in sizing. Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/aqua.2022.034.

can perform calculations by considering more than 100 years of daily data. This does not reduce the search for greater precision in sizing, whether through software or new techniques (Imteaz *et al.* 2015; Morales-Pinzón *et al.* 2015; Lopes *et al.* 2016; Peterson 2016; Tavakol-Davani *et al.* 2016; Amos *et al.* 2018), different types of rainfall data other than those from meteorological stations (Warrick *et al.* 2012; Seo *et al.* 2013; Lash *et al.* 2014; Alamdari *et al.* 2018; Lúcio *et al.* 2020; Quinn *et al.* 2021) or other temporal resolutions (Jones & Hunt 2010; Steffen *et al.* 2013; Sample & Liu 2014; Guo & Guo 2018; Park & Um 2018; Dijk *et al.* 2020).

Imteaz *et al.* (2011b) were able to conclude that the use of daily resolution can generate more realistic scenarios than the use of data with more widely spaced temporal resolutions. They also concluded that calculations using mean annual precipitation produce unrealistic results regarding storm water quantity, overflow and potable water savings. Imteaz *et al.* (2012b) found that the use of average monthly rainfall data overestimates the size of the RWHS tanks. The authors consider that the use of daily data in the water balance can produce more realistic results. It is also noteworthy that, among the papers that specified the type of water balance used, 19 papers used the yield after spillage (YAS) method and 5 papers used the yield before spillage (YBS) method.

The sizes of the historical series of rainfall data used in the research were surveyed. In Figure 5, it can be seen that the use of series with 26–30 years is more common in studies. However, smaller series have also been used, and such use may be related to data gaps in the series, a lack of monitoring in certain regions or even the recent monitoring in certain places (Campisano & Modica 2016; Fulton 2018).

Three adherent papers addressed the influence of the size of the historical series and all by two authors (Geraldi & Ghisi 2017, 2018, 2019). The sizes analysed in the surveys were 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15, 20 and 30 years and the papers differ from each other in terms of study sites and analysed parameters. The study published in 2017 was carried out in the city of Berlin, Germany and analysed the ideal capacity of the RWHS tank and the ideal potential for saving potable water. In 2018, the authors conducted the study in 13 cities: Alexandria, Egypt; Barcelona, Spain; Berlin, Germany; Dar-El-Beida, Algeria; Darwin, Australia; Encarnación, Paraguay; Moscow, Russia; New York, United States of America; Paris, France; Quebec, Canada; Santarém and Santo Amaro, Brazil; and Shanwei in China. The potable water saving potential was entered as an analysis parameter, along with the ideal rainwater tank capacity and the ideal potable water saving potential. In 2019, the authors continued their research from the previous year and used the average annual precipitation, the average number of dry days per year and the seasonality index as precipitation indicators to characterise the historical series and analyse the relationship between the sizing parameters obtained for each series size.

