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TRENDS AND INNOVATIONS IN RAINWATER HARVESTING SYSTEMS IN THE CARIBBEAN REGION

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ABSTRACT

Rainwater harvesting systems are conventional technologies designed to foster water security using sustainable water management practices. The design of these systems is becoming more integrated through technological advancements.

Even though many studies have been conducted on the design of rainwater harvesting systems, there is limited data about the existing infrastructure of these systems in the Caribbean region. To fill this gap, the objectives of the study are focused on the analysis of the constraints using existing research on the efficacy of such systems and formulated into a questionnaire survey. Responses were obtained from key stakeholders who have been or are actively involved in the construction industry.

Using the insights from construction professionals the key success factors, challenges, and opportunities for improvement on the implementation of rainwater harvesting system are reduced.

The severity of these critical factors was evaluated, ranked, and categorized using the relative importance index (RII) approach. The top-ranking factors were effectiveness of conserving water resources, the improper installation of the rainwater harvesting system, the utilization of filters and filtration systems and the use of pitched roofs. The lowest ranking factors were public awareness, low quality storage tanks, pumps and distribution systems and flat roofs.

These findings reveal that there is a requirement for the implementation of workshops about the importance of rainwater harvesting systems and appropriate training of personnel which corresponds with the advancement of rainwater harvesting systems. Additionally, adequate consideration should be given by Governments to enact appropriate legislation that can help create a conducive environment for the implementation of the system.

Keywords: Sustainable, Water Security, Caribbean, Efficiency, Rainwater Harvesting

INTRODUCTION

Rainwater is the foundation of the hydrologic cycle which replenishes the natural sources of freshwater, rivers and lakes (Bentalha, 2023). Rainwater harvesting (RWH) refers to the practice of collecting and storing rainwater for later use (Aroua, 2018; Bouly et al., 2019; Shah et al., 2022; Aroua, 2022; Tholibon et al., 2023), and it has been a longstanding method of water management across the Caribbean, especially in rural and island communities with limited access to centralized water supply systems (Nibbs, et. all, 2018). The capturing of freshwater has become an element in green plumbing systems and sustainable construction. The systems used in Rainwater harvesting range from simple rain barrels to more complex setups with gutters, tanks, pumps, and filtration units, such as biosand filters, which remove contaminants and make the water suitable for domestic use.

Approximately 500,000 people in the region rely on rainwater harvesting systems, particularly in areas characterized by low annual rainfall, limited land area, and intermittent streams (Peters, 2011). Islands such as Antigua and Barbuda, the Bahamas, the US and British Virgin Islands, the Turks and Caicos, and the Grenadines heavily depend on RWH systems (Peters, 2011). For instance, Carriacou in the Grenadines receives only about 1,200 mm of rainfall annually and lacks perennial streams, making RWH essential for its water supply. The region's tropical climate, characterized by seasonal rainfall patterns, makes RWH a viable and sustainable water source.

Rainwater harvesting provides a promising solution for addressing water scarcity caused by climate change (Nichane and Khelil, 2015; Remini, 2020a; Assemian et al., 2021; Chadee et al., 2023), population growth (Remini, 2020b; 2020c; 2020d), and environmental degradation (Amos at al., 2018). By collecting and treating rainwater from impervious surfaces, rainwater provides an alternative to unsustainable groundwater extraction practices (Ouis, 2012; Rajput et al., 2023; Qureshi et al., 2024). Numerous environmental and practical benefits, such as reduced water costs enhanced water supply (Boutebba et al., 2014; Pandey et al., 2022; Patel and Mehta, 2022; Kouloughli and Telli, 2023), improved quality of life, and increased resilience to droughts are provided by rainwater harvesting systems (N'Guessan et al., 2020; Benali Khodja and Ferdjouni, 2024; Koussa, 2025).

The integration of RWH into building envelopes supports climate change adaptation efforts, decreases carbon footprint, and contributes to responsible environmental practices. RWH plays a crucial role in promoting sustainable development and fostering water conservation (Sivanappan, 2006). Additional benefits include reduced water bills, minimized flood risks and mitigation of the impacts of droughts (Aroua, 2020; Sefton et al. 2023; Ben Said et al., 2024).

Rainwater harvesting provides several benefits to the local environment. It can provide a non-potable water source, reducing demand from distribution systems. Rainwater Harvesting Systems (RWH) are crucial for sustainable water management, contributing to water conservation and reducing urban floods (Hountondji et al., 2019; Zegait and Pizzo, 2023; Hafnaoui et al., 2023). Moreover, it mitigates urban floods, reduces water pollution (reducing the activation of combined sewer overflows) and preserves high-quality water sources, hence public health (Faye, 2017; Baba Hamed, 2021; Ihsan and Derosya, 2024).

