A review on harvesting and harnessing rainwater: an alternative strategy to cope with drinking water scarcity
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ABSTRACT
Currently available sources of water face extreme pressures around the globe because of oblivious human activities as well as changing climate. The rainwater harvesting system (RWHS) carries a huge potential to enhance surface and groundwater resources in regions having a poor water supply. Recently, several countries have started to promote the updated implementation of such practice to tackle the problem of growing water demand. These considerations motivated our enthusiasm for looking at its current circumstances and the possibility of RWHS in the future. In this regard, the study aims to identify the evidence gap among different determinants (climate change, reliability, water quality and financial viability) intertwined with RWHS. In the paper, studies related to the significance of RWHS amidst scarcity of water around the globe, published in valued journals from 2000 to 2020, are reviewed. We found that the RWHS becomes economically viable when certain steps and risk assessment methods are executed in planning and maintaining this system. The study concludes that drinking water sufficiency is possible if a sustainable drinking water supply system is built via RWHS.

Key words | alternative water source, climate change, economic feasibility, rainwater harvesting system, water quality, water scarcity

HIGHLIGHTS

• Rainwater harvesting system (RWHS) carries a huge potential as an alternative strategy to cope with drinking water scarcity.
• RWHS becomes economically feasible when certain steps and risk assessment procedures are implemented in designing and maintaining this system.
• Drinking water sufficiency is possible if a sustainable drinking water supply system is established via RWHS.

INTRODUCTION
Being a critical and perpetual natural resource, water is essential for the health of every species on Earth, socio-economic prosperity of a country, food production, and environment (Boretti & Rosa 2019). Despite the fact that water covers 70% of the Earth’s surface, having proper access to water supply has become a multifaceted issue for nations throughout the world (Khatri et al. 2014). It is predicted that by 2025 the number of people suffering from scarcity of water will reach three billion (Hanjra & Qureshi 2010). Rainwater harvesting (RWH), among others, can be

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doi: 10.2166/ws.2020.264
an appropriate solution as it has many advantages for users as well as for governments and the environment (Che-Ani et al. 2009).

Rainwater harvesting is an old practice of water protection measures, particularly in areas where other water resources are scant or hard to access. However, in recent years, scientists and policy-makers have indicated renewed enthusiasm for water utilization procedures because of rising water demand and increased interest in conservation (Ogale 2011). As the ongoing endeavors of both government and non-governmental institutions are focused on encouraging water harvesting and groundwater recharge in urban and rural regions, it has been an emerging avenue in water resource development and management (Dey & Sikka 2010). Harvesting, conservation and reuse of rainwater are sustainable practices through which there will be an increase in water availability (Yannopoulos et al. 2017). With the increasing demand for water, RWH for non-potable or irrigation uses and for groundwater recharge is presently being considered in numerous urban areas (Oke & Oyebola 2015).

Prof. Geddes in 1964 coined the term ‘Rainwater harvesting’ for the collection and storage of any form of waters, either overflow or creek flow, for irrigation use (Geddes 1964). Moreover, today water harvesting is defined as an act of direct collection of rainwater, which can be kept for direct consumption or can revive the groundwater. It is the gathering of runoff for productive purposes (Julius et al. 2013). This study defines it as a strategy by which precipitation that falls upon a surface catchment area (rooftop, walkways, parking areas, landscaped areas, etc.) is collected and routed to a reservoir for daily consumption and irrigation.

Many countries are facing severe pressure of water scarcity around the world. On the other side, changing demographic patterns, socio-economic development, technological innovation and environmental degradation, especially climate change, are responsible for creating an acute water shortage for human life (Wu et al. 2020). In such a situation, it has been found that technological solutions like rainwater harvesting, wastewater reuse and desalination can reduce the problem to some extent, also in countries with modest economical means (Elimelech 2006). From an environmental viewpoint, water reuse can diminish demand for freshwater resources, expand water sources and improve the reliability of the access to resources; and it can reduce the amount of wastewater discharged into the environment.

