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Review article

Rainwater harvesting and storage systems for domestic supply: An overview of research for water scarcity management in rural areas

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A R T I C L E I N F O

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A B S T R A C T

This article aimed to carry out a systematic review of rainwater harvesting and storage systems (RWHSS) between 2012 and 2022. This study used the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses statement (PRISMA) as reviewing method. The systematic review process involved four stages: identification, screening, eligibility and inclusion. To carry out this research, the Scopus, ScienceDirect and Springer Link digital databases were consulted using the keywords “rainwater”, “storage”, “harvesting”, “rural”, “treatment”; initially obtaining 581 results, after filtering the information through PRISMA, 15 articles were obtained to carry out the analysis of the results linked to the questions raised in this work. The results showed that all the RWHSS have four main components: 1) Catchment area, 2) gutters, 3) pipes and 4) storage system. Regarding the most used material in the system's catchment area, it is galvanized metal with 25.71% of the studies and for the construction of the cistern, it is concrete with 41.66%. The quality of the rainwater collected in the RWHSS varies according to some factors such as the material, maintenance, weather conditions, etc. The main rainwater quality parameters considered by the authors at the time of implementing and using an RWHSS were identified, and compliance of the parameters with the WHO standard values was also evaluated. The main parameters considered by the authors were: pH (66.66%), turbidity (53.33%), E. Coli (53.33%), lead (40%) and nitrates (40%).

1. Introduction

Guaranteeing universal access to clean water and sanitation constitutes the sixth Sustainable Development Goal (SDG) 6 [1]. Its purpose is to ensure that water and sanitation are available in a sustainable and accessible manner for all and to achieve efficient and sustainable management of water resources throughout the planet [2,3]. The potential growth of the population, lack of planning of human settlements in rural areas and anthropogenic contamination of water resources [4,5], make it difficult to achieve (SDG) 6, so it is necessary to implement new technologies and concepts to give solutions and thus adapt to the risks and threats regarding the subject [6,7].

Rainwater harvesting and storage systems (RWHSS) have been considered and used in some countries as self-supply alternatives, and even in countries such as China, Brazil, Australia and India it is mandatory to take into account a RWHSS in the planning stage of cities for the local authority approval [8]. Opting for rainwater systems in rural or urban communities where access to quality water is limited by scarcity, contamination, etc., brings benefits such as economic savings since rainwater is a free resource [9]. Once the rainwater has been collected, its use can be used for activities that require or do not require a purification [10]. These systems have a simple structure and components, in general terms a rainwater harvesting system consists of a catchment, storage and distribution area [11]. Using these systems also generates environmental benefits since taking advantage of rainwater through a RWHSS allows water reserves to improve their availability and minimizes the overexploitation of water sources [12,13].

According to the WHO, RWHSS are a water alternative that can be

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used as long as several conditions are considered: that the system is designed taking into account factors such as site precipitation, surface catchment area, runoff coefficient, material of the roof and the losses of water in the system. In this way, the RWHSS is able to supply sufficient potable water to meet the domestic needs of users [14]. RWHSS are classified according to the type of collection surface used. There are two types of RWHSS, one based on in situ water conservation (small water bodies, wells, embankments), generally used for agriculture, and runoff-based systems (capture and/or storage) [15]. The runoff RWHSS are those used for domestic use; therefore, they are the systems that were analyzed in this work. This type of RWHSS is characterized by using the structure of the roofs and/or patios to collect water in tanks, within which two important factors are considered for efficient operation: 1. The dimension of the storage system and 2. The area of the capture system [8,16].

Regarding the quality of the rainwater collected and deposited in the storage tanks, theoretically it is less contaminated than water from other supply sources such as underground or surface, therefore, in different sectors this water after a disinfection process not very complex is used for drinking [17,18]. However, its quality will depend on the conditions where the system has been implemented, for example, in the Netherlands people use the collected water to flush the toilet, as well as to irrigate gardens or crops because it reduces expenses by not using potable water from the public system. However, this water is not used for drinking due to the presence of human pathogens such as Campylobacter, Cryptosporidium, Giardia, etc. [19,20].

Although this type of self-supply system can be used as a solution to the scarcity of the resource in rural areas or with scarcity problems, it is also necessary to overcome some limitations through an investigation of the possible health risks associated with it. Its use [21]. Thus, for example, chemical and microbiological contaminants have been found in rainwater storage tanks, which can compromise the immune system of the most susceptible people through waterborne diseases [22]. Due to increasing environmental issues such as climate change, aquifer depletion, groundwater salinity, contamination of surface water with metals, fertilizers, fats and oils, fecal matter, pathogens, etc. [23,24]; RWHSS practices continue to meet part of the freshwater need and are attracting attention as a possible alternative to water scarcity of water [25].

RWHSS continues to be an important and integral part of water management strategies in societies around the world, especially at the rural level [26]. Despite the above, the literature lacks a general approach to investigate the problems and strengths of RWHSS in rural areas. For this reason, the objective of this work was to analyze the published literature on the implementation of RWHSS in rural areas during the last 11 years. Other objectives of this review were to identify technological and social considerations in RWHSS research. The benefits and characteristics of the implementation of collection systems applied in other parts of the world can be considered as an alternative for domestic consumption in rural areas or with problems of water scarcity.

2. Methodology

To carry out this review, the methodology of systematic review of the scientific literature was used, which seeks evidence on the same topic to identify, evaluate and simplify the available evidence and also define the gaps in the existing information to solve them in the future [27]**.** For a correct systematic review, the guidelines of the PRISMA statement (Preferred reporting items for Systematic reviews and Meta- Analyses) [28]. The PRISMA statement was published in July 2009 and is intended to help authors improve the presentation of systematic reviews. It includes information that is essential to properly write, interpret, and use the results in a systematic review. It is a set of guidelines for submitting review manuscripts (Page et al., 2021).

The systematic review was carried out based on a strategy that defined: the main theme through the site to be investigated (rural areas or places with water scarcity); the intervention carried out (rainwater collection) and the expected result (domestic use). Through this strategy, the key questions to be investigated were formulated.

2.1. Research questions

1. What are the main components of the systems used to collect and store rainwater for domestic use?
2. What is the influence of materials on water quality in rainwater collection and storage systems?
3. What benefits can be acquired by implementing rainwater collection and treatment systems?
4. What are the important parameters when assessing the quality of rainwater as an alternative for domestic use?

2.2. Selection and evaluation of sources based on the PRISMA statement

For the research process, the following process was carried out: limit the topic, specify the research keywords, choose the databases to apply the keywords, filter the information to eliminate low-quality information and finally analyze the results obtained [29,30].

To start with the searches in the digital databases, the keywords were used: rainwater, rainwater collection and storage, rainwater harvesting, rural community and domestic use. This search was carried out in the Scopus, Springer Link and ScienceDirect databases. For which, AND OR boolean operators were used as appropriate. With this search, 581 results were obtained regarding the subject, filters were applied to identify articles that were in more than one database and other articles that were not related to the questions posed in this work. The search guidelines based on the PRISMA methodology are presented in detail below, as well as the exclusion criteria for some documents.

Scopus, SpringerLink, and ScienceDirect databases. The combination of keywords that presented the best results in the three databases were:

(TITLE-ABS-KEY (rainwater) AND TITLE-ABS-KEY (rainwater AND harvesting) AND TITLE-ABS-KEY (rainwater AND storage) AND TITLE-ABS-KEY (rural))

277 documents were obtained from Scopus, 41 from ScienceDirect and 263 from Springer Link.

2.2.1. Scopus

Created in 2004 by *Elsevier,* it is the largest bibliographic database and abstracts of peer-reviewed literature and high-quality sources on the Web [31].

2.2.2. ScienceDirect

It is one of the most important sources of information for scientific, technical and medical research. Offers the full text of scientific journals and books published by *Elsevier* [32].

2.2.3. Springer Link

It is one of the main multidisciplinary electronic information platforms used by researchers, professors and students, which provides access to all types of documents from *Springer publishing academic journals* [33].

Prior to the selection of the articles, some inclusion and exclusion criteria were defined.

2.3. Inclusion and exclusion criteria

For the inclusion of the articles, it was considered.

- The words used in the search must appear in the title, abstract and/or keywords of the article.
- The studies must be directly related to the use of rainwater for domestic use.

- The studies must be related to the use of rainwater collection and treatment systems intended for rural areas or areas with water scarcity problems.
- The language in which studies are presented limited to English.
- Empirical studies related to the topic and published in scientific articles
- That have been published between the year 2012 and 2022

For the exclusion of the articles, it was considered.

- Studies related to rainwater collection systems in the field were excluded due to the scale and complexity of their infrastructure (agriculture, institutional buildings).
- Articles repeated between digital databases were excluded.
- Articles that do not contribute to answering the research questions were excluded.

Applying the aforementioned criteria, the combination of terms was as follows:

TITLE-ABS-KEY (rainwater) AND TITLE-ABS-KEY (rainwater AND harvesting) AND TITLE-ABS-KEY (water AND quality) AND TITLE-ABS-KEY (rainwater AND storage) AND TITLE-ABS-KEY (rural) AND (LIMIT-TO (LANGUAGE, "English") AND (LIMIT-TO (DOCTYPE, "ar") AND PUBYEAR >2011 AND PUBYEAR <2022.