Despite its benefits, widespread adoption of RWH in the Caribbean faces challenges which include high installation costs, limited public awareness, and a lack of technical expertise and supportive policies (Peters, 2011). As climate change continues to impact water availability and infrastructure, rainwater harvesting is increasingly seen as a sustainable and necessary solution for the region's long-term water resilience.

The aim of this research is to assess the types of rainwater harvesting systems integrated into Caribbean building envelopes, while also developing an innovative storage system for municipal applications that meet water quality standards. The objectives of this study are as follows:

1. Evaluate existing research on the effectiveness of rainwater collection systems and the potential limitations.
2. Deduce the perspectives from professionals in the construction industry regarding key factors for success, typical obstacles, and potential opportunities for enhancing the design and deployment of rainwater harvesting systems.
3. Evaluate the efficiency and performance of various rainwater harvesting systems integrated into different building envelopes.

LITERATURE REVIEW

This literature review examines the success factors, challenges, and potential advancements of rainwater harvesting systems in the construction industry. A comparison of the performance and efficiency of various rainwater harvesting systems in different building envelopes is identified for the implementation of the most effective strategies for the capture and utilization of rainwater resources. Current research on rainwater harvesting systems has been evaluated, gaps and areas for further exploration are identified.

Overview of rainwater harvesting systems

Rainwater harvesting systems consist of five sub-systems: collection, treatment, storage, distribution, and water back-up (Vieira et al., 2014). They are crucial in urban areas for non-potable end uses. Alade Nola et al. (2016) outlined four key components: catchment area, conveyance system, screening and treatment, and storage system. These systems capture, transport, store, and distribute rainwater, providing localized water sources.

Fig.1 illustrates the typical design of the rainwater harvesting system which consists of the primary components for the collection and the storage of water.

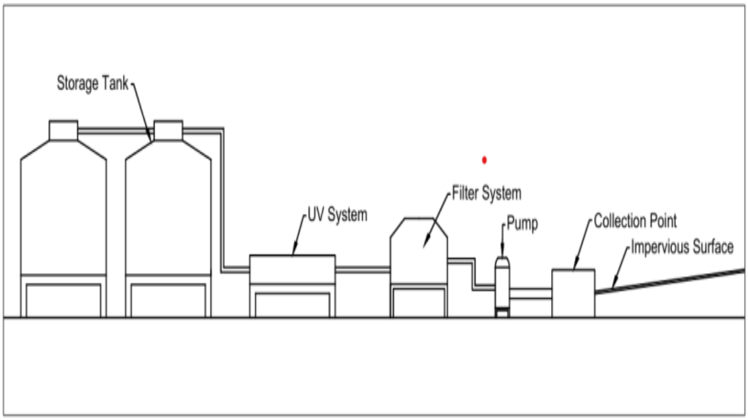

Figure 1: Typical design of a Rainwater Harvesting System (Sonika, 2023)

Sefton et al. (2023) states that rainwater harvesting systems (RWH) are sustainable solutions for water-related issues, offering emergency water reserves, reduced runoff, and improved water quality. These systems assist in the mitigation of flooding and pollution during drought and water scarcity. However, the efficiency of rainwater harvesting systems depends on rainfall frequency and intensity, and their storage capacities can be limited. Without proper maintenance, collected rainwater can become contaminated, posing health risks. The implementation of rainwater harvesting systems can be costly due to initial investment in equipment, infrastructure, and labour optimizing benefits requires considering site-specific factors, proper maintenance protocols, and raising awareness about potential risks.

Mun (2012) identified essential elements of RWH systems, including catchment areas, conveyance systems, storage facilities, water treatment techniques, and distribution networks. RWH systems can be installed as rooftop, ground-based, or underground configurations, with key design factors such as precipitation patterns, catchment area, storage volume, water quality, and user needs influencing their overall performance.

Su (2009) developed a model to predict storage capacities and deficit rates of Rainwater Harvesting Systems (RWH) in Taipei. Through the utilization of a simulation model and historical rainfall data, engineers were provided with insightful curves to inform decision-making processes. While demonstrating continuous relationships under different exceedance probabilities, the model's applicability beyond Taipei remains limited. Future research endeavours could expand the model's scope to encompass factors like climate change impacts, losses during collection, installation, and maintenance, as well as integration with existing water infrastructure. Roman (2017) introduced a Continuous Monitoring and Adaptive Control (CMAC) system aimed at optimizing the efficiency of rainwater harvesting systems (RWH) in New York City. Despite showcasing potential, the model's effectiveness was hindered by its reliance on a theoretical model and specificity to the city. To broaden the applicability of the CMAC system in diverse contexts, further research is essential to refine and adapt the model accordingly. Kucukkaya (2020) devised a passive rainwater harvesting system (RWH) for the Engineering Faculty building at Yalova University in Turkey, emphasizing the utilization of meteorological rain data and a gravity-based delivery mechanism to conserve and reuse rainwater. Despite its potential for water conservation, the model overlooked certain losses during collection, installation, and maintenance processes, as well as environmental impacts.