This research extrapolates the evidence gap among different factors intertwined with RWH, focusing on financial viability, usefulness/reliability analysis, water quality and impacts of climate change. Moreover, recent studies on RWHS were reviewed to investigate: (1) how climate change can influence the reliability of a small-scale RWHS; (2) to what extent people can rely on harvested water: completely or partially; (3) whether the quality of harvested rainwater meets drinking water standards; and (4) whether RWHS is financially viable or not.

Research papers are exhaustively selected from scientific databases like Scopus, Web of Science, Science Direct and Google Scholar by developing criteria for each component to ensure the idea goes in-depth and analyzes the roles of the RWHS in minimizing water scarcity. In the process of paper selection, we set a criterion that the paper should directly or indirectly comprise any one of the five components: RWH system, financial viability, usefulness/reliability analysis, water quality and impacts of climate change. This was set with the purpose of finding the evidence gap in the reviewed papers from 2000 to 2020. The main components of the RWH system and its significance amidst the scarcity of water around the globe are reviewed based on some selected potential past pieces of evidence.

**EVIDENCE ON INTERCONNECTION AMONG RAINWATER HARVESTING SYSTEMS AND ITS DETERMINANTS**

Among various determinants of RWH, this study focuses its attention on the four most important factors. First, the variability of rainfall under a climate change scenario is a pivotal facet to analyze while harvesting and harnessing rainwater. Second, financial-cum-technical cost incurred and affordability for people along with water quality are the other important areas to look at before designing and implementing RWHS. Each subheading discussed below links with the importance of rainwater in terms of socio-economic development.
Climate change and RWHS

Along with the rapid increase in population, industrialization and urbanization, climate change plays a decisive role in the meeting of water demand and supply (Elmahdi et al. 2009). As put by Haque et al. (2015), climate change is one of the major factors that impact catchment water. Due to climate change conditions resulting from global warming, the availability of water resources could be severely affected. On account of worldwide temperature alteration, evapotranspiration and atmospheric water storage are probably going to be influenced, and this as a result would change the magnitudes, intensities and frequencies of rainfall in the future (Wang et al. 2015). The reliability of RWHS depends on the rainfall pattern and duration of the dry period, and these boundaries would differ with climate change. The assurance of ideal tank size from the Water Balance Model (WBM) utilizing local rainfall data without considering climate change outcome would result in an insufficient design (Basinger et al. 2010; Wallace et al. 2015). The indecision of future rainfall events with regards to climate change is an important parameter to be considered in the WBM (Haque et al. 2015; Lo & Koralegedara 2015; Wallace et al. 2015).

Similarly, Musayev et al. (2018) investigated the capability of RWHS for unwavering quality in residential water security for significant world climatic zones under various atmosphere situations. Using recorded information from 94 sites to simulate synthetic daily rainfall in their model, they found that climate change would marginally affect the dependability of the RWHS. Alamdari et al. (2018) also examined the impact of climate change on the reliability of RWHS in the USA. It was accounted for that in certain spots, the overflow catch may diminish to as low as 12% whereas the water supply reliability would tumble to 18%. Notwithstanding, it was additionally assessed that parts of the region would encounter a lift in reliability as high as 22% regarding the water supply.

Likewise, Kisakye et al. (2018) reported the impacts of climate change on the reliability of the RWHS in Kabarole district, Uganda. It was found that the dependability of the system would increase in rainy seasons; nonetheless, in the dry periods, the dependability could lessen to as much as 40%, which would prompt a 27% decrease in water security in the area. Zhang et al. (2018) assessed the impact of climate change on the reliability of RWHS in three different Chinese cities. It was accounted that the weather pattern would be as regularly depicted, that ‘dry gets drier, wet gets wetter’. For dry areas, it was proposed that the tank size ought to be greater to accommodate climate change sway. Based on these findings, it tends to contend that the impacts of climate change on the reliability of an RWHS fluctuate considerably as per the location.