ScienceDirect and Springer Link digital databases, the structure of the equation was changed. However, the keywords and criteria were the same. Scopus, ScienceDirect and SpringerLink were reduced to 51, 18 and 35 respectively. By reading the title of the selected articles, 38 documents were obtained for Scopus, 10 for ScienceDirect and 23 for Springer Link. Subsequently, the abstract of the articles was read, resulting in 14 articles for Scopus, 7 for ScienceDirect and 9 for SpringerLink.

2.4. Selection of articles

After an in-depth reading, 15 articles were chosen, considering that they include different situations (contamination, water availability, water consumption, materials, pathogens, benefits, etc.) of the use of the basic components of a rainwater collection and storage system. (RWHSS) (capture-roofs, conduction-pipes and storage-tanks). Likewise, these articles considered presented in their results quantitative data of the factors directly related to the use of the RWHSS (type of materials, physicochemical and biological parameters of the water, environmental aspects of the place, etc.). In addition, these manuscripts analyze within their objectives the use of rainwater at the domestic level in rural areas. Whereas the excluded articles presented information outside the time period established for the analysis; Likewise, the studies were applied in industries, schools, agriculture, etc., and likewise their analyzes were on a pilot scale and their results were not related to the research questions of this study.

Fig. 1 shows the diagram used for the selection of articles under the PRISMA statement. The search and filtering of the results was carried out following the indicated procedure, thus obtaining 15 articles for their respective review.

3. Results and discussion

Initially, the information obtained from the review process was selected and organized in Table 1 that includes: article number, author, place of study, original title of the article, year of publication, and abstract.

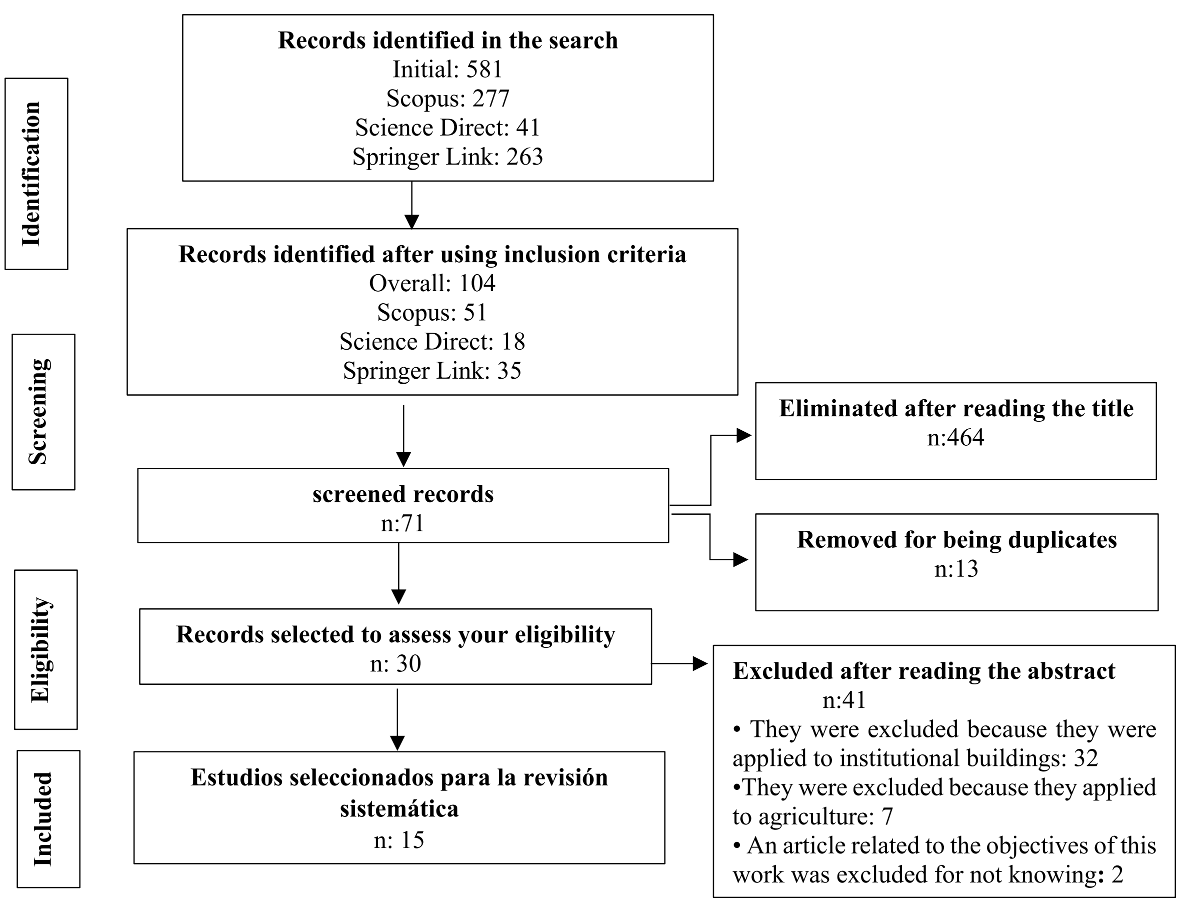

Fig. 1. Selection of relevant articles for the systematic review on the use of RWHSS. PRISMA methodology flowchart.

Table 1
Selected articles in the Scopus, ScienceDirect and Springer Link digital databases.

No.	Author	Place	original title	Year	Summary
1	[34]	Palestine	Heavy Metals in Harvested Rainwater Used for Domestic Purposes in Rural Areas: Yatta Area, Palestine as a Case Study	2022	The collected rainwater is used for domestic purposes, including human consumption, cooking, baths and showers, etc. Analysis was performed to test for a number of heavy metals: Pb, Cr, Mn, Co, Ni, Cu, Zn, and Cd. For the metals Pb, Cr, and Ni, two samples exceeded WHO limits. For the metal, Zn, only one sample exceeded the WHO limit.
2	[35]	Nigeria	Assessment of potability of stored rainwater and impact of environmental conditions on its quality	2019	The collected rainwater is used for washing clothes, cooking and human consumption. Specific environmental conditions such as defecation in the open, proximity of the cistern to the septic tanks, manual extraction of collected water and the rearing of animals in the open affect the optimal functioning of the RWHSS, therefore, a control in the Selection of collection materials, appropriate storage and disinfection of rainwater help to improve its quality.
3	[36]	Bolivian	Arsenic contamination in rainwater harvesting tanks around Lake Poopó in Oruro, Bolivia: An unrecognized health risk	2019	The sources of water for human consumption used by the communities in the study area are mainly affected by mining. The quality of rainwater stored in cisterns was monitored and compared to alternative sources of surface and groundwater that the communities previously relied on. The contaminant found was arsenic due to particles that settled on the roof surface and subsequently entered the system.
4	[37]	Greece	Effect of first-flush device, roofing material, and antecedent dry days on water quality of harvested rainwater	2017	The water quality of two RWHSS, which had first discharge devices, was analyzed. Samples were analyzed to examine the water quality of the storage tanks and first flush devices. The samples showed a satisfactory water quality (not for human consumption) in the storage tanks, while the water in the first discharge device was of poor quality.
5	[38]	Vietnam	Effects of local and spatial conditions on the quality of harvested Rainwater in the Mekong Delta, Vietnam	2013	In this study, the quality of the collected rainwater and its relationship with local conditions (types of roofs, storage system and duration) and spatial conditions (proximity to the industry, main roads, coast) Thatched roofs increased COD (max 23.2 mg/L) and turbidity (max 10.1 NTU) while galvanized roofs caused an increase in Zn (max 2.2 mg/L). However, lead (Pb) (max. 16.9 mg/L) and total coliforms (max. 102,500 CFU 100/mL) were recorded in high concentrations, due to household characteristics, such as storage and handling practices. of rainwater.
6	[39]	Nigeria	Rainfall Harvesting as an Alternative Water Supply in Water Stressed Communities in Aguata-Awka Area of Southeastern Nigeria	2013	The aquifers that supply the population in this study are found at great depths and surface waters are far from homes. The scarcity of water has forced people to adopt mechanisms for collecting rainwater. The mechanisms consist of collecting rainwater from the

(continued on next page)

Table 1 (*continued*)

No.	Author	Place	original title	Year	Summary
					roofs and transporting it to large underground tanks. The parameters analyzed, with the exception of pH, in the aluminum and galvanized iron roofs used, complied with the values established for drinking water quality by the WHO.
7	[40]	Australia	Quality and Quantity Monitoring of Five Rainwater Tanks in Western Sydney, Australia	2013	In this study, five tanks built to store rainwater and for a specific use were analyzed. The first tank is made of galvanized steel, used for shower, toilet and kitchen. Second polyethylene tank for toilet use and irrigation. The third concrete tank provides water for toilets, showers, cooking and for human consumption. The water stored in the fourth and fifth tanks made of galvanized iron were used for toilets and irrigation. The iron tanks presented higher values of aluminum, copper and zinc, while the concrete tank presented high values of hardness, conductivity and pH. The temperature of the site directly affected the water collected in all the tanks.
8	[41]	Italy	A Reliability Analysis of a Rainfall Harvesting System in Southern Italy	2016	This study provides an analysis of the reliability of implementing a RWHSS for toilet flushing and landscape irrigation. The RWHSS can be integrated into the conventional system for domestic uses, in addition to being used as the main source of supply in areas where the resource is scarce.
9	[42]	Nepal	Rainwater harvesting for human consumption and livelihood improvement in rural Nepal: benefits and risks	2012	A survey was conducted in the hills of Nepal to analyze the performance of the RWHSS. Users are satisfied with the added benefits they obtained with the use of RWHSS as is the case with their health. The analyzes showed that the rainwater presents an acceptable quality, but it also shows that the correct practices of operation and maintenance are necessary to ensure the collection of good quality water.
10	[43]	USA	Demographics, practices and water quality from domestic drinking rainwater harvesting systems	2012	In this study, an analysis of the practices carried out by users to harvest rainwater was carried out, as well as the quality of the water harvested in the RWHSS. The results indicated that 64% of the users never carried out an analysis of the RWHSS water, so it was necessary to carry out periodic tests to avoid possible health problems related to the presence of contaminants such as Pb that was present in the pre-filtration samples and post filtration, due to the brass fittings used on the collection surface.
11	[44]	USA	An examination of the microbial community and occurrence of potential human pathogens in rainwater harvested from different roofing materials	2019	In this research, the influence of the type of material used on the roof and its relationship with the microbial community found in the harvested rainwater was analyzed. The materials were concrete tile, bituminous membrane, green roof, galvanized metal, fiberglass tiles. Variation was observed in the microbial communities of the different materials, for example, the roof with concrete tile had the highest