A study conducted by Ward (2010) in the United Kingdom revealed the potential of RWH systems to meet a substantial portion of water closet demand for residential and commercial properties. However, the study's model exhibited limitations, including an inclination to overestimate tank sizes, a narrow focus on case studies, and a neglect of climate change impacts. Addressing these shortcomings requires future research to implement advanced design methods, broaden the scope of case studies, and incorporate climate change projections for more accurate and comprehensive results.

The research by Behzadian et al. (2018) focuses on enhancing urban flood resilience through the strategic implementation of rainwater harvesting (RWH) systems within integrated urban water systems. The study demonstrates that smart RWH schemes, which proactively manage tank water levels to maintain sufficient spare storage for storm events, can significantly improve the efficiency of urban water systems. This approach mitigates local flooding during rainfall and enhances the reliability of water supply from harvested rainwater. The research utilized the WaterMet2 model to assess system performance, showing that optimally designed smart RWH systems outperform conventional RWH in terms of flood mitigation and water supply reliability. The findings support the integration of multifunctional infrastructure, such as dual-purpose RWH systems, which provide water conservation and distributed stormwater control, contributing to overall urban drainage system resilience.

To further refine the model and adapt it to various contexts, future research should consider expanding case studies, incorporating climate change projections, and addressing regulatory obstacles. However, challenges like context- specific applicability, climate change impacts, integration issues need to be addressed. By incorporating advanced design methods and refining existing models, RWH systems can be fully realized, resulting in more sustainable and resilient wat, and integration practices.

Effect of the roof size and material on a rainwater harvesting system

The efficiency and resilience of rainwater harvesting systems are significantly impacted by roof size, as it affects water yield, system performance, cost-effectiveness, and adaptability to climate change. Raimondi (2023) states that rainwater harvesting systems' efficiency and resilience are significantly influenced by roof size. Larger roofs provide more surface area for collecting rainwater, leading to higher water yield and increased water security. Smaller roofs may reduce efficiency due to limited capacity to capture rainwater.

Despite higher initial installation costs, long-term benefits like increased water yield and reduced reliance on conventional water sources outweigh these costs. Investing in rainwater harvesting systems can provide climate resilience and adaptation strategies in regions like the Caribbean.

Fig. 2 illustrates the dependence of the quantity of the rainwater captured and the size of the roof. Burgess (2012) indicates that it is evident that the larger the roof catchment, the more rainwater is able to be captured from rainfall events.

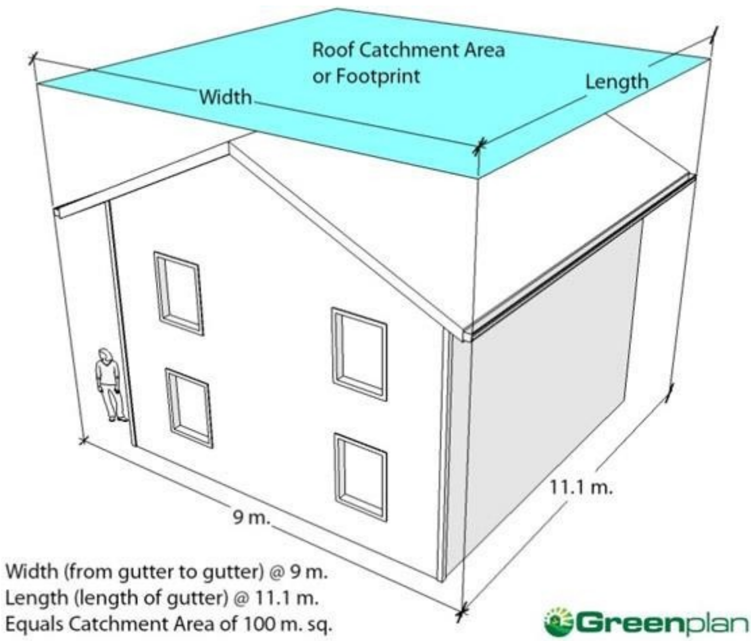

Figure 2: Relation between roof area and rainwater collection (Burgess, 2012)

The study conducted Mun (2012) aimed to optimize rainwater availability and quality in an urban Mediterranean environment by selecting and monitoring four types of roofs over two years. Sloping, smooth roofs showed higher runoff coefficients and potential for 50% more rainwater harvesting than flat, rough roofs. Rainwater quality was generally better than average. However, the study's focus on a Mediterranean-weather environment may limit its generalizability. Future research should explore roof runoff performance in different contexts, long-term effects of roof aging, maintenance, and environmental exposure, and cost-effectiveness of recommended roof selection criteria for sustainable rainwater management.