Moreover, the seasonal and inter-annual inconsistency of rainfall and ecological distributions are other areas that can be affected by climate change. These probable discrepancies in rainfall and rise in temperature are probably going to worsen water deficiency conditions around the world in the future. Rainfall is the principal variable of interest for an RWHS (Silva et al. 2015), particularly transient inconsistency of rainfall as the basic administering factor in its exhibition. The plan of an RWHS is commonly concerned about deciding the ideal tank size to guarantee water supply for the projected consumption. An oversized tank is a loss of resources (e.g. energy, time and money); on the other hand, an undersized tank will not have the option to satisfy the necessary water demand. Thus, when designing an RWHS, water demand, water uses and the characteristics of the geographical locations should be taken into account. Table 1 below lists some more seminal research related to climate change and RWHS.

Similarly, temporal variability of rainfall, the central governing factor in the structure of a capacity tank in an RWHS, is probably going to be altered in coming days under the impacts of climate change. According to Khanal (2020), mostly the developing countries will experience the negative effects of climate change. Changes in rainfall patterns are probably going to prompt serious water deficiencies and flooding. The IPCC 2014 Climate Change, Synthesis Report asserts that changes linked to outrageous climate and atmospheric occasions have been related to human activities, including a lowering of cold temperature extremes, a heightening of warm temperature extremes, an expansion in extraordinary high ocean levels and an expansion in the quantity of heavy precipitation occasions in various localities. Because of the variability of rainfall under a climate change situation, the rainfall harvesting units structured on the basis of the current rainfall data
may confront enormous vulnerabilities in giving sufficient stockpiling amounts. Therefore, the reliability curves of community RWHS considering rainfall variability due to climate change is a need of the hour.

**Reliability/usefulness and RWHS**

The probability of the dam–catchment combination being able to supply the required demand during a specified time period is known as the reliability of the RWHS. On the basis of catchment size, the capacity of the dam, the amount of rainfall, water demand and evaporation losses, the reliability of RWH can be assessed.

One promising solution to address the concern of water shortage can find appropriate and sustainable alternatives for drinking water. Drinking water used for various purposes such as household use and agricultural activities could be replaced with harvested rainwater (Kaposztasova et al. 2014). Four steps are necessary for sustainable RWH: the choice of a set of suitable criteria, evaluation of the suitability of the classification of every criterion, choice of the sites and the making of suitability maps for the designated sites envisioned for RWH. Moreover, in order to identify an appropriate spot for water harvesting, remote sensing and the geographical information system (GIS) play a pivotal role. Adoption of remote sensing along with GIS can make it simpler to find the standard data with respect to the hydrological potential of an area (Kumar et al. 2008).

The study by Naseef & Thomas (2016) focused on essential parameters to identify appropriate destinations for RWH like the amount of rainfall, soil types, drainage, slope, and the land spread/use. It was found that the mean yearly rainfall is the most crucial parameter for RWH models (Rahman et al. 2016). Some seminal research conducted on reliability and RWHS is shown in Table 2 below.

The elements that are involved in designing the RWHS vary according to the aim of the designer for the system performance as well. Even if the physical apparatus of the system – assortment zone, conveyance and storage – stay steady to a large extent, the diverse objectives and attractions of people have prompted the utilization of various metrics and restrictions upon which to evaluate RWH performance, and the most important design decision is how much storage capacity to build (Zavala et al. 2018). Since the rainfall patterns are closely connected with the overall

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**Table 1: Climate change and RWHS**