(*continued on next page*)

Table 1 (*continued*)

No.	Author	Place	original title	Year	Summary
					concentration (3.6×10^3 CFU/100 mL). Among the roofs with lower concentrations of pathogens was the galvanized metal roof (1.1×10^3 CFU/100 mL).
12	[45]	Vietnam	Status of water use and potential of rainwater harvesting for replacing centralized supply system in remote mountainous areas: a case study	2020	In this study, a community with water supply problems due to failures in the centralized supply system was evaluated. Through a household survey, it was found that 86.5% depended on sources such as rivers and 13.5% on RWH systems. In the study, methods were applied to determine the dimensions of the storage tanks to reduce the problems caused by the dry months.
13	[46]	India	Assessment of adoption potential of rooftop rainwater harvesting to combat water scarcity: a case study of North 24 Parganas district of West Bengal, India	2021	The study mentions that the population has been consuming water contaminated with arsenic from its sources (shallow wells). In order to reduce water stress, an assessment of aspects such as the economic benefit of implementing a RWHSS was made. A socio-economic study was carried out to assess some aspects such as income, savings, physical availability where to implement the RWHSS, etc. The results allowed us to observe that family size, monthly savings, and expensive assets (television, cable, car, etc.) influence the implementation of a RWHSS in rural communities.
14	[47]	Nigeria	Preliminary Assessment of Rainwater Harvesting Potential in Nigeria: Focus on Flood Mitigation and Domestic Toilet supplies	2014	A water balance was carried out to determine the percentage of water demand that a RWHSS can satisfy. The results indicated that in some areas, such as the tropical forest, more than 80% of the demand can be met with rainwater. It is also considered that the use of RWHSS can serve as a measure to reduce runoff and thus minimize the effects of flooding.
15	[48]	Bangladesh	Feasibility study of rainwater harvesting system in Sylhet City	2012	In rural areas of the study area, the main source of water is underground. However, 61 of the 64 districts found arsenic concentrations higher than 0.05 mg/L. Collecting rainwater for drinking use can be a solution to the consumption of contaminated water, especially due to the availability of rainwater that is available in the area between the months of March and October. This study analyzed the possibility of collecting rainwater in rural communities and the impact of implementing a RWHSS with a simple and low-cost technology. The results showed that a family can meet its annual needs with rainwater because the rainfall measured in the last 44 years shows that it is sufficient. In addition, its implementation is also feasible because rainwater was between three and five times cheaper than that of the conventional supply system.

3.1. Q1. What are the main components of the RWHSS used to collect and store rainwater for domestic use?

The components of a RWHSS can vary (dimensions, materials, quantity) due to factors such as economics or the weather conditions of the place.

The results of the analyzes indicated in Table 2 showed that all the

Table 2
Main components of a RWHSS applied in the selected articles.

Components	Articles
Capture system – Roof (15) gutter system Piping system storage system	[34–48].
First flush system (7)	[36,37,40–43,48].
Filters – meshes (4)	[39,41–43].
Overflow pipe (1)	[40].
Pumping system (1)	[41]

RWHSS used in the 15 articles used at least the following primary components.

- Catchment system: It is the surface destined to capture the water (roofs) and distribute it towards the gutter system.
- Gutter System: Responsible for receiving and transporting rainwater from the catchment surface to the pipes.
- Piping systems: Pipes responsible for transporting the liquid from the gutters to the storage system.
- Storage system: It is the structure or set of physical structures intended to store water.

Fig. 2 shows the aforementioned components within the RWHSS.

In some articles, secondary components that fulfill different functions were also found. For this reason, an analysis of the RWHSS used in the 15 articles and their components was carried out separately. In Table 2 it can be seen that the first column indicates the identified components and the number of articles in which it has been used, in the second column the item(s) where the component has been used within the rainwater system is mentioned.

Among the accessories found are:

First flush system: it is a resource used to divert water that contains undesirable materials accumulated on the roof (Fig. 3) [50]. In general, before the first rain (once the dry season ends), the catchment area has a large accumulation of pollutants (particulate matter, rocks, leaves, animal feces, etc.), which causes the first rain to captured is the most contaminated and therefore represents a potential risk to health and the optimal functioning of the system [37]. This water can be diverted by the first flush system. However, the results showed that of the 15 RWHSS only 46.66% of the cases were implemented. In the study carried out by Ref. [40] the importance of implementing a first discharge system was appreciated since turbidity, total phosphorus, total nitrogen, zinc and Escherichia Coli from the diverted water reached values of 16.6 NTU, 0.34 mg/L, 1.27 mg/L, 59.8 mg/L, and 3860 CFU/100 mL respectively, while the water subsequently collected in the tank reached an average of 2.96 NTU, 0.179 mg/L, 0.59 mg/L, 2.63 mg/L and 11 CFU/100 mL

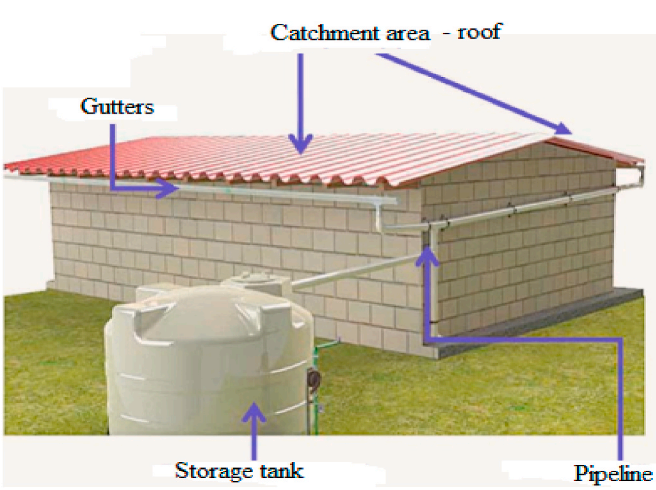

Fig. 2. Principal components in a RWHSS. Retrieved from Ref. [49].

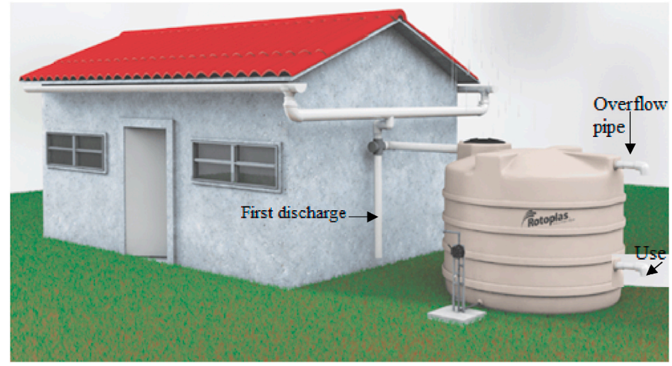

Fig. 3. First discharge system. Source: https://rotoplas.com.mx/captacion-pluvial/.

respectively.

Filters: These are devices that help remove impurities or sediments from water through a physical, chemical or biological barrier (Bunch, 2017). The filters used in the articles were metallic and nylon mesh placed at the entrance of the storage tank. These were applied in 26.66% of the 15 articles studied.

Overflow pipe: The overflow pipe enables the discharge of the flow that feeds the cistern when it is full (Fig. 3). The overflow system was mentioned in 6.67% of the 15 articles.

Pumping system: These are devices whose purpose is to distribute the liquid from one point to another at a higher altitude. The device was used in 6.67% of the cases studied.

Table 2 presents the main components of a RWHSS applied in the 15 articles selected for this review.

3.2. P2. What is the influence of materials on water quality in rainwater collection and storage systems?

The RWHSS and its components were examined to understand the preference of the most commonly used materials, as well as their influence on the quality of the collected water. It is important to mention that according to the articles analyzed, the main components that contribute to contamination are the collection system and the storage system; therefore, these two components were mainly analyzed.

During the analysis of the articles, a total of 35 roofs used for rainwater collection were identified. The reason was that in some articles like the one by Ref. [44] five types of roofs were analyzed: concrete, green roof, bituminous membrane, galvanized metal and fiberglass tiles. The results found are shown in Fig. 4.

The three most used materials for the collection system are galvanized metal with 25.71% followed by the roof with concrete tile with 22.86% and finally the roofs made of zinc plates with 20.00%.