Impact of building envelope on rainwater harvesting

The building envelope is a crucial component in rainwater harvesting systems, acting as a physical barrier between the interior and exterior environments. It includes elements like walls, roofs, windows, and doors (Ghoudsi, et al., 2023). The design and materials of the building envelope significantly influence the efficiency and effectiveness of rainwater harvesting. The roof's slope, orientation, and material directly influence rainwater collection efficiency. Steeply sloped roofs promote better water runoff, while durable and clean materials like metal or tile enhance rainwater quality (Montazeri, 2020). The choice of envelope materials can affect rainwater quality, and opting for eco-friendly, non-toxic materials minimizes contamination risks.

Rainwater harvesting systems in the Caribbean

Studies have been conducted to emphasize the potential of rainwater harvesting (RWH) systems as a sustainable approach to tackling water scarcity and improving water security in the Caribbean region. By examining multiple dimensions of RWH, including financing mechanisms, success factors, and its effectiveness in different contexts, these studies contribute to a better understanding of the feasibility and relevance of this water management strategy for the region.

Peters (2017) examined financing mechanisms for Domestic Rainwater Harvesting (DRWH) systems in the Caribbean, with a focus on self-financing to overcome high initial capital costs. The study analyzed case studies, theoretical models, household income levels and interest rates. Although the findings offer valuable insights into self-financing as a potential solution for promoting DRWH in the Caribbean, the study's applicability may be limited to other regions or countries with different socio-economic contexts. Further research should explore household income, interest rates, and the feasibility of self-financing models.

Peters (2016) explored the success factors of DRWH projects in the Caribbean, considering stakeholders' perspectives and performance indicators. The metrics such as community involvement, uptake rate, awareness, training impact, system use, increased rainwater usage, improved leadership capacity, and private sector support were evaluated. While the study offered important insights into the success factors of Domestic Rainwater Harvesting projects, it has some gaps, including reliance on stakeholders' perceptions and self-reported data, as well as a primary focus on the Caribbean region. To improve the study, incorporating quantitative data, longitudinal studies, and expanding the geographical scope were suggested.

Aladenola (2016) assessed the effectiveness of RWH in Jamaica, taking into account historical rainfall data, climate change projections, and El Niño episodes. The study utilized community survey and climate change scenarios to assess RWH capacity and water availability. However, its generalizations were limited due to its focus on a specific community and the lack of consideration for anthropogenic factors affecting efficiency. Further research is needed to explore RWH's potential in meeting domestic water needs amidst climate variability and change.

Peters (2015) examined the feasibility of rainwater harvesting for meeting water demand on Carriacou Island, Grenada, by assessing rainfall availability, per capita water demand, and costs between rainwater harvesting and desalinated water. The research employed methods such as water demand assessment, rainfall data analysis, and cost comparison. While the study demonstrates the potential of rainwater harvesting for meeting water demand on water-scarce islands like Carriacou, it overlooks factors such as rainwater quality, climate variability, and energy requirements. Additionally, it does not consider the environmental impacts of desalination or the energy requirements of both systems. To enhance the study, it should include an assessment of rainwater quality, investigate climate variability's impact on rainfall patterns, and conduct a life cycle assessment of both systems.

Dean (2012) investigated rainwater harvesting systems in rural Trinidadian communities, focusing on demographics, water practices, health beliefs, and satisfaction with water quality. A survey of 1,523 participants revealed that nearly half of households use rainwater as their primary source, with most satisfied with its quality. However, the gaps in the study were non-adoption reasons, technical aspects, and seasonal variations, which need to be addressed for effective rainwater harvesting policies.

Collectively, these studies contribute to the understanding of RWH's potential in addressing water challenges in the Caribbean region, emphasizing the importance of evaluating financing mechanisms, success factors, climate variability, and other contextual factors for the successful implementation of RWH systems.

The building envelope also impacts on the location and design of rainwater storage tanks or cisterns, supporting their weight and size. It also plays a role in water conservation, minimizing water infiltration and maximizing retention, contributing to sustainable water management practices. The envelope's insulation properties also impact energy efficiency, reducing heating and cooling demands and lowering water consumption associated with energy production (Ross et al., 2022).

One of the most common types of rainwater harvesting systems used is the barrel rainwater harvesting system. This system is illustrated on Fig. 3.

Figure 3: Barrel rainwater harvesting (Peters, 2016)

Barrel Systems can have moderate to high efficiency which typically only store small amounts of water and therefore may be prone to overflow in torrential rainfall; however, this can be mitigated if more barrels are installed in series increasing efficiency. First flush diverters can be used to reduce contamination but also discard some of the water, reducing efficiency. If the barrels are not properly maintained, leaks may occur. Community Rainwater Harvesting systems also have a high variance in efficiency based on the type, such as open or closed systems which have different rates of evaporation based on their size. The area of the catchment required is based on the demand of the community. The efficiency of the system ranges between 50% and 85% (UNEP, 2009).