| Authors and Year | Study Area | Methods and Models | Summary Results |
|-----------------|------------|--------------------|-----------------|
| Jha (2012)      | Nepal      | SimCLIM Software   | A mix of methodologies, i.e. rooftop RWH, artificial groundwater recharge and greywater recycling, would be able to meet water demand until 2050. |
| Lebel et al. (2015) | Africa     | Continental Scale Modelling | RWHS can connect more than 40% of the yield gaps credited to water shortages under current conditions and 31% under future (2050) climatic conditions during the major growing season for maize. |
| Lo & Koralegedara (2015) | Sri Lanka | Long Ashton Research Station Weather Generator | The study predicted that there is a chance of more rainfall because of climate change towards the end of this century (2080–2099). The residential RWHS will get more impact in comparison with non-residential systems. |
| Islam et al. (2015) | Bangladesh | Simulation Model | Volumetric reliability covers 35–37% in the case of individual-based RWHS for historical rainfall patterns whereas the range becomes 48–50% for anticipated future rainfall. |
| Haque et al. (2016) | Australia | Water-balance Simulation Model | Performances of an RWHS will show negative impacts due to future climate change conditions. |
| Zhang et al. (2019) | China | Downscaling Technique | Water-saving performance has a positive relationship with the increase in future rainfall whereas stormwater capture performance has an inverse effect as a bigger tank size is needed to accomplish a calculated stormwater capture efficiency in the future. |
operation of the system, a superior comprehension of the effects of rainfall patterns on the system’s functioning could offer some hints in system designing, particularly in sizing storage.

**Water quality and RWHS**

Though rainwater harvesting can be considered one of the best alternatives to cope with growing water shortages,
maintaining water quality is a daunting task primarily for potable use of water. Except for some impurities taken from the atmosphere by rain, rainwater is comparatively free from impurities, but the quality of rainwater during harvesting, storage and household use can deteriorate. The rainwater could be contaminated from numerous sources such as wind-blown soil, fecal droppings from birds and livestock, insects, leaves, and infected litter, resulting in health hazards from storage tank ingestion of polluted water (Chidamba & Korsten 2015). Bad hygiene in storing water in and abstracting water from tanks or at the point of use can be a health issue as well. However, risks from these hazards can be minimized by good design and use of systematic and scientific processes and practices. According to Mendez et al. (2011), consideration of well-designed rainwater harvesting systems and processes with clean catchments and storage tanks strengthened by good hygiene at the point of use can offer very little health risk to drinking water, whereas poorly designed and managed systems can pose high health risks.

The physicochemical and microbiological content of the collected water is impaired by numerous factors including numerous contaminants such as heavy metals and trace organic pollutants in roof runoff. The physical–chemical quality of the rainwater collected is determined by various factors such as roof runoff water quality, roof content, rainfall strength, the dry period preceding a rainfall event, and pollution proximity, whereas microbiological quality, roof content and any dry period may play a significant role in quality determination (Meera & Ahammed 2006). On the other hand, heavy metals are of special concern for rainwater harvesting due to their toxicity, ubiquity and the fact that metals cannot be chemically changed or easily extracted by ordinary treatment methods (Davis et al. 2001). As stated by Moilleron et al. (2002), other considerations for assessing the amount of trace organics in roof runoff are the roof characteristics and chemical properties of organic pollutants. The process started from a stage where large contaminant particles were separated by straining. The next was a series of sponge, charcoal, coarse and fine sand that filled the sea. And lastly, chlorination, which treated the rainwater for the bacteria that had not been separated from the system before (Karim 2010).

Thus, various disinfection processes are adopted to purify harvested rainwater such as chlorination and chloramination, ultraviolet/hydrogen peroxide (UV/H2O2), pre-oxidation by potassium permanganate (KMnO4) and potassium ferrate (K2FeO4), ultraviolet/persulfate (UV/PS) and so on. The study by Liu et al. (2019) reported that chloramination was effective for minimizing the formation of carbonaceous disinfection by-products (C-DBPs), but not nitrogenous DBPs (N-DBPs). Better reduction of almost all DBPs was observed during K2FeO4 pre-oxidation in comparison with KMnO4 pre-oxidation. Using granular activated carbon post-treatment in a similar vein could significantly reduce DBP concentrations and poisonous effects (Ghernaout & Elboughdiri 2020). The following Table 3 lists the studies related to water qualities and RWHS.