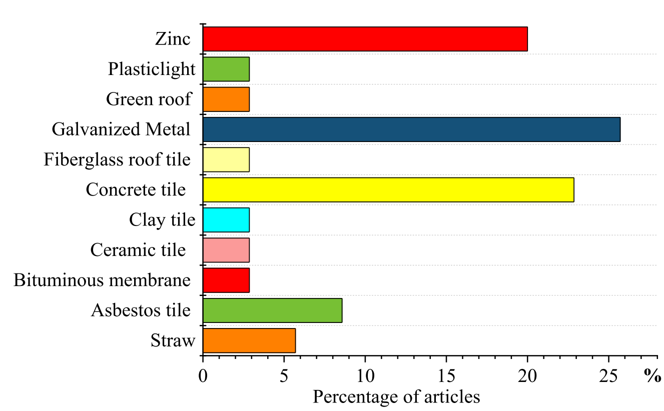

Fig. 4. Materials used to make the roof in a RWHSS system.

The cistern is a deposit whose function is to store water for later use, they are generally used in times of scarcity. In a RWHSS that is intended to provide water for domestic uses, it is necessary for the water quality to meet certain requirements, so it is important to monitor it. For this reason, the material used for its construction must be adjusted to the needs of the users and to the characteristic conditions of the environment where it is to be implemented. Fig. 5 shows the materials used to make the storage system.

The storage system is a complex component due to the cost of implementation and the maintenance required for long-term efficient use of the RWHSS system. The preferred material for the construction of the cistern was concrete with 41.66%, followed by polypropylene tanks with 25%.

This review has revealed that the components with the greatest impact in terms of the quality of the collected rainwater are the catchment system (Roof) and the storage system (Storage tanks or cisterns). The results also show that these components are characterized by being composed mostly of materials such as galvanized metal and concrete, respectively.

3.2.1. *Collection system materials*

The results of the RWHSS review establish that the catchment area is the main source of contamination of collected rainwater. This is due to the fact that various materials are deposited on the roof, which, when they come into contact with rainwater, cause the leaching of substances from the roof and enter the storage system. In the studies carried out by Refs. [36,37]; found arsenic and gypsum in the storage tank. Through the analysis of samples taken from the runoff from the roofs, it was possible to rule out that the contamination was related to the material in the cistern, but rather that it was the result of the leaching of dust deposited on the roof originating from the surroundings due to activities such as construction and industries. These events in the catchment system are corroborated by some authors who mention other forms of contamination on the roof, such as from the excrement of animals, rodents, birds, lizards, and dry lichens that can release ammoniacal nitrogen, phosphates, and pathogens in the air. runoff water [37,41].

The catchment surface is very susceptible to contamination, however, the type of material used can also contribute [34]. According to Ref. [44] the type of roof material selected is an important factor because it has been proven that the concentrations of pathogens (Bacteroides, Enterococci, Legionella, Actinobacteria, etc.) change between different roofs (metallic, green, concrete), which is You can check with what [34]; who conclude that the type of roofing material exerts benefits or disadvantages on the microbial community and in the same way causes alteration to the physical or chemical parameters of rainwater.

As observed in the results of Fig. 4, the most used materials for the catchment surface are galvanized metal (25.71%) and concrete tile (22.86%), which when interacting with rainwater can cause corrosion of the material and drag of substances. In the studies carried out by Refs. [39,45] it has been possible to identify the release of substances from this type of roof such as iron, arsenic, zinc, microorganisms (E. Coli, Enterococci), putting the operation of the RWHSS and the health of the person at risk, this is corroborated by other studies such as those carried out by Refs. [35,38,40,42] and [45]; where the roofing material, inappropriate storage and environmental conditions affect the operation of the RWHSS due to contamination with lead, iron, fecal coliforms, etc.

The accessories used to implement the materials in the catchment system can also be a source of rainwater contamination, this is evidenced in the study carried out by Ref. [43]; where lead concentrations were found in rainwater runoff from the roof. After an analysis of the zinc sheets used and the storage cistern, the authors concluded that the flashings (nails) to fix the zinc sheets on the roof would be responsible for releasing lead into rainwater, this because these materials were composed of 8% lead.

The material least recommended by authors such as [38] is straw, since, despite the ease of implementation, it is a material that affects the quality of rainwater since it can change its color to yellowish, increase turbidity, COD, phosphates, manganese, sodium, pH and total hardness, this was also observed in the studies carried out by Refs. [40,45,46]. The aforementioned authors indicated that the quality of the water collected and analyzed in the runoff from this type of roof was worse compared to that of concrete and that of zinc sheet.

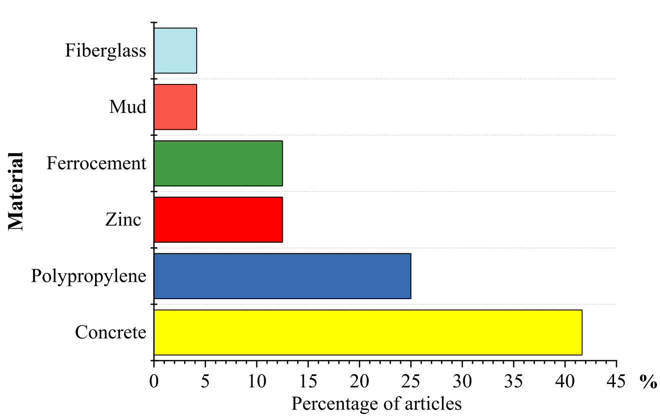

Fig. 5. Materials used to build the storage system in a RWHSS.

3.2.2. *Storage system materials*

The use of certain materials and conditions such as: years of use, maintenance and environmental conditions, influence the quality of rainwater within a storage system. It is necessary that prior to storing the water in the cistern, measures are used (cleaning the catchment area and gutters, use of filters), to prevent the passage of particulate material, animal excreta and plant matter [39], which makes it possible to ensure that the water has an acceptable quality inside the cistern. However, once the water is in the cistern it is important to monitor (smell, color, plant matter, and if possible, parameters such as pH, Turbidity, Coliforms) and maintain the material (fix possible cracks and leaks) of the which the cistern is constituted, since it could become a source of contamination [41].

This investigation determined that the cisterns built with concrete are the most used, representing 41.66% of the results (Fig. 5). These types of tanks are generally composed of cement, water, aggregate materials, and additives [38,40]. It is important to mention that rainwater comes into contact with pollutants in the air (carbon dioxide forming carbonic acid) which causes chemical reactions and changes its pH below 5.6, which is why it is considered acid rainwater [51]. When this water comes into contact with the cistern, it is susceptible to releasing minerals into the water and consequently altering parameters such as total hardness, conductivity, bicarbonates, total alkalinity, calcium, nitrates, zinc, sulfates and magnesium; which can be harmful to health [34,35,39–41,43] and [45]. [42] indicated that a lack of planning in the construction of the concrete tank can cause cracks and with it the proliferation of mosquitoes, representing a health risk for users suffering from vector-borne diseases such as chikungunya, zika, yellow fever, etc. [52].

3.3. *Q3. What benefits can be acquired by implementing rainwater collection and treatment systems?*

The search allowed to observe different benefits for the users of a RWHSS system. Fig. 6 shows the benefits commented by authors where it is observed that the benefits most commented by RWHSS users are those related to health (20%) and the reduction in the use of contaminated sources (20%).

A RWHSS encompasses a set of interrelated components, which by complying with the quality requirements under international norms and standards allow benefits such as safe water supply [41]. The benefits

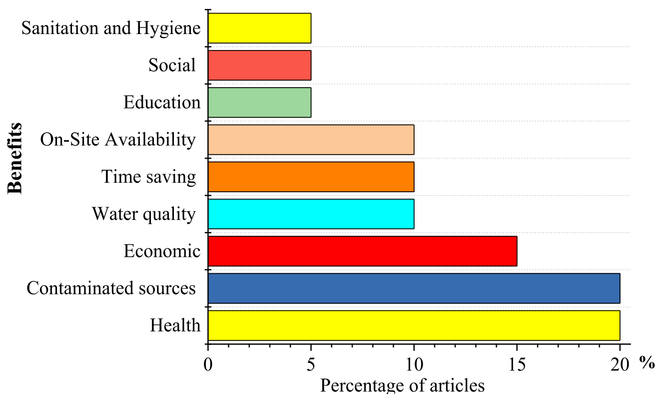

Fig. 6. Benefits related to the use of RWHSS in areas with water scarcity.

have been divided into four categories: 1. Economic, 2. Health, 3. Sanitation and Hygiene, 4. Time saved.

3.3.1. *Economic benefits*

[38] conducted surveys of a population that obtained the resource for domestic consumption from underground and surface sources, the results of the study indicated that 60% of households use rainwater for potable use since it was better in terms of color, odor and taste unlike other potential sources (river water, groundwater) which had a strong saline taste. In this study it was revealed that the inhabitants acquired economic benefits, because the drilling costs to obtain groundwater were high, therefore, the RWHSS system was an alternative source to reduce the difficulties inherent to the scarcity of the resource in the study area. Something similar was manifested in the study carried out by Ref. [43]; where 44% of the households surveyed decided to purchase a rainwater system because it was the least expensive way to obtain drinking water for their homes. In the same way [45], mention that for those surveyed, the use of groundwater is not viable because it is at a deep level and the material to be drilled is hard stone, so the costs of the perforation are high.

In the study carried out by Ref. [42] called "Rainwater collection for human consumption and livelihood improvement in rural Nepal: Risks and Benefits" multiple benefits were reported with the use of RWHSS and a total satisfaction of 78.3% of its population. In this study, the respondents mentioned benefits such as: 1. convenience due to the availability of water on site, 2. saving time and effort, 3. reduction in accidents and injuries during water collection.