Rainwater tends to have high efficiency on the rooftops, especially those that are sloping. This shape maximizes the amount of water that flows into storage, however excessive flow if not managed properly can lead to spills. Once the roof is kept clean, little to no debris will be found within the system that needs discarding, however this can be improved further by using first flush systems. The main losses incurred by this system are through the first flush system mechanisms and spills. The efficiency of this system is typically very high, around 70% to 90% (Tomas and Martison, 2007). Surface runoff harvesting Systems experience more losses than Rooftop Systems as water can be lost due to infiltration or percolation into the soil before it reaches the storage area, as well as blocking any channels created to divert more water from the channel into the storage area. Once in storage, further losses can be incurred due to evaporation if storage is uncovered. The efficiency of this system is around 40% to 60% (Gould and Nissen-Petersen, 1999). Underground cisterns reduce the amount of water lost due to evaporation as it is covered, however older tanks may experience leakage. In addition, water is typically collected from rooftops, which as previously established increases that amount of water captured. This RWH system also has high efficiency, between 60% and 80% (Rainwater Harvesting and Cisterns Life Cycle Costs).

METHODOLOGY

Using the findings from the literature review, a questionnaire survey was developed consisting of open-ended and closed-ended questions to collect insights from construction professionals on water harvesting systems. A sample of the questionnaire survey is given in the Appendix. To assess the importance, effectiveness, and efficiency of different aspects related to water harvesting systems, the survey employed a 5-point Likert scale.

An evaluation of the current trends of Rainwater Harvesting projects was carried out by soliciting the views of key stakeholders who are actively involved in the construction industry. These stakeholders are experts in RWH who are identified as suitable for participation in the survey since it required much less resources than that for surveying beneficiaries spread over many islands.

The collected data was then analyzed using statistical techniques, leveraging the capabilities of SPSS software. This analysis included inferential tests for the Relative Important Index and Spearman t-test.

Analytical tools

The collection, analysis and interpretation of the data were done using google forms. Microsoft Excel and SPSS Statistics.

1. Google Forms: This was the primary tool utilized for the collection and organization of data, facilitating a smooth and effective data management process.
2. Microsoft Excel: Excel is an essential tool for quantitative analysis in this study due to its ability to manage large datasets, efficiently tabulate information, perform rapid and precise calculations, and its wide availability, making it a convenient and reliable choice for data organization and analysis.
3. SPSS Statistics: This tool provided an advanced statistical analysis. SPSS offers tools for data manipulation, exploration, and modelling, including descriptive analysis, hypothesis testing, and multivariate analysis. This will help interpret survey results, identify patterns, and explore relationships among variables.

The combination of Google Forms, Microsoft Excel, and SPSS Statistics creates a powerful and adaptable data management infrastructure for this research. This comprehensive framework enables streamlined data collection, organization, and analysis, facilitating an in-depth investigation into the elements influencing the adoption, effectiveness, and challenges of water harvesting systems within the construction industry.

RESULTS AND DISCUSSION

Demographics

The purpose of the questionnaire is to gather information about the factors affecting the efficiency of the rainwater harvesting system, Components that are likely to compromise a RWHS's efficiency, the key components of the Rainwater Harvesting System and the roof design of the rainwater harvesting system.

Questionnaire responses from 24 participants were analysed. The participants were a wide range of professionals from different sectors and positions within the construction industry. This diverse group of professionals provided a comprehensive understanding of the perceptions and experiences of different stakeholders involved in the construction industry regarding rainwater harvesting systems.

The participants of the survey include 3 Supervisors (12.50% of sample size), 3 Labourers (12.50% of sample size), 6 Technicians (25.00% of sample size), 3 Managers (12.50% of sample size), 1 Contractor (4.17% of sample size), 2 Civil Engineers (8.33% of sample size), 4 Coordinators (16.67% of sample size), and 2 Directors (8.33% of sample size). This data is illustrated in Fig. 4.

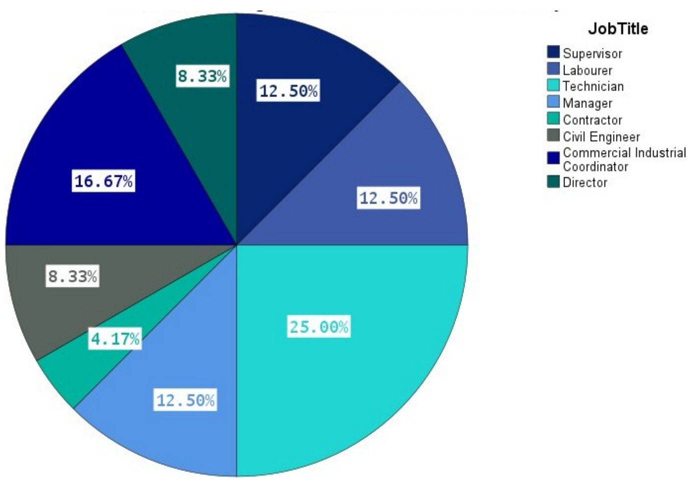

Figure 4: Categories of Participants

Relative importance index

The data collected from participants were compiled, and the Relative Importance Index (RII) was calculated to assess the significance of each factor and rank them accordingly.