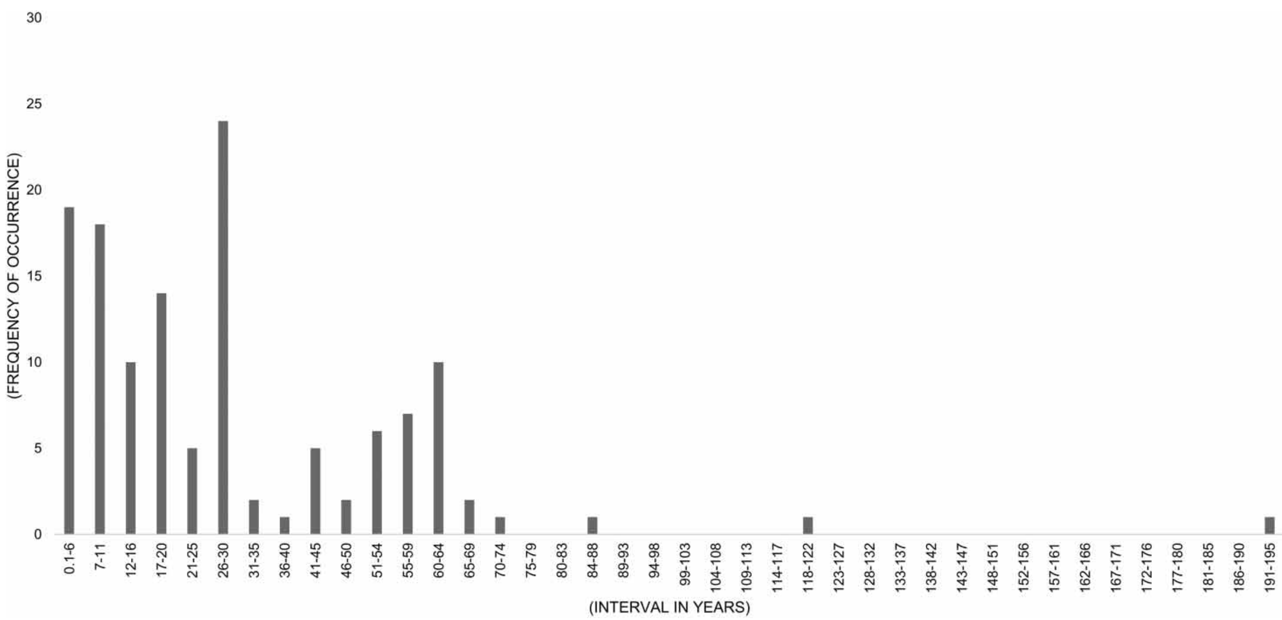


Figure 5 | Sizes of the rainfall data series in the studies. Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/aqua.2022.034.

In general, the authors concluded that, in places that have recently implemented rainfall monitoring, the use of short historical series would provide an opportunity for the adequate sizing of the RWHS tank. However, research is restricted to the places studied, requiring more research to obtain greater results.

It is noteworthy that many studies have justified the use of historical series sizes as a function of data availability (Ghisi 2010; Rahman *et al.* 2012; Ghisi & Schondermark 2013; Steffen *et al.* 2013; Hajani & Rahman 2014; Liaw & Chiang 2014; Londra *et al.* 2015; Jing *et al.* 2017; Amos *et al.* 2018; Guo & Guo 2018; Zhang *et al.* 2018; Abu-Zreig *et al.* 2019). There was also the consideration of climate variability over time, considering the use of a short series (5 years) to be more appropriate for characterising the current climate context of the studied region (Rezende & Tecedor 2017). Still, the size of the historical series was considered as being proportional to the life cycle period of a building's hydraulic system which, in this case, was 20 years (Cardoso *et al.* 2020).

Another analysis was performed in relation to the type of rainfall data used. It was found that most studies (75.47%) used only meteorological stations. Less than 20% of the surveys used data from meteorological stations together with another type of data and less than 10% exclusively used another type of rainfall data, other than that from meteorological stations.

The use of rainfall data from meteorological stations for the dimensioning of RWHS tanks is prevalent throughout the world, as can be seen in Figure 6. It can also be seen that all continents use rainfall data that do not come from meteorological stations, with the greatest occurrence being on the European continent. The search for other types of data may be related to the scarcity of precipitation records from meteorological stations, gaps in the historical series of rainfall data, and future precipitation projections (Campisano & Modica 2016; Fulton 2018; Zhang *et al.* 2019; Lúcio *et al.* 2020).

Still regarding the type of rainfall data used, data from the following sources were found: meteorological stations; climate generators; probabilistic modelling; grid and the Köppen–Geiger classification. As for the research that exclusively considered the meteorological stations as a type of rainfall data, the origins of these (in relation to the country studied) were raised and are summarised in Table 5.