3.3.2. *Health benefits*

The second benefit reported by Ref. [42] on health, users now avoid worries of suffering from diseases such as cholera, diarrhea, hepatitis A, dysentery, typhoid fever, etc. [53] related to the consumption of contaminated water, as presented in the results of the socioeconomic survey where it was mentioned that 81.5% of users no longer suffer from diarrhea after the implementation of the RWHSS. This was also verified in the study carried out by Ref. [43] where 75% of the respondents alluded to the fact that rainwater is healthier than well water since it helped reduce the gastrointestinal diseases they suffered.

Those surveyed by Ref. [36] mentioned that their main source of water is underground, however, after a quality analysis, the water showed arsenic concentrations that exceed Bolivian and WHO limits by 25 times; therefore, adopting a RWHSS would benefit the health of the users with the consumption of the resource without the presence of arsenic. Similarly, in the study carried out in the 24th district of West Bengal, India by Ref. [46] it is mentioned that 95% of the population depends on water wells, which present unsanitary conditions where concentrations of arsenic and iron were found that caused skin disorders and diseases such as frequent diarrhea, dysentery, frequent jaundice, fever typhoid, gastrointestinal problems, and vector-borne diseases, therefore, the author concluded that implementing a RWHSS would help meet users' water needs safely.

3.3.3. *Hygiene and sanitation*

Regarding the hygiene and sanitation category [42], reports that RWHSS users can carry out activities such as washing and showering more frequently since they can do it within the home facilities, eliminating the effort of traveling long distances; It also reports that more than 90% of the population wash their hands more frequently (approximately six times a day) and also 85% of households were also able to use the latrine more frequently after implementing the RWHSS.

3.3.4. *Time saving*

[42] mentioned that the respondents dedicate 6.4 h a day of their time to collect water to meet domestic needs. After the implementation of the RWHSS, advantages were obtained, as stated by 89% of the respondents with school-age children. An increase in classroom attendance was achieved due to greater availability over time and a decrease in illnesses among children and women. Another situation related to time was expressed by those surveyed by Refs. [39,40]; where water sources such as rivers, streams and springs were far from their homes, so people had to spend effort and time collecting water, putting them in dangerous situations. Implementing a RWHSS allowed safe supply during the dry season and allowed them to carry out activities other than transporting water to their homes.

3.4. *Q4. What are the important parameters when assessing the quality of rainwater as an alternative for domestic use?*

In this investigation, some parameters used to determine the quality of rainwater collected in a RWHSS were identified. The samples taken were analyzed for general parameters, nutrients, microbial indicators and metals. Table 3 lists the parameters found in the review and their respective references.

The most used parameters to evaluate the quality of the collected rainwater was the pH cited in ten of the fifteen articles (66.66% of the total), followed by turbidity and E. Coli cited in eight of the fifteen articles (53.33%) and lead and nitrates cited in six of the fifteen articles (40%) (Fig. 7).

The authors [39] in their study Rainfall Harvesting as an Alternative Water Supply in Water stressed Communities in Aguata- Awka Area of southeastern Nigeria the pH (6.4) did not meet the standard values established by the WHO for the quality of water for human consumption (6.5–8.5), this is due to the fact that the water used for the analysis is acidic in nature, even so, this value does not represents a health risk.

In the bacteriological analysis carried out in the study by Ref. [35]; the value for *Escherichia coli* (62.6 CFU/100 mL) did not meet the value recommended by the WHO (0 CFU/100 mL). This is because 40% of the population practices open defecation and also approximately 35% of cisterns are located near trees, which increases the risk of fecal contamination. Similarly [36,38,40], for total coliforms, they reached values higher than those recommended by the WHO (0 CFU/100 mL), these being 1600, 426 and 0.31 CFU/100 mL respectively. The causes would be the type of material used for the roof, the water storage location (interior or exterior), poor hygiene practices and the frequency of cleaning the cisterns and catchment surface.

Authors like [40,48] found lead values (0.011 and 0.029 respectively) that exceeded what is suggested by the WHO (0.01 mg/L). This would be caused by factors such as the use of intermittent lead in roofing (waterproofing), use of lead-containing materials, general atmospheric deposition, or resuspension of lead from sediment in the tank.

The authors [36]; **i**n their study, they obtained samples that reached values for arsenic of 0.02 mg/L, which exceeds the WHO value (0.01 mg/L), putting the health of consumers at risk. This concentration was caused by the mineral dust particles generated in the system's environment and which subsequently settled on the roof and entered the

Table 3
Parameters analyzed in the case studies.

parameters	Item No.	Author	Average value	Complies with WHO standard
pH **WHO:6.5–8.5**	10	[35]	**6.4**	**Fails**
		[36]	7.36	Complies
		[37]	6.62	Complies
		[38]	7.1	Complies
		[39]	**6.4**	**Fails**
		[40]	6.60	Complies
		[42]	8.4	Complies
		[48]	7.4	Complies
		[43]	6.9	Complies
		[45]	7.3	Complies
turbidity **WHO: 5 NTU**	8	[35]	0.3	Complies
		[36]	2.13	Complies
		[38]	2	Complies
		[39]	2.06	Complies
		[40]	2.96	Complies
		[42]	5	Complies
		[45]	0.8	Complies
		[48]	0.49	Complies
E. coli **WHO: 0 CFU/100 mL**	8	[35]	**62.6**	**Fails**
		[36]	**0.25**	**Fails**
		[38]	0	Complies
		[40]	**eleven**	**Fails**
		[42]	0	Complies
		[43]	0	Complies
		[39]	0	Complies
		[45]	0	Complies
Lead **WHO: 0.01 mg/L**	6	[34]	0.0018	Complies
		[35]	0	Complies
		[38]	0.005	Complies
		[40]	**0.011**	**Fails**
		[43]	0.00379	Complies
		[48]	**0.029**	**Fails**
total iron **WHO: 0.3 mg/L**	4	[35]	0.1	Complies
		[38]	0.0132	Complies
		[39]	0.1	Complies
		[43]	0.0483	Complies
Nitrates **WHO: 50 mg/L**	6	[35]	3.7	Complies
		[37]	0.65	Complies
		[38]	0.7	Complies
		[39]	0	Complies
		[45]	2.5	Complies
		[43]	0.3	Complies
Arsenic **WHO: 0.01 mg/L**	4	[35]	0.007	Complies
		[36]	**0.02**	**Fails**
		[38]	0.002	Complies
		[43]	0.00065	Complies
Zinc **WHO: 3 mg/L**	5	[34]	0.00234	Complies
		[35]	0.3	Complies
		[38]	0.0838	Complies
		[40]	2.63	Complies
		[43]	0.381	Complies
Copper **WHO: 2000 μg/L**	4	[34]	8.18	Complies
		[38]	0.9	Complies
		[40]	221	Complies
		[43]	261.60	Complies
Cadmium **WHO: 3 μg/L**	3	[34]	0.1	Complies
		[35]	0	Complies
		[38]	0.2	Complies
Chrome **WHO: 50 μg/L**	3	[34]	4.31	Complies
		[35]	0	Complies
		[38]	0.5	Complies
Chloride **WHO: 250 mg/L**	3	[35]	1	Complies
		[37]	5.50	Complies
		[39]	0.3	Complies
Aluminum **WHO: 200 μg/L**	2	[40]	0.115	Complies
		[43]	0.017	Complies
Nickel **WHO: 70 μg/L**	1	[38]	0.4	Complies
Color **WHO: 15 PCU**	1	[39].	2.33	Complies
total coliforms **WHO: 0 CFU/100 mL**	4	[36]	**0.31**	**Fails**
		[38].	**1600**	**Fails**
		[40].	**426**	**Fails**
		[39].	0	Complies
Mercury **WHO: 0.001 mg/L**	1	[38].	**0.0012**	**Fails**
fluorides DWS: 1.5 mg/L	1	[37].	0.11	Complies

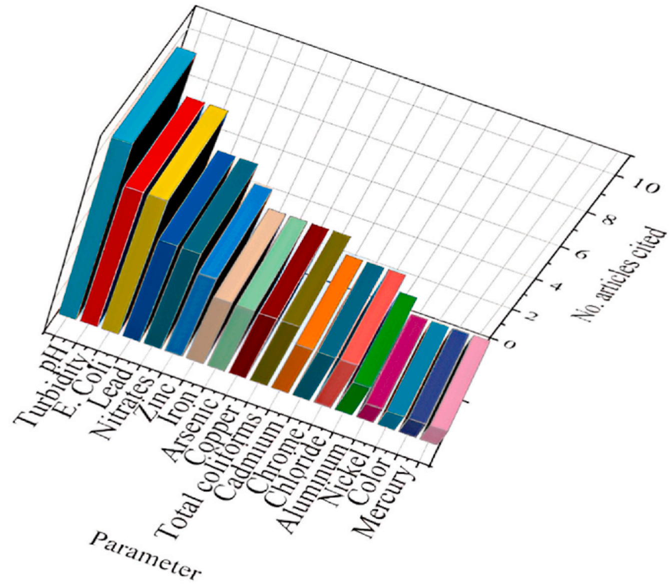

Fig. 7. Main physicochemical and microbiological parameters monitored in the RWHSs.

system when rainwater came into contact with the catchment surface.

3.5. Main findings found in the review

Water scarcity is a problem that affects all continents, therefore, opting for the use of RWHSS would help to improve this situation because they are easy to adapt to the existing structures of a house. In Canada, for example, there are approximately 5000 households in communities that do not have access to potable water or sewerage and are 90% more likely to run out of potable water [54].