The RII is an effective method for prioritizing factors based on their relative importance, as indicated by the respondents.

The Relative Importance Index (RII) is determined by the following:

$$\mathrm{RII} = \frac{\sum_{n=1}^{s} (w)}{\mathrm{AN}} \tag{1}$$

where W: Weight given to each factor by respondent in a range from 1 to 5; A = Highest weight; N: Number of participants (24 participants).

Table 1 illustrates the RII values for the different factors which affect the effectiveness of the Rainwater Harvesting systems. The effectiveness of conserving water resources and the sustainability of RWHS in capturing and storing wastewater have the highest RII value of 0.8 whereas public awareness about the rainwater harvesting system ranked the lowest at a value of 0.4. These values indicate that even though the utilisation of the rainwater harvesting system is crucial in conserving water, the public is not adequately informed about its significance and remain the least important.

Table 1: RII values for the effectiveness of the rainwater harvesting system

Factors	RII
Effectiveness of RWHS in conserving Water resources	0.8
Efficiency of RWHS in terms of capturing and storing RW	0.6
Sustainability of RWHS compared to other water management strategies	0.8
Cost effectiveness of RWHS	0.7
Integration of RWHS in existing infrastructure	0.7
Public awareness	0.4

Fig. 5 shows the graphical distribution of the RII values as given in Table 2 for the effectiveness of the Rainwater Harvesting System in water conservation. The highest-ranking factors of water conservation and sustainability of RWHS compared to other water management strategies indicate that the participants support the role of the system in ensuring that an adequate supply of water is maintained. This was followed by the sustainability and cost effectiveness of the system which both have an RII value of 0.7 However, the extent to which the public is aware of the system is the lowest.

The implementation of educational programs could be fostered to supplement the importance of rainwater harvesting in the Caribbean region.

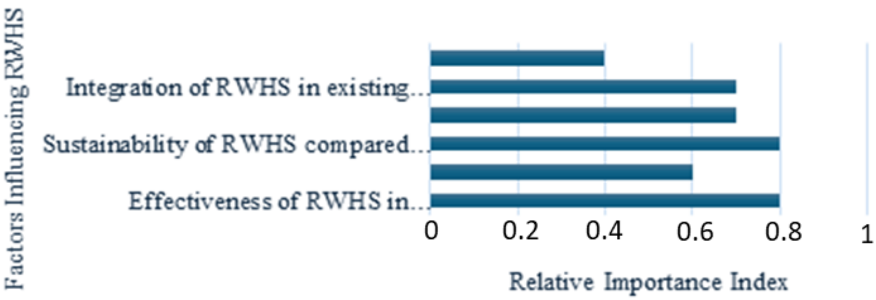

Figure 5: Relative importance index values for factors influencing RWHS

Table 2 illustrates the RII values for the components that are likely to compromise the efficiency of the RWHS. improper installation of the rainwater harvesting system ranked the highest at 0.84 whereas the low-quality storage tanks ranked the lowest of 0.69. These values indicate that many participants agree that improper installation affects the performance of the rainwater harvesting system whereas few of the participants supported that the low-quality storage tanks ranked the lowest of 0.69.

Table 2: RII values for the Components that are likely to compromise a RWHS's efficiency

Factors influencing RWHS Efficiency	RII
Poor System Design/ Inadequate Design	0.80
Lack of Maintenance	0.77
Insufficient Catchment Area	0.79
Lack of Purification/Filtration	0.72
Inappropriate Slope/Layout	0.73
Improper Installation	0.84
Low quality storage tanks	0.69
Climate Variability	0.74
Lack of Backup Water Supply	0.73
Improper Overflow and Runoff Management	0.75

Fig. 6 depicts the graphical variation of the factors which compromise the efficiency of the rainwater harvesting system with the RII values. The highest-ranking factor is the improper installation which has RII value of 0.84. However, the lowest ranking factor is low quality storage tanks which have RII value of 0.69. The improper installation of the system could be attributed to the lack of trained personnel in the formulation of the design of the system. By observing the other influential factors, it could be deduced that the topography of the area contributes significantly to the functioning of the rainwater harvesting system.