Current knowledge production on assessing rainwater quality indicates that harvested rainwater does not contain much health risk to a large extent though it is imperative that the designs and processes involved should be built carefully. The study by Jordan et al. (2008) indicated that point-of-use devices sufficiently cleaned harvested rainwater of complete coliforms, Enterococci and Escherichia coli but functioned marginally with respect to refining turbidity and heterotrophic bacteria. Another study, by Kim et al. (2016), highlighted that potential human pathogens (Mycobacterium avium, Aspergillus fumigatus, Mycobacterium intracellulare, and Aspergillus niger) were often observed in cisterns and in treated rainwater delivered at the tap; Legionella pneumophila was not detected as regularly, but it continued in a system after its first detection. A water safety plan may be more appropriate to Nunavut, Canada, since these communities face unique challenges and would give the communities control of their water sources and an improved method to protect public health through risk detection and monitoring (Lane et al. 2018).

Financial viability and RWHS

Financial viability can be defined as the capability to create adequate income to meet operational costs, debt obligations and, where pertinent, to allow growth while maintaining service levels. Similar to economic analysis, financial viability analysis is understood as an efficient way to deal with the ideal utilization of scarce resources, including a correlation
of at least two or more alternatives in achieving a specific objective under the given assumptions and constraints. It tries to measure in monetary terms the private and social costs and benefits of a project to the community or economy. Understanding the necessity of addressing a broader perspective while dealing with the financial viability of RWH, it needs to consider the cost implications of an entire range of issues considering environmental benefits, the cost of alternative water supplies (Bichai et al. 2015; Scarborough et al. 2015), water-saving alternatives, and, especially in overseas aid projects, the expenses of training people and of ongoing maintenance of RWHS (Bichai et al. 2015).

A substantial body of study has been conducted in recent days to identify the necessity for tools to facilitate the technical and economic analysis of RWHS. The major issues of the financial feasibility of an RWH system include the quality and quantity of collected water, the scale of the installation, water pricing, the period of analysis, the water demand profile, real estate value, interest rates, and the water–energy–food connection. Other indicators include net present value (NPV), internal rate of return (IRR), and payback period (PP), comparing the projected system and the traditional alternatives (Oviedo-Ocaña et al. 2018). Amos et al. (2016) have studied the financial viability of RWHS, categorizing it in four parameters: (1) Life Cycle Cost Analysis, (2) Water Price, Interest, Inflation, and Period of Analysis, (3) Costs, and (4) Benefits, and concluded that RWHS can save a huge quantity of comparatively high-quality water at a reasonable cost. Table 4 below lists some seminal research representing financial viability and RWHS.

### Table 3: Water quality and RWHS

| Authors and Year | Study Area          | Methods and Models                  | Summary Results                                                                 |
|------------------|---------------------|-------------------------------------|---------------------------------------------------------------------------------|
| Wright et al. (2004) | Developing Countries | Meta-analysis                       | After collection in many settings, the bacteriological quality of drinking water considerably declines. |
| Meera & Ahammed (2006) | India               | Review Paper                       | The cleanliness of rooftop harvested rainwater should not be taken for granted, and analysis of the harvested water especially for microbiological contamination should be undertaken. |
| Kahinda et al. (2007) | South Africa       | Exploratory Analysis                | There are risks of waterborne diseases beyond the costs of installation, maintenance and proper use of the Domestic Water Harvesting system for ensuring its sustainability. |
| Baguma et al. (2010) | Uganda              | Logistic Regression Model           | The risk of biological contamination of harvested water was known to 84% of respondents. |
| Islam et al. (2010) | Bangladesh          | A_1–V_4 Relation Method            | The stored rainwater quality was acceptable as safe drinking water in Dhaka areas for up to three months without any treatment. |
| Domènech et al. (2012) | Nepal               | Free Listing and Household Survey   | The results of water quality testing usually demonstrate good water quality but confirm that appropriate operation and maintenance practices are critical to ensure the collection of good quality water. |
| Lade & Okunlola (2017) | Nigeria             | Sampling-cum-Laboratory Analysis   | Rainwater storage in an underground tank for a 28-day duration is suitable for drinking use with easy point-of-use treatment such as filtering and chlorination. |
| Fuentes-Galván et al. (2018) | Mexico             | Descriptive Analysis               | Harvested water requires treatment before consumption. |
| Mattos et al. (2019) | USA                 | Descriptive Analysis               | More than 80% of the samples were below United States metal limits and met international requirements of microbiological water quality. |
| Pitao et al. (2019) | Philippines         | Process Analysis                   | Harvested rainwater could be an alternative for other uses besides drinking. |
| Ghernaout & Elboughdiri (2020) | Saudi Arabia   | Tried Disinfection Technique       | Rainwater in the metropolitan area contains large amounts of contaminants that include solids, bacteria, heavy metals, and OM and cannot be used without adequate treatment. |
### Table 4 | Financial viability and RWHs