In Asia, mainly in the south, there are critical problems regarding the overexploitation of water resources due to overpopulation, climate change, poor water management, destruction and contamination of freshwater systems [55]. In India, the availability of potable water is threatened by population growth which increases the demand for potable water. For example, the residents of New Delhi currently have water supply problems since the demand is approximately 1236 million gallons per day, however, they are only provided with 935 million gallons per day [56].

In sub-Saharan Africa there is low population density but high growth, and in this region there is also endemic poverty, limited infrastructure and an uncertain climate future [57]. Nigeria is one of the 46 countries most affected by the global water crisis, having a supply of 9 L per day, while the WHO recommends 100 L per day [58].

It is important to take into account some considerations prior to implementing a RWHSS to get the most out of it during system operation. In the studio called Preliminary Assessment of Rainwater Harvesting Potential in Nigeria: Focus on flood Mitigation and Domestic Toilet supplies [47], factors are examined to determine the percentage of water demand that can be met by a RWHSS. Among these we have: The roof area, Consumption level, Average annual precipitation.

Also, the study Feasibility study of rainwater harvesting system in Sylhet City mentions that the implementation of a RWHSS can imply an investment of 3–4 times cheaper than the conventional system [48]. Regarding the demand that can be supplied, in this study a reliability analysis was carried out that allowed us to observe that a system with a catchment area of 5.3 m^2 can supply a family of 5 people with a per capita demand of 5 L/day for drinking and cooking activities. A similar calculation was made in the study called Status of water use and potential of rainwater harvesting for replacing centralized supplies system in remote mountainous areas: a case study: in which it was determined that for a family of 5 people with a per capita demand of 14 L/day the average area should be 60 m^2 allowing a water supply for the whole year [45].

In the world there are many neglected areas with respect to drinking water, especially in rural areas where the population does not have access to vital liquid; however, some of these places have high rainfall, which allows the implementation of a RWHSS as an alternative source of water for domestic use [59,60].

3.6. Practical applications, limitations and challenges

Rainwater collection and storage systems are becoming increasingly popular around the world as a solution to combat water scarcity. More and more countries are adopting this technology to capture and store rainwater for later use in various applications.

Handia et al. (2003) and Fisher-Jeffes (2015) indicate that in Africa, the RWHSS could provide a substantial water source across the continent. This has led to the expansion of RWHSS in Africa and the formation of rainwater harvesting associations in several countries. In many parts of the African continent, RWHSS are implemented as a result of water scarcity, but the infrastructure to store, treat and transport it to where it is needed is lacking. Small-scale community RWHSS (i.e. where a pond/tank is used to collect rainwater for a series of homes or a large public building) is probably the most widespread level of RWHSS application in Africa [61,62].

In Asia specifically in Japan, since the early 1980s, local governments began to promote the introduction of water recycling systems as an effective mitigation countermeasure for large cities facing water scarcity problems and urban flooding [63]. Since then, RWHSS has been actively introduced into large public and private buildings thanks to local municipalities' support for promoting special financial programs. The number of RWHSS increases significantly after the introduction of government financial support, with 10 times more facilities registered at the end of 2012 compared to 1990 (MLIT, 2014; [62]. In Gansu Province, China, until the year 2000, a RWHSS demonstration project enabled the construction of more than 2 million rainwater tanks supplying drinking water to nearly 2 million people. Following the example of Gansu province, seventeen provinces have adopted RWHSS since 2001 and have built more than 5.5 million tanks for drinking water and supplemental irrigation throughout China (Gould et al., 2014; [62].

The Australian Bureau of Statistics found that around 1.7 million Australian households installed rainwater tanks, providing about 8% of domestic water use. Between 2007 and 2013 approximately 34% of Australian households installed a rainwater tank. The increase in tank installation is attributed to water restrictions, favorable regulations and price factors. Households outside of state capitals had the highest rate of implementation. The primary motivation for installing a RWHSS system was to save drinking water. 77% of households had no problems implementing the RWHSS (ABS, 2015; [62]. In New Zealand the installation of RWHSS has been made mandatory, which had positive effects, mandatory rainwater collection could increase social welfare [64].

The implementation of RWHSS has varied implementation in European countries. In the UK, people have traditionally collected and stored rainwater for domestic use; however, incentive mechanisms to charge for collected rainwater have not been received from regulatory and management authorities in the UK (Ward et al., 2014).

Germany leads the way in promoting the RWHSS for domestic use, with almost a third of new buildings equipped with RWHSS thanks to government subsidies. Due to industrial pollution and strict drinking water regulations, rainwater is mainly used for non-potable purposes in Germany (Schuetze, 2013). Spain has launched a similar incentive program and France has enacted a regulatory framework [65]; De Gouvello et al., 2014). Italy has also issued technical guidelines and other countries such as Austria, Switzerland, Belgium and Denmark are adopting RWHSS due to the price of drinking water) (UNI, 2012; e Godskesen et al., 2013; Ringelstein, 2015).

The use of RWHSS in the Americas varies by country and state. In the US, there are over 100,000 residential RWHSS in use, ranging from simple landscape irrigation rain barrels to large-scale complex multi-use systems (Lye, 2002). Texas has the highest level of RWHSS implementation and offers financial incentives and local subsidy tools to encourage its construction and water conservation (Texas Water Development Board, 2005). Other states such as Oregon and New Mexico allow rainwater harvesting with strict requirements [62].

In South America, rainwater harvesting programs have been evaluated and implemented in several locations, such as the "One Million Cisterns" program in Brazil, which benefited around two million people (De Moraes and Rocha, 2013). Studies indicate that households with access to rainwater have a lower risk of infections (Marcynuk et al., 2013). However, there is still debate on how to incentivize and charge for the use of these techniques in Brazil (Ward et al., 2014). In Mexico City, the Isla Urbana initiative collects rainwater from roofs to alleviate water scarcity and local flooding problems [66].

The behavior of rainwater harvesting and storage systems (RWHSS) at the building scale has been extensively studied [62], but there is still a lack of knowledge about the impacts at a larger scale. Precise simulations have been carried out at the urban scale but limited to blocks of multiple units or neighborhoods [65]. Some studies have considered entire cities, demonstrating that the potential water savings vary significantly between different cities, ranging from 34% to 92% (average 69%) [67]. Different methodologies have been proposed to assess the potential for rainwater harvesting at the urban scale, taking into account the characteristics and consumption patterns of buildings, and the effect of climate change on the performance of an RWHSS in a specific community in Bangladesh has also been analyzed (Lucio et al., 2020; [68]. Government policies and regulations have a significant influence on the effectiveness and acceptance of the system, and further research is needed to improve institutional and sociopolitical support.

3.7. Knowledge gaps regarding RWHSS

Below are some of the gaps that can be analyzed after the preparation of this research.

In almost all the studies selected for the systematic review, sampling was done on the quality of the water harvested in the cistern or storage tank, however, the results in some study cases show contamination outside the component examined, so it should be considered carry out an analysis of the rainwater coming from the roof, followed by the analysis in the cistern to make a comparison of the quality between both components. This process would help to identify potential sources of contamination and leaks throughout the stormwater journey.

The application of the RWHSS has the objective of improving the quality of life of people by providing them with a safe water supply with different practices from the conventional system, however, the quality of the rainwater collected in all the case studies was not suitable. for direct consumption, so in the future it is necessary to adapt mechanisms to retain or divert pollutants and capture better quality rainwater. Firstly, it is recommended that RWHSS have a first discharge system because this would avoid the storage of polluting substances, however, in the studies this mechanism is not used regularly because, being manually controlled, its use is restricted to the availability of users. To use it or not. Therefore, including electronic systems that allow the diversion of the first rain in an automated way would improve the quality conditions of the rainwater in the cistern.

The position and distance of the RWHSS components in relation to the dwelling was not specified by users in any of the studies. Only, it is mentioned that the cistern must be far from the latrines (at least 15 m) or in the case that the cistern is underground it must be above the level of the latrine. In the future, the influence of the position of the components should be analyzed, as well as the angle of inclination of the roof to be used in relation to the prevailing winds in the area and its possible effect as a cleaning mechanism.

Another suggestion for future work is the use of barriers and disinfection systems. In the cases analyzed, the barrier mechanisms were mesh filters; however, they were rarely applied by the users, and the results were not clear regarding the benefits associated with their use. Applying filtration processes (slow or fast) or chlorination should be considered and analyzed to integrate the RWHSS and observe their effect on rainwater quality.

Rainwater harvesting and storage systems require regular maintenance to ensure their proper functioning and durability. Research is needed to develop technologies that are durable and require less maintenance.

The calculations to estimate the size of some components such as the cistern were made based on data collected from precipitation in certain periods of time, however, the current phenomenon of climate change should also be considered due to the fluctuations that could cause in the estimates of component dimensions. Also, the impact of the use of RWHSS on a large scale for the mitigation of floods due to climate change should be analyzed.

4. Conclusions

The PRISMA statement appears to be a useful method for conducting a systematic review. The main components of the RWHSSs for domestic use include: a collection surface, a system of gutters and tubes, and a storage system, but it is important to integrate a first discharge system in the event that its use is intended for human consumption, due to that serves as a barrier to protect the quality of the rainwater that is going to be stored in the cistern. The materials used in roofs can have a significant influence on the quality of the water; such is the case of galvanized metal or zinc, which through UV radiation help control the diversity of pathogenic microorganisms. It is better to use tanks made of polypropylene for storage, since it hardly cracks, preventing the infiltration of polluting substances into the collected rainwater. The implementation of RWHSSs can provide several benefits, such as saving drinking water by using rainwater for domestic activities such as garden watering, cleaning or laundry. Reduced runoff by collecting it at home, which decreases the amount of water flowing into storm drainage systems and prevents the risk of flooding. In addition, the use of locally collected rainwater saves energy by reducing the need to transport and treat potable water. The important parameters when evaluating the quality of rainwater as an alternative for domestic use include pH, E. Coli, lead and nitrates. RWHSSs can be an effective solution for water supply in rural or water-scarce areas, provided they are properly implemented and properly maintained.