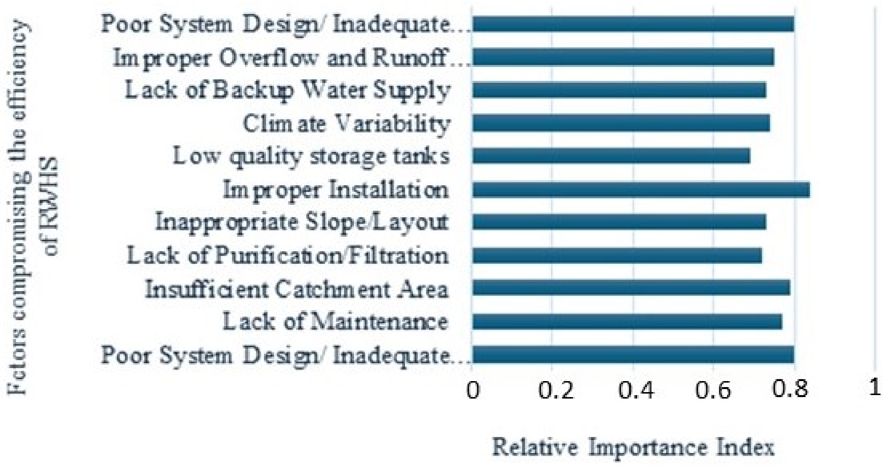

Figure 6: Relative Importance Index Values for Factors Compromising Efficiency of RWHS

Table 3 shows the RII values for the key components of the Rainwater Harvesting System. The filters and filtration systems were ranked the highest with an RII value of 0.90 and were most essential whereas pumps and distribution systems ranked the lowest at a value of 0.78. This suggests that the participants strongly supported the view that the water contaminants need to be proficiently removed and that the water is of high quality.

Table 3: RII values for the Key components a RWHS must possess

Factors	RII
Catchment Surface	0.88
Gutters and Downspout	0.89
Filters	0.90
Storage tanks	0.89
First Flush Diverter	0.81
Filtration System	0.90
Pumps	0.78
Distribution systems	0.78
Overflow System	0.82
Water Treatment and Quality Testing	0.83
Monitoring and Control Systems	0.83

Fig. 7 displays the variation of the Key Components of the Rainwater Harvesting System with the RII values which are represented in Table 4. In comparison to all the other key components, the participants in the survey ranked the filtration system and the filters the highest. This ranking indicates the participants' perspectives about the critical importance of having clean purified water for consumption. Additionally, the pumps and distribution system ranked the lowest. This indicates that the distribution system of the rainwater to other networks needs to be improved.

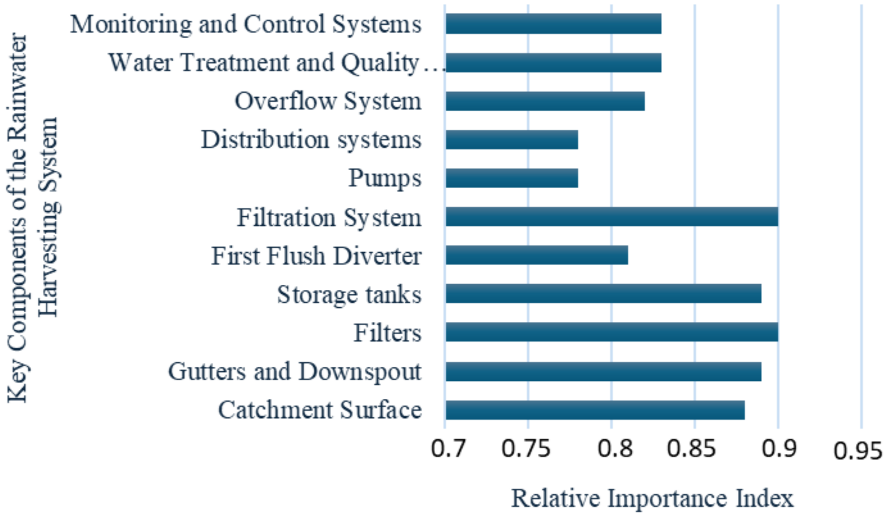

Figure 7: Relative importance index values for key components of RWHS

Table 4 represents the data for the type of roofs that are used in the design of the Rainwater Harvesting systems. Pitched roofs have the highest RII values whereas the use of flat roofs is ranked the lowest. Pitched roofs are ranked the highest with an RII of 0.84; however, flat roofs had the lowest R value of 0.43 and ranked the lowest.

Table 4: RII and rank values for the types of roofs that could be used to create a rainwater harvesting system

Factors	RII
Pitched Roofs	0.84
Flat Roofs	0.43
Metal Roofs	0.83
Tile or Ceramic Roofing	0.73
Slate Roof	0.60
Asphalt Shingle Roofing	0.48
Green Roofs	0.60

Fig. 8 shows a graphical representation of the data shown in Table 4. As seen in Fig. 7, Pitched roofs were ranked the highest as compared to the other designs of the roofs. This implies that the majority of the participants had given preference to the use of pitched roof designs for the Rainwater Harvesting system. Pitched roofs are preferred because they are designed with a very steep slope which can allow easy runoff and accumulation of the water in the guttering. However, in flat roofs, the water accumulates on top of the roof and there no design features which allows the runoff of the water from the roof.