| Authors and Year | Study Area | Methods and Models | Summary Results |
|------------------|------------|--------------------|-----------------|
| Fletcher et al. (2008) | Australia | Review of Evidence | Implementation of stormwater harvesting systems are obstructed by poor data on risk, lifecycle costs, water-energy tradeoffs and externalities. |
| Segers et al. (2008) | Ethiopia | Descriptive Analysis | The development and implementation of household and RWH schemes are of small-scale as well as low-cost alternatives to communal micro-dams and large-scale irrigation projects that went before them yet did not deliver the ideal outcomes. |
| Song et al. (2009) | Indonesia | Descriptive Analysis | Both tap water and wells face higher water costs, which represent a substantial part of their incomes with a range from 20% to 25% of their incomes. |
| Zhang et al. (2009) | Australia | Desk Review and Descriptive Study | Sydney has the shortest payback period in comparison with different urban communities either with 3A-rated appliances (8.6 years) or 5A ones installed (10.4 years). |
| Rahman et al. (2010) | Australia | Water Balance Model | Financial viability of RWHS is enhanced by lower interest and increased water price regimes. |
| Domènec & Saurí (2011) | Spain | A Comparative Study | To advocate and expand RWH technologies in residential areas, both regulations and subsidies are considered as acceptable methodologies. |
| Farreny et al. (2011) | Spain | Case Study Method | Under Mediterranean conditions, RWH strategies in RWHS in thick urban territories seem to be economically beneficial whenever done at a suitable scale in order to support economies of scale and considering the projected evolution of water prices. |
| Ghimire et al. (2012) | USA | Life Cycle Cost Assessment | Higher hypothetical water prices ($5 m\text{2}$) may prompt positive net present value benefits after only five years of service. |
| Rahman et al. (2012) | Australia | Water Balance Simulation Model | The benefit-cost ratios for the rainwater tanks are smaller than 1.00 without the government’s rebate. |
| Berwanger & Ghisi (2014) | Brazil | Computer Simulation | Although the potential for potable water savings can be as high as 59% amongst all cases, only 45 were found financially feasible. |
| Owusu & Kofi Teye (2015) | Ghana | Simple Random Sampling | It costs about GHS 5,000 (USD 2,500) to develop a little underground storeroom that can store water for more than one month for a four-person family. Households cannot afford such investments. |
| Kattel (2015) | Nepal | Treatment-Effects Model | RWH technology is feasible from a household point of view, having steady yearly advantages of NRs 69,456 (USD 700). |
| Campisano et al. (2017) | Life Cycle Analysis | The financial viability of RWHS is likely to be far from being acceptable with payback periods still too high to provide an appropriate return on investment. |
| Oviedo-Ocaña et al. (2018) | Colombia | Bottom-up Design Approach | The projected potable water saving using RWHS was 44% (equivalent to 131 m\text{3}/year) with a rate of return on investment of 6.5% and an estimated payback period of 23 years. |
| Custódio & Ghisi (2019) | Brazil | Case Study Analysis | The outcomes show the need for appropriately measured water tanks to satisfy water needs, subsequently reassuring more individuals to receive RWHS as an elective hotspot for non-potable water in buildings. |
| Phuyal et al. (2019) | Nepal | Willingness-to-Pay Approach | 68% of people living in Kathmandu valley are willing to pay higher costs for good quality water. People in the study area are found to be aware of water-related health issues. |
| Islam & Afrin (2020) | Bangladesh | Cost–benefit Analysis | ‘Net present value’ of a typical RWHS positive, indicating that RWH is a financially viable solution in the study area. |
CONCLUSION AND EVIDENCE GAP