All these findings have implications for future research that can range from the life cycle of RWHSSs to water quality assessment, design and implementation, cost-benefit analysis, development of more efficient technologies.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

References

[1] P. Dwivedi, D. Sharma, Application of Shannon Entropy and COCOSO techniques to analyze performance of sustainable development goals: the case of the Indian Union Territories, Results in Engineering 14 (2022), 100416, https://doi.org/10.1016/j.rineng.2022.100416.

[2] C. Tortajada, A.K. Biswas, Achieving universal access to clean water and sanitation in an era of water scarcity: strengthening contributions from academia, Curr. Opin. Environ. Sustain. 34 (2018) 21–25, https://doi.org/10.1016/j.cosust.2018.08.001.

[3] F. García-Ávila, A. Méndez-Heredia, A. Trelles-Agurto, E. Sánchez-Cordero, E. A. Alfaro-Paredes, F. Criollo-Illescas, M.D. Tonon-Ordoñez, G. Heredia-Cabrera, Experimental evaluation of tubular flocculator implemented in the field for drinking water supply: application in the developing world, Water 15 (2023) 833, https://doi.org/10.3390/w15050833.

[4] A. Murei, B. Mogané, D.P. Mothiba, O.T.W. Mochware, J.M. Sekgobela, M. Mudau, N. Musumuvhi, C.M. Khabo-Mmekoa, R.C. Moropeng, M.N.B. Momba, Barriers to water and sanitation safety plans in rural areas of South Africa—a case study in the vhembe district, limpopo province, Water 14 (2022) 1244, https://doi.org/10.3390/w14081244.

[5] G. Cheng, Y. Li, Y. Cao, Z. Zhang, A novel method for the desulfurization of medium–high sulfur coking coal, Fuel 335 (2023), 126988, https://doi.org/10.1016/j.fuel.2022.126988.

[6] F. García-Ávila, L. Valdiviezo-Gonzales, S. Iglesias-Abad, H. Gutiérrez-Ortega, M. Cadme-Galabay, S. Donoso-Moscoso, C. Zhindón- Arévalo, Opportunities for improvement in a potabilization plant based on cleaner production: experimental and theoretical investigations, Results in Engineering 11 (2021), 100274, https://doi.org/10.1016/j.rineng.2021.100274.

[7] D. Kakoulas, S. Golfinopoulos, D.D. Koumparou Alexakis, The effectiveness of rainwater harvesting infrastructure in a mediterranean island, Water 14 (5) (2022) 1–19, https://doi.org/10.3390/w14050716.

[8] O. Aladenola, O. Adeboye, Assessing the potential for rainwater harvesting, Water Resour. Manag. 24 (10) (2010) 2129–2137, https://doi.org/10.1007/s11269-009-9542-y.

[9] N. Sagüi, R.S. Madrigal Estigarribia, Adaptándose a la escasez de agua en comunidades rurales del corredor seco centroamericano: análisis de costo-beneficio para mejorar a provisión de agua potable en la comunidad de Maraxco, vol. 9, Chiquimula, Guatemala, 2017, pp. 85–101.

[10] G. Sandoval, Ventajas económicas del aprovechamiento del agua lluvia, Equidad y Desarrollo 26 (2016) 101, https://doi.org/10.19052/ed.3650.

[11] L. Álvarez, Usos y beneficios de agua fluvial, Asociación Españolas de Empresas Del Sector Agua, 2018.

[12] A. Pérez, O. Palacios, M. Garduño, J. Tovar, Agua de lluvia para consumo humano y uso doméstico en San Miguel Tulancingo, Oaxaca, Revista Mexicana de Ciencias Agrícolas 8 (2017) 1427–1432.

[13] S. Ortiz, P. de Barros Barreto, M. Castier, Rainwater harvesting for domestic applications: the case of Asunción, Paraguay, Results in Engineering 16 (2022), 100638, https://doi.org/10.1016/j.rineng.2022.100638.

[14] WHO, Rainwater Collection and Storage. Integrated Greenhouse Systems for Mild Climates (2021), https://doi.org/10.1007/978-3-642-14582-7_14. February, 321–327.

[15] A.K. Binyam Desale, Rainwater harvesting: an option for dry land agriculture in arid and semi-arid Ethiopia, Int. J. Water Resour. Environ. Eng. 7 (2) (2015) 17–28, https://doi.org/10.5897/ijwree2014.0539.

[16] M. Kwaadsteniet, P. Dobrowsky, A. Van Deventer, W.T. Khan Cloete, Domestic Rainwater Harvesting: Microbial and Chemical Water Quality and Point-of-Use Treatment Systems, 2013, https://doi.org/10.1007/s11270-013-1629-7.

[17] B. Vilane, E. Mwendera, An inventory of rainwater harvesting technologies in Swaziland, Afr. J. Agric. Res. 6 (6) (2011) 1313–1321, https://doi.org/10.5897/AJAR09.117.

[18] R. Torres, La captación del agua de lluvia como solución en el pasado y el presente, Ing. Hidraul. Ambient. 40 (2) (2019) 125–139.

[19] F. Schets, R. Italiaander, H.A. Van Den Berg De Roda Husman, Rainwater harvesting: quality assessment and utilization in The Netherlands, J. Water Health 8 (2) (2010) 224–235, https://doi.org/10.2166/wh.2009.037.

[20] C. Solano, F. Gonzaga, F. Espinoza, J. Espinoza, Sistema de captación de agua de lluvia para uso doméstico, Isla Jambelí, cantón Santa Rosa, Cumbres 3 (1) (2017) 151–159. http://investigacion.utmachala.edu.ec/revistas/index.php/Cumbres/article/view/201.

[21] A. Fiorentino, G. Lofrano, R. Cucciniello, M. Carotenuto, O. Motta, A. Proto, L. Rizzo, Disinfection of roof harvested rainwater inoculated with E. coli and Enterococcus and post-treatment bacterial regrowth: conventional vs solar driven advanced oxidation processes, Sci. Total Environ. 801 (2021), 149763, https://doi.org/10.1016/j.scitotenv.2021.149763.

[22] W. Shuster, D. Lye, A. De La Cruz, L. Rhea, K. O'Connell, A. Kelty, Assessment of residential rain barrel water quality and use in Cincinnati, Ohio1, J. Am. Water Resour. Assoc. 49 (4) (2013) 753–765, https://doi.org/10.1111/jawr.12036.

[23] N. Akhtar, M.I. Syakir Ishak, S.A. Bhawani, K. Umar, Various natural and anthropogenic factors responsible for water quality degradation: a review, Water 13 (2021) 2660, https://doi.org/10.3390/w13192660.

[24] G. Cheng, M. Zhang, y. Lu, y. Zhang, B. Lin, E.V. Lau, A novel method for the green utilization of waste fried oil, Particuology 84 (2024) 1–11, https://doi.org/10.1016/j.partic.2023.02.019.

[25] S. Opare, Rainwater harvesting: an option for sustainable rural water supply in Ghana, Geojournal 77 (5) (2012) 695–705, https://doi.org/10.1007/s10708-011-9418-6.

[26] T. Islam, M. Ullah, M. Amin, S. Hossain, Rainwater harvesting potential for farming system development in a hilly watershed of Bangladesh, Appl. Water Sci. 7 (5) (2017) 2523–2532, https://doi.org/10.1007/s13201-016-0444-x.

[27] E. Linares, V. Hernández, J. Domínguez, S. Fernández, V. Hevia, J. Mayor, B. Padilla, M. Ribal, Methodology of a systematic review, Actas Urol. Esp. 42 (8) (2018) 499–506, https://doi.org/10.1016/j.acuro.2018.01.010.