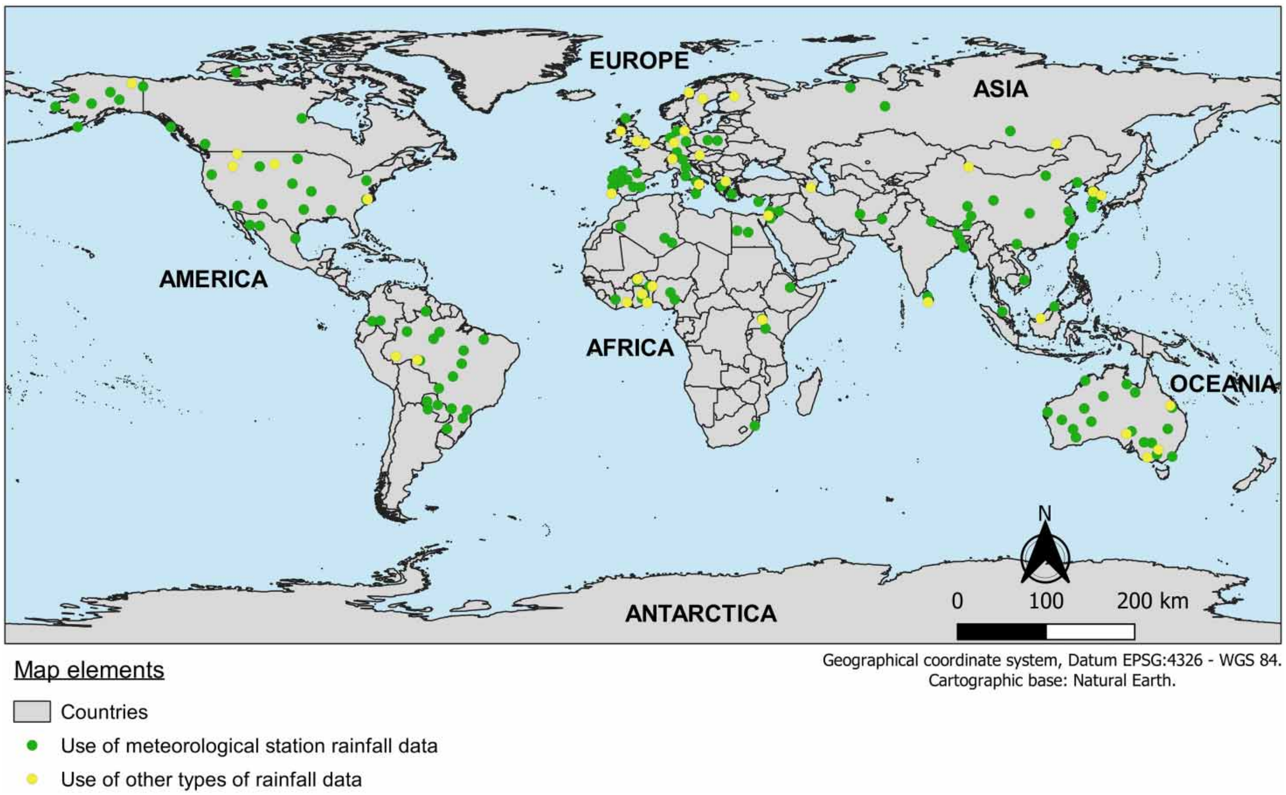


Figure 6 | Geographical distribution of the use of data from meteorological stations or otherwise. Please refer to the online version of this paper to see this figure in colour: https://dx.doi.org/10.2166/aqua.2022.034.

Table 5 | Origin of data used in studies that had meteorological stations as their only source