Globally, some countries are struggling with water shortages due to the continued increase in demand for domestic, agricultural, industrial, and environmental uses. In addition, growing urbanization, water pollution and climate change are further intensifying the pressure. To overcome these challenges, countries are directing the construction of large-scale projects such as dams, pumping stations and long-distance pipelines. However, these projects have socio-economic and environmental impacts and demand huge investments. As a result, worldwide interest in searching for alternative water sources like greywater, desalination and RWHS have been increasing. In this regard, RWHS looks like a comparatively more reliable option or supplemental water resource due to minimal environmental impact and minimum treatment requirement comparing it with other alternative water sources and the advantages of flood mitigation.

In this study, we have explored the different factors intertwined with the RWHS focusing on financial viability, usefulness/reliability analysis, water quality and impacts of climate change. In the majority of times, the RWHS was found to be sustainable if certain steps were adopted wisely. In almost all the cases, the payback period of a RWHS was below 15 years and the choice of Water Balance Model (WBM) influenced this parameter significantly. It very well may be asserted that with suitable measures, the health risk with drinking harvested rainwater can significantly be minimized.

While analyzing the economic feasibility of RWHS, researchers found conflicting opinions; lack of scientific guidelines for financial examination created contradictory results. The major hydrological factor affecting system behavior is the length of dry periods in a particular area that is susceptible to climate change. The principal reason for project failure is oversizing RWHS because of increased cost and this results if an inappropriate Water Balance Model is followed while designed such as by using monthly rainfall data instead of daily. Currently, the available literature reflects that the RWHS is feasible for both developed and developing countries despite the distinction in per capita income. Be that as it may, based on current studies, it is exceptionally hard to totally anticipate which of the two systems; individual and community-owned, carries more favorable circumstances. But, the studies conducted on the economic viability of a small-scale RWHS for potable water supply in developing countries are nearly non-existent.

Discussing the quality of rainwater and the subsequent use for drinking purposes, the harvested water requires treatment before human consumption, and the degree of treatment is determined on the basis of the geographical area of the system. The presence of bio-film helps to minimize metal contaminants. In order to reduce microbial contamination considerably, maximizing sun exposure and continuous cleaning of the rooftop surface play a vital role. To minimize the risk of water quality degradation over time, treated water must be well maintained with appropriate disinfectants.

Future research on RWHS can concentrate on the nature and quality of harvested rainwater. Another potential research direction would be to look at the association between the RWHS and urban stormwater management. The study suggests that future studies on RWHS can address the following three priority challenges. First, the various aspects of maintenance and how they can affect the quality of harvested rainwater ought to be investigated as an approach to expand trust in rainwater utilization assuring water quality and safety for the user. Research ought to be led on the best ways to support maintenance by the system owners. Second, more empirical data on system procedures are expected to permit improved modelling considering several objectives of RWHS. Finally, studies should be focused on the comprehension of how institutional and socio-political support can be best focused to strengthen system efficacy and community acceptance.

Current knowledge production on RWHS suffers from the lack of relative analysis of different RWH technologies and innovations in terms of their performances and adaptability. Many studies on RWHS are modelled numerically; nevertheless, authentic experimental results are obligatory for progress and bring up-to-date design guides and regulations. Though the economic payback time of the RWHS looks a little longer, it gives durable benefits of addressing water demand and controlling urban flooding. Each of these facets of RWHS requires further research to materialize practically. Moreover, training, workshops, seminars, media propagation, public lectures, and pilot RWHS
should be organized to promote RWHS. On top of all, a sense of urgency needs to be recognized to establish a sustainable water provision system for the coming generations.

DATA AVAILABILITY STATEMENT

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

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First received 8 July 2020; accepted in revised form 2 October 2020. Available online 16 October 2020