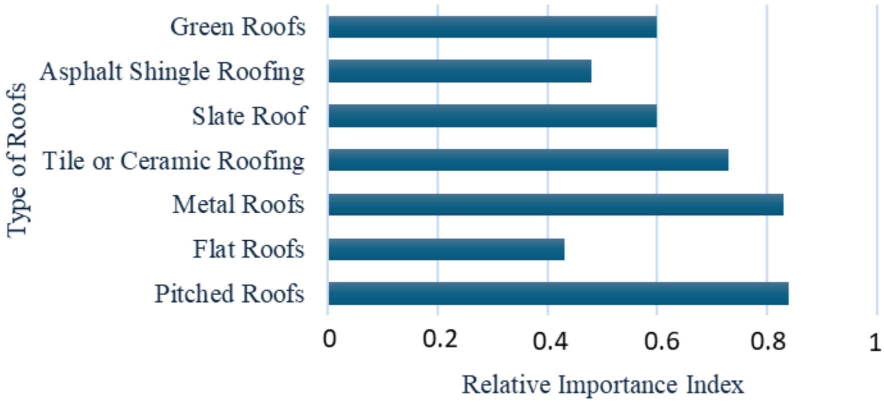

Figure 8: Relative Importance Index Values for roof designs for RWHS

Paired Sample t -Test

A paired samples t-test was conducted to compare the perceived effectiveness of rainwater harvesting systems (RWHS) in private, public, and combined sectors. The test revealed significant differences in perspectives on RWHS effectiveness across sectors. The result of the test is shown in Table 6. It illustrates that the private sector viewed RWHS as significantly more effective than the public sector, with a mean difference of 2.17 and a p-value of 0.002. Furthermore, the private sector also considered RWHS significantly more effective than the combined group, with a mean difference of 2.21 and a p-value of 0.001. However, no significant difference was found between the perceived effectiveness of RWHS in the public sector and the combined group, with a p-value of 0.46. These findings suggest that the private sector holds a more favorable view of RWHS effectiveness compared to the public sector and combined group, which can inform decision-making and guide improvements in RWHS implementation across sectors.

Table 5: Values of Paired Sample t-test

		Paired Samples								
		Paired Differences					**t**	**dt**	**Significance**	
		Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of Difference				One-Sided	Two-Sided
					Lower	**Upper**				
Pair 1	Effective Private RWHS Effective Public RWHS	2.17	3.00	0.61	0.90	3.43	3.54	23	< 0.001	0.002
Pair 2	Effective Private RWHS – Effective Both RWHS	2.21	2.95	0.60	0.96	3.45	3.67	23	< 0.001	0.001
Pair 3	Effective Public RWHS – Effective Both RWHS	.04	2.20	0.45	-0.89	0.97	0.09	23	0.46	0.93

CONCLUSION

Amidst the global challenges, rainwater harvesting has emerged as a pivotal solution and offers a sustainable approach to water conservation and management. This study analyzed its effectiveness of conserving water resources, the factors affecting the efficiency of the system, the key components of the system and the type of roofs preferred for the system.

The findings indicate a high RII value of 0.8 for the effectiveness of conserving water resources, whereas public awareness about the rainwater harvesting system ranked the lowest at a value of 0.4. The efficiency of the rainwater harvesting system was compromised due to improper installation with the highest RII value of 0.84; whereas the low-quality storage tanks ranked the lowest of 0.69. These findings indicate that there is a need for technical inputs into the development of efficient rainwater harvesting systems. For the key components of the rainwater harvesting system, filters and filtration systems were ranked the highest with RII of 0.90 and were most essential whereas pumps and distribution systems ranked the lowest at a value of 0.78.Pitched roofs are ranked first with an RII of 0.84; however, flat roofs had the lowest R value of 0.43.From the findings of the t test, the private sector viewed rainwater harvesting as significantly more effective than the public sector, with a mean difference of 2.17 and a p-value of 0.002.

RECOMMENDATIONS

From the identification of the gaps in literature, there are no specific policies or legislative provisions to support rainwater harvesting systems in some of the islands. Adequate consideration should be given by the Governments to enact appropriate legislation to facilitate the implementation of rainwater harvesting systems. It is recommended that in the conceptualisation and design of future rainwater projects in the region, these factors identified in the study should be given adequate consideration for adequate long-term performance of the systems.

From the findings, it is evident that the public remains unaware about the importance of rainwater harvesting in addressing water security issues. As such, the development and implementation of awareness programmes and workshops should be done to foster knowledge on how the systems operate and its role in the conservation of water.

Notice to readers: The questionnaire referenced in this article is available upon request.

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.

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