Country	Origin
Algeria	GHCN (Global Historical Climatology Network)
Australia	Australian Bureau of Meteorology; GHCN (Global Historical Climatology Network); Patched Point Dataset (PPD); Raintank Analyzer software database
Bangladesh	Bangladesh Meteorological Department (BMD)
Brazil	Brazilian National Water and Sanitation Agency (ANA); Department of Water and Electricity of São Paulo; Jahu University of Technology – Fatec Jahu; Brazilian Air Force; GHCN (Global Historical Climatology Network); Brazilian National Institute of Meteorology (INMET); Paraná Meteorological System (SIMEPAR)
Canada	GHCN (Global Historical Climatology Network)
China	National Climatic Center (NCC); GHCN (Global Historical Climatology Network)
Colombia	Instituto de Hidrología, Meteorología y Estudios Ambientales from Colombia (IDEAM)
Egypt	GHCN (Global Historical Climatology Network)
Ethiopia	National Meteorology Agency of Ethiopia (NMA)
France	GHCN (Global Historical Climatology Network)
Germany	GHCN (Global Historical Climatology Network)
Greece	Ministry of the Environment, Energy and Climate Change
Italy	ARPAE – Regional Agency for Prevention, Environment and Energy; Osservatorio delle Acque-Agenzia Regionale per Rifiuti and le Acque (OA-ARRA) of Sicily; Servizio Informativo Agrometeorologico Siciliano (SIAS)
Jordan	Jordanian Meteorological Department; Water Authority of Jordan
Kenya	Kenyan Bureau of Meteorology
Malaysia	Department of Irrigation and Drainage in Malaysia (DID); Senai International Airport
Mexico	Development Management System (SiGeDes- Sistema Gestor de Desarrollo); Servicio Meteorológico Nacional México (SMN)
Nepal	Nepal Department of Hydrology and Meteorology
Nigeria	Department of Meteorological Services
Pakistan	Climate Data Processing Centre, Pakistan Meteorological Department
Paraguay	GHCN (Global Historical Climatology Network)
Portugal	IPMA – Instituto Português do Mar e da Atmosfera; Portuguese Water Institute e The Azores University; Portuguese National Information System of Water Resources (SNIRH)
Russia	GHCN (Global Historical Climatology Network)
South Africa	GHCN (Global Historical Climatology Network)
South Korea	Korea Meteorological Administration
Spain	Catalonia Meteorological Service (SMC); State Meteorological Agency of Spain; GHCN (Global Historical Climatology Network)
Taiwan	Water Resources Agency of the Ministry of Economic Affairs
USA	National Climatic Data Center (NCDC); GHCN (Global Historical Climatology Network); National Centers for Environmental Information (NCEI); National Oceanic and Atmospheric Administration (NOAA); Northeast Regional Climate Centre; State Climate Office of North Carolina; US Climate Data

With an emphasis on data from meteorological stations, some studies used these together with another type of data. Information regarding the location of the study, the type of data used in conjunction with the meteorological station and the origin of the first were collected for each of the 18 papers and are summarised in Table 6. In most cases, the joint use of data occurred due to the scope of the study being related to the influence of climate change on the design of the RWHS. For this, the researchers used data from the past period and, for future scenarios, they used data from sources that carried out climate projections (Cowden *et al.* 2008; Youn *et al.* 2012; Giacomoni & Berglund 2015; Lo & Koralegedara 2015; Wallace

Table 6 | Summary of studies that used data from a meteorological station together with another type of data.

Reference	Study location	Data type	Data origin
Cowden *et al.* (2008)	Western Africa	Meteorological station/Markov and LARS-WG stochastic climate generator	National Climatic Data Center (NCDC)
Haque *et al.* (2016)	Australia (Sydney)	Meteorological station/Commonwealth Scientific and Industrial Research Organisation (CSIRO Mk.3)	Australian Bureau of Meteorology & NARCliM project
Wang & Blackmore (2012)	Australia (Melbourne)	Meteorological station/Probabilistic modelling	Bureau of Meteorology (Australia)
Santos & Farias (2017)	Brazil (71 cities in Pernambuco)	Meteorological station/Climate generator with Thiessen method	–
Lopes *et al.* (2017)	Brazil (Montes Claros)	Meteorological station/Markov and Gamma stochastic climate generator	Brazilian National Water and Sanitation Agency – ANA
Zhang *et al.* (2019)	China (Yinchuan, Urumqi, Beijing, Fuzhou)	Meteorological station/Climate generator (CLIGEN)	National Climatic Centre (NCC) of China
Youn *et al.* (2012)	South Korea (Seoul)	Meteorological station/CGCM 3 (Canadian Global Coupled Model 3)	Intergovernmental Panel on Climate Change (IPCC)
Rozos & Makropoulos (2012)	Greece (Athens)	Meteorological station/Climate generator (model ZYGOS)	National Technical University of Athens
Toosi *et al.* (2020)	Iran (Mashhad)	Meteorological station/Downscaled Coupled Model Intercomparison Project Phase5 (CMIP5)	Iran Metrological Organisation
Wallace *et al.* (2015)	Micronesia	Meteorological station/Markov stochastic climate generator	–
Lo & Koralegedara (2015)	Sri Lanka (Columbus)	Meteorological station/LARS-WG stochastic weather generator with CMIP3	Sri Lanka Department of Meteorology
Kisakye *et al.* (2018)	Uganda (Kabarole)	Meteorological station/Global circulation models (GCMs)	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology; Beijing Climate Center, China Meteorological Administration; Commonwealth Scientific and Industrial Research Organisation/Bureau of Meteorology (CSIRO-BOM); Centre National de Recherches Meteorologiques/Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique (CNRM/CERFACS); Met Office Hadley Centre
Fulton (2018)	USA (San Antonio)	Meteorological station/Climate generator with Poisson method	National Oceanic and Atmospheric Administration (NOAA)
Tavakol-Davani *et al.* (2016)	USA (Toledo)	Meteorological station/Downscaled Coupled Model Intercomparison Project Phase5 (CMIP5)	World Climate Research Program
Basinger *et al.* (2010)	USA (New York)	Meteorological station/Stochastic climate generator of SARET	–
Giacomoni & Berglund (2015)	USA (Arlington)	Meteorological station/Grid – model WCRP-CMIP3	World Climate Research Program