[28] G. Urrutia, X. Bonfill, PRISMA_Spanish.pdf, in: Medicina Clínica, 2010, pp. 507–511. Vol. 135, Issue 11, http://es.cochrane.org/sites/es.cochrane.org/files/public/uploads/PRISMA_Spanish.pdf.
[29] E. Aromataris, A. Pearson, The systematic review: an overview, Am. J. Nurs. 114 (3) (2014) 53–58, https://doi.org/10.1097/01.NAJ.0000444496.24228.2c.
[30] B. Moreno, M. Muñoz, J. Cuellar, S. Domancic, J. Villanueva, Revisiones Sistemáticas: definición y nociones básicas, Revista Clínica de Periodoncia, Implantología y Rehabilitación Oral 11 (3) (2018) 184–186, https://doi.org/10.4067/s0719-01072018000300184.
[31] R. Cañedo, R. Rodríguez, M. Montejo, Scopus: la mayor base de datos de literatura científica arbitrada al alcance de los países subdesarrollados, Revista Cubana de ACIMED 21 (3) (2010) 270–282.
[32] M. Tober, PubMed, ScienceDirect, Scopus or Google Scholar - which is the best search engine for an effective literature research in laser medicine? Med. Laser Appl. 26 (3) (2011) 139–144, https://doi.org/10.1016/j.mla.2011.05.006.
[33] M. Flores, P. Gómez, C. Feregrino, Bases de datos academicas en Ciencias Computacionales (2011) 1–8.
[34] F. Anabtawi, N. Mahmoud, I. Al-Khatib, Y. Hung, Heavy metals in harvested rainwater used for domestic purposes in rural areas (yatta, hebron as a case study), Int. J. Environ. Res. Publ. Health (2022) 1–14.
[35] C.J. Nnaji Nnam, Assessment of potability of stored rainwater and impact of environmental conditions on its quality, Int. J. Environ. Sci. Technol. 16 (12) (2019) 8471–8484, https://doi.org/10.1007/s13762-019-02456-7.
[36] W. Quaghebeur, R.E. Mulhern, S. Ronsse, S. Heylen, H. Blommaert, S. Potemans, C. Valdivia, J. Terrazas, Arsenic contamination in rainwater harvesting tanks around Lake Poopó in Oruro, Bolivia: an unrecognized health risk, Sci. Total Environ. 688 (2019) 224–230, https://doi.org/10.1016/j.scitotenv.2019.06.126.
[37] G. Gikas, V. Tsihrintzis, Effect of first-flush device, roofing material, and antecedent dry days on water quality of harvested rainwater, Environ. Sci. Pollut. Control Ser. 24 (27) (2017) 21997–22006, https://doi.org/10.1007/s11356-017-9868-6.
[38] G. Wilbers, Z. Sebesvari, A. Rechenburg, F. Renaud, Effects of local and spatial conditions on the quality of harvested rainwater in the Mekong Delta, Vietnam, Environ. Pollut. 182 (2013) 225–232, https://doi.org/10.1016/j.envpol.2013.07.019.
[39] E. Okpoko, B. Egboka, L. Anike, E. Okoro, Rainfall harvesting as an alternative water supply in water stressed communities in Aguata-Awka area of Southeastern Nigeria, Environmental Engineering Research 18 (2) (2013) 95–101, https://doi.org/10.4491/eer.2013.18.2.095.
[40] M. Van der Sterren, A. Rahman, G. Dennis, Quality and quantity monitoring of five rainwater tanks in western sydney, Australia, J. Environ. Eng. 139 (3) (2013) 332–340, https://doi.org/10.1061/(asce)ee.1943-7870.0000614.
[41] L. Liuzzo, V. Notaro, G. Freni, A reliability analysis of a rainfall harvesting system in Southern Italy, Water (Switzerland) 8 (1) (2016) 1–20, https://doi.org/10.3390/w8010018.
[42] L. Domènech, H. Heijnen, D. Saurí, Rainwater harvesting for human consumption and livelihood improvement in rural Nepal: benefits and risks, Water Environ. J. 26 (4) (2012) 465–472, https://doi.org/10.1111/j.1747-6593.2011.00305.x.
[43] B. Stump, M. McBroom, R. Darville, Demographics, practices and water quality from domestic potable rainwater harvesting systems, J. Water Supply Res. Technol. - Aqua 61 (5) (2012) 261–271, https://doi.org/10.2166/aqua.2012.007.
[44] S. Bae, J. Maestre, K. Kinney, M. Kirisits, An examination of the microbial community and occurrence of potential human pathogens in rainwater harvested from different roofing materials, Water Res. 159 (2019) 406–413, https://doi.org/10.1016/j.watres.2019.05.029.
[45] X. Nguyen, T. Nguyen, X. Bui, X. Tran, T. Tran, T. Phuong, N. Hoang, D. Duong, S. Chang, H. Ngo, D. Nguyen, Status of water use and potential of rainwater harvesting for replacing centralized supply system in remote mountainous areas: a case study, Environ. Sci. Pollut. Control Ser. 28 (45) (2020) 63589–63598, https://doi.org/10.1007/s11356-020-11154-8.
[46] S. Biswas, S. Sahoo, A. Debsarkar, M. Pal, Assessment of adoption potential of rooftop rainwater harvesting to combat water scarcity: a case study of North 24 Parganas district of West Bengal, India, Arabian J. Geosci. 14 (16) (2021), https://doi.org/10.1007/s12517-021-07989-1.
[47] C.N. Nnaji Mama, Preliminary assessment of rainwater harvesting potential in Nigeria: Focus on flood mitigation and domestic water supply, Water Resour. Manag. 28 (7) (2014) 1907–1920, https://doi.org/10.1007/s11269-014-0579-1.
[48] R. Alam, G. Munna, M. Chowdhury, M. Sarkar, M. Ahmed, M. Rahman, F. M. Jesmin Toimoor, Feasibility study of rainwater harvesting system in Sylhet City, Environ. Monit. Assess. 184 (1) (2012) 573–580, https://doi.org/10.1007/s10661-011-1989-7.
[49] Huairou Commission, Cosecha de agua lluvia. La plataforma de practicantes comunitarias para resilencia, 2016.
[50] P. Cisneros, Sustainable Sanitation and Water Management Toolbox. Obtenido de Sustainable Sanitation and Water Management Toolbox, 2020. https://sswm.info/es/gass-perspective-es/tecnologias-de-agua-y-saneamiento/tecnologias-de-abastecimiento-de-agua-para-11/tuber%C3%ADas-de-agua-de-lluvia.
[51] J. Bluhm, Aspectos de la medición del pH del agua de lluvia. January, 2009. https://www.researchgate.net/publication/291166684.
[52] WHO, World Health Organization, Vector-borne diseases. https://www.who.int/news-room/fact-sheets/detail/vector-borne-diseases, 2020. (Accessed 4 December 2023).
[53] WHO, World Health Organization, Drinking-water. https://www.who.int/news-room/fact-sheets/detail/drinking-water, 2022. (Accessed 11 December 2023).
[54] L. Guppy, K. Anderson, L. Guppy, K. Anderson, Water Crisis Report. United Nations University Institute for Water, Environment and Health, Hamilton, Canada, 2017, https://doi.org/10.13140/RG.2.2.14415.02720. Technical Report · January 2017. January 2020.
[55] A. Salmivaara, M. Porkka, M. Kummu, M. Keskinen, J.H.A. Guillaume, O. Varis, Exploring the modifiable areal unit problem in spatial water assessments: a case of water shortage in Monsoon Asia, Water (Switzerland) 7 (3) (2015) 898–917, https://doi.org/10.3390/w7030898.
[56] UNESCO, Asia and the Pacific: Megacities, Water , and Climate Change: First MAWAC Regional Meeting for Asia and the Pacific (MAWAC-ASPAC) Official Statements from Megacities, 2021, pp. 14–15.
[57] D. Anim, R. Ofori, Water scarcity and COVID-19 in sub-Saharan Africa, J. Infect. 81 (2) (2020) e108–e109, https://doi.org/10.1016/j.jinf.2020.05.032.
[58] M. Kanjere, K. Thaba, M. Lekoana, Water shortage management at letaba water catchment area in limpopo province, of South Africa, Mediterr. J. Soc. Sci. 5 (27) (2014) 1356–1360, https://doi.org/10.5901/mjss.2014.v5n27p1356.
[59] Md Hafizi, N. Lani, Z. Yusop, A.A. Syafiuddin, Review of rainwater harvesting in Malaysia: prospects and challenges, Water 10 (4) (2018) 506, https://doi.org/10.3390/w1004050.
[60] T.T. Ross, M.A. Alim, A. Rahman, Community-scale rural drinking water supply systems based on harvested rainwater: a case study of Australia and vietnam, Water 14 (11) (2022) 1763, https://doi.org/10.3390/w14111763, 2022.
[61] P. Dobrowsky, S. Khan, T.E. Cloete, W. Khan, Microbial and physico-chemical characteristics associated with the incidence of Legionella spp. and acanthamoeba spp. in rainwater harvested from different roofing materials, Water Air Soil Pollut. 228 (2) (2017), https://doi.org/10.1007/s11270-017-3270-3.
[62] A. Campisano, D. Butler, S. Ward, M.J. Burns, E. Friedler, K. DeBusk, L. Fisher-Jeffes, E. Ghisi, A. Rahman, H. Furumai, M. Han, Urban rainwater harvesting systems: research, implementation and future perspectives, Water Res. 115 (2017) 195–209, https://doi.org/10.1016/j.watres.2017.02.056.
[63] H. Takeuchi, H. Tanaka, Water reuse and recycling in Japan — history, current situation, and future perspectives, Water Cycle 1 (2020) 1–12, https://doi.org/10.1016/j.watcyc.2020.05.001.
[64] J. Gabe, S. Trowsdale, M. Mistry, Mandatory urban rainwater harvesting: learning from experience, Water Sci. Technol. 65 (7) (2012) 1200–1207, https://doi.org/10.2166/wst.2012.955.
[65] L. Domènech, D. Saurí, A comparative appraisal of the use of rainwater harvesting in single and multi-family buildings of the metropolitan area of Barcelona (Spain): social experience, drinking water savings and economic costs, J. Clean. Prod. 19 (2011) 598–608.
[66] Isla Urbana, Isla Urbana, 2016. http://islaurbana.org/english/. (Accessed 14 April 2023).
[67] E. Ghisi, A. Montibeller, R.W. Schmidt, Potential for potable water savings by using rainwater: an analysis over 62 cities in southern Brazil, Build. Environ. 41 (2006) 204–210.
[68] M.M. Islam, S. Afrin, M.H. Tarek, M.M. Rahman, Reliability and financial feasibility assessment of a community rainwater harvesting system considering precipitation variability due to climate change, J. Environ. Manag. 289 (2021), 112507 pmid:33839610.