(*Continued.*)

Table 6 | Continued

Reference	Study location	Data type	Data origin
Musayev *et al.* (2018)	41 countries	Meteorological station/Stochastic climate generator LARS-WG	National Oceanic and Atmospheric Administration (NOAA)
Morales-Pinzón *et al.* (2015)	–	Meteorological station/Markov and Gamma stochastic climate generator	Agencia Estatal de Meteorología

et al. 2015; Haque *et al.* 2016; Tavakol-Davani *et al.* 2016; Fulton 2018; Kisakye *et al.* 2018; Musayev *et al.* 2018; Zhang *et al.* 2019; Toosi *et al.* 2020).

There were cases in which, due to the size of the historical series of the meteorological station not being considered sufficient for the study, climate generators were used from these data to obtain synthetic series (Rozos & Makropoulos 2012; Wang & Blackmore 2012; Morales-Pinzón *et al.* 2015; Santos & Farias 2017). There were also papers where, with the objective of proposing models for RWHS sizing that did not require long historical series from meteorological stations, a stochastic climate generator was also used to produce synthetic series (Basinger *et al.* 2010; Lopes *et al.* 2017).

There were also research cases that did not use rainfall data from a meteorological station. Information regarding the location of the study, the type of data used and its origin were collected for each of the eight studies and are summarised in Table 7. The approach of most research, when using data other than from the meteorological stations, was to carry out spatial analysis of precipitation and future projections, in relation to climate change (Warrick *et al.* 2012; Seo *et al.* 2013; Lash *et al.* 2014; Alamdari *et al.* 2018; Quinn *et al.* 2021). Due to the lack of availability of the same monitoring period from meteorological stations for the spatial analysis of precipitation, it was decided to use another data source (Lúcio *et al.* 2020). The Köppen–Geiger classification was also used to consider the precipitation of the studied climate zones (Palla *et al.* 2012; Campisano *et al.* 2013).

Initially, in this work, six questions were asked that supported this research. They were answered in detail throughout the paper and are listed briefly below:

Table 7 | Summary of studies that did not use rainfall data from a meteorological station.

Reference	Study location	Data type	Data origin
Warrick *et al.* (2012)	Australia (Queensland)	Grade – modelo WCRP-CMIP3/ SimCLIM	Bureau of Meteorology (Australia)
Seo *et al.* (2013)	South Korea (Gangneung, Seoul, Busan, Gwangju)	Global circulation models (GCM): CNRM1, CSIRO, and ECHO-G	IPCC Data Distribution Centre (DDC)
Campisano *et al.* (2013)	Italy (44 cities)	Köppen–Geiger classification	–
Lúcio *et al.* (2020)	Portugal (Lisboa)	Grid (model IB02)	–
Quinn *et al.* (2021)	United Kingdom (Sheffield)	UKCP09 UK Climate Projections 2009	Department for Environment, Food and Rural Affairs
Lash *et al.* (2014)	United Kingdom (Penryn, Cambridge, Aberdeen, Ammanford)	UKCP09 UK Climate Projections 2009/UKCP09 Weather Generator	Department for Environment, Food and Rural Affairs
Alamdari *et al.* (2018)	USA (17 cities)	NARCCAP MM5I-CCSM Weather Generator	North American Regional Climate Change Assessment Program (NARCCAP)
Palla *et al.* (2012)	Sweden; Austria; Finland; Germany; Russia; Denmark; Norway; Switzerland (46 cities in these countries)	Köppen–Geiger classification	–

1. What types of rainfall data are used on the RWHS tank sizing?
   The use of precipitation from a meteorological station was observed; climate generators; probabilistic modelling; grid and the Köppen–Geiger classification.
2. What are the sizes and temporal resolution of the historical series of rainfall data used in the sizing of the tanks?
   The historical precipitation series for carrying out the sizing were found to be up to 195 years. In addition, the most used sizes were up to 30 years. As for the temporal resolution of the data, minute, hourly, daily, monthly and annual data were used, with daily data being widely used.
3. From which sources were the data obtained?
   Data were obtained from different sources, depending on the country studied. In addition, the Global Historical Climatology Network (GHCN) was consulted to obtain data from several countries around the world.
4. Is it possible to verify the impact of the types of rainfall data on the results of the sizing of the tanks?
   It was not possible to answer the question. There is a knowledge gap in relation to research with themes that focus on the influence of the use of different types of rainfall data in RWHS tank sizing.
5. Is there any relationship between the type of sizing and the type of rainfall data?
   It was not possible to completely answer the question. However, there is a greater use of the water balance model using data with daily resolution.
6. Is there a relationship between the location of the study and the type of data considered?
   It was not possible to completely answer the question. However, there was greater use of data from sources other than those from meteorological stations on the European continent.

Finally, it should be noted that it was not the object of this work to discuss the impact that different types of data can bring to the final design of the system. It is known that there are important impacts on the type of data used, however, in most cases, the data are used depending on the availability of the region and the designers' familiarity with obtaining them.

CONCLUSION

Through the bibliometric and systematic review of the literature carried out in this paper, a general understanding of the types of precipitation data that are used in research into RWHS tank sizing was obtained. After the selection step, considering the pre-established criteria, there were found to be 106 adherent studies on the subject.

It was found that rainfall data from meteorological stations were used for RWHS tank sizing in most surveys and in all parts of the world. The volumetric capture of rain can be considered to be the closest condition to reality, in terms of monitoring. However, the lack of monitoring in several regions of the world has motivated scientists to research alternatives that can minimise the lack of data and enable analyses in regions with an absence of, or only recent, monitoring. There is a clear knowledge gap in topics that focus on the influence of the use of different types of rainfall data in the RWHS tank sizing, including answering the question: 'Is it possible to verify the impact of the types of rainfall data on the results of the sizing of the tanks?'

Another subject with a growing research trend relates to global climate change. There is a need to analyse the dimensioning of future conditions and, consequently, using rainfall data obtained through projection may be required. Such projections have been developed in order to obtain the best representation of the future rainfall regime. Furthermore, it has been suggested that there is a need for more studies that analyse the influence of different types of projection data for RWHS tank sizing.

It was not possible to identify a clear relationship between the type of dimensioning and the type of rainfall data used. However, it can be stated that there was a greater use of data with daily temporal resolution for most of the dimensions adopted in the published works and that the water balance model with this resolution was also predominant. For the designs, the most used sizes of rainfall historical series were up to 30 years. There is a perceived need for more studies that focus on the use of short series of meteorological stations in the RWHS tank sizing. Such studies may provide better results on the rainfall regime and the influence on the dimensioning for regions with scarce data.

This study also suggests that different types of rainfall data will raise important issues that will receive increasing scientific attention. This has mainly been observed in research that has been looking for alternatives to meteorological station data for their studies.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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