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Rooftop Rainwater Harvesting Systems for Enhancing Climatic Resilience in the Dry Zone of Sri Lanka: A Case Study of Polpithigama Division, Kurunegala District.

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Abstract: Rooftop Rainwater Harvesting (RWH) systems are critical interventions for addressing water scarcity in climate-vulnerable, water-stressed regions. In Sri Lanka's dry zone, these systems have been promoted for over two decades to support communities facing seasonal droughts and limited access to surface water. This study evaluates the performance and socio-environmental impact of RWH systems in the Polpithigama Division, Kurunegala District, focusing on system configurations, water security contributions, and spatial priority mapping. A case study conducted with 20 purposively selected households revealed that 84% use 5,000-liter storage tanks, while the remaining 16% use smaller tanks ranging from 1,000 to 3,000 liters. These systems are primarily used for domestic purposes (70%) and home gardening (30%). Roofing materials include asbestos sheets (65%), galvanized iron sheets (25%), and clay tiles (10%). Most systems incorporate first-flush diverters and PVC gutters, combining traditional and modern conveyance techniques to enhance collection efficiency and water quality. Water security analysis indicated that RWH systems increased household water availability by 30–40% during the early dry season (June to August), with 60% of households reporting sufficient supply for at least three consecutive dry-season months. Socio-environmental assessments indicated a 35% reduction in dependency on municipal water supply and an 18–25% improvement in home garden productivity during the dry season. These findings highlight the role of RWH systems in enhancing climate resilience and contributing to Sustainable Development Goal 6 (Clean Water and Sanitation). The study recommends targeted policy interventions, including district-level training on system maintenance and financial subsidies for low-income households to promote broader adoption of RWH systems in Sri Lanka's dry zone.

Index Terms: Climate variability, Domestic needs, Rainwater harvesting systems, Water security

1 Introduction

Water is essential for all life, and ensuring its sustainable availability is a global challenge, particularly in regions vulnerable to climatic variability and limited natural resources.[1] The sustainability of water resources and the well-being of all living things, from humans to ecosystems, are closely interlinked. Water scarcity threatens not only human health and livelihoods but also agricultural productivity, biodiversity, and ecological balance. [2] In the face of increasing water demand and climate change impacts, innovative water management strategies are needed to secure access to this vital resource for all.[3]

Rooftop rainwater harvesting (RWH) offers a promising decentralized solution to address water scarcity, promoting environmental sustainability and enhancing the resilience of communities and ecosystems alike. RWH involves the collection, storage, and utilization of rainwater from rooftops or other catchment surfaces.[4] This ancient practice is experiencing a resurgence due to its multifaceted benefits, including improved water security, reduced reliance on conventional water supplies, groundwater recharge, and minimized urban flooding risks. By capturing and utilizing rainwater, we reduce the pressure on existing water sources and mitigate the potential harm to aquatic ecosystems. RWH systems provide a sustainable source of water for domestic use, agriculture, and even industrial processes, thus helping to preserve essential resources.[5]

This research focuses on the Kurunegala District, specifically the Polpithigama area in Sri Lanka, a region representative of the challenges faced by dry zone communities. [6] The dry zone covers nearly two-thirds of Sri Lanka, receiving less than 1750 mm of annual rainfall, and experiences prolonged dry spells, which can last up to eight months. The water problem in the dry zone is further aggravated by the low water retention capacity of the reddish-brown earth soil, which dominates most parts of the dry zone. [7] This research seeks to evaluate the effectiveness of RWH systems in this specific context, with the broader purpose of contributing to the well-being of all living things by promoting sustainable water management practices.

This study aims to:

1. Identify the variations in design, storage capacities, and implementation techniques of existing RWH systems.
2. Assess the effectiveness of these systems in ensuring water security through reliability and storage capacity analysis.
3. Evaluate the socio-environmental benefits of RWH adoption in terms of community resilience, groundwater conservation, and environmental sustainability.

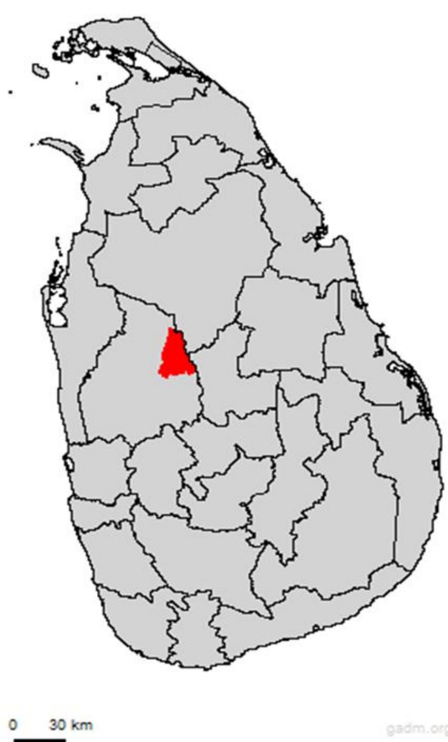
By examining randomly selected households that utilize RWH primarily for domestic purposes and home gardening, this study aims to improve the water security and living conditions for communities by promoting better implementation of RWH. Ultimately, it seeks to promote a water-wise approach that considers the needs of all living things and fosters a harmonious relationship between humans and the environment.

2 Materials and Methods

2.1 Study Area

The study was conducted in Polpithigama, Kurunegala District represent from Fig 1, situated in the heart of Sri Lanka's dry zone. This area was deliberately selected to reflect the characteristic challenges of regions with limited water resources. The rationale for choosing this area is grounded in its specific climatic, soil, and socio-economic conditions:

- Climate: Polpithigama experiences a pronounced bimodal rainfall pattern typical of the dry zone, with an annual average of less than 1750 mm. The area endures prolonged dry spells, often lasting from February to October, coupled with high evaporation rates ranging from 1700 to 1900 mm per year [8]. This climatic pattern severely restricts water availability for domestic and agricultural uses.
- Soil: The dominant soil type in Polpithigama is reddish-brown earth, known for its low water retention capacity [9]. This characteristic further exacerbates water scarcity by reducing the soil's ability to store moisture during the rainy season for use during dry periods.
- Socio-economic Context: A significant portion of the population in Polpithigama, approximately 42% of households, lives below the poverty line and has limited access to centralized water infrastructure. The dependence on unreliable traditional water sources and the lack of modern water supply systems underscores the urgency for alternative water management strategies such as RWH.



Polpithigama Area

Fig. 1.Map of Polpithigama Area

3 Research Design

A mixed-methods approach was adopted to comprehensively address the research objectives. This approach integrates quantitative surveys, technical assessments, and geospatial analysis, allowing for a robust understanding of the current state, potential impact, and optimal deployment of RWH systems in the study area. The mixed-methods design ensures a holistic assessment by combining empirical data with contextual insights [10].

Data Collection

Household Surveys

- Sampling: To ensure representation across various socio-economic levels, 20 households with RWH systems were randomly selected using stratified sampling. The sample size was determined based on the need to balance statistical power with practical constraints, allowing for meaningful insights into the diverse experiences of RWH adopters.
- Variables Recorded: Comprehensive household surveys were conducted to gather detailed information on RWH practices:
- System Design: Assessment of roof material (corrugated metal, tile, etc.), gutter type (PVC, metal), and filtration methods (first-flush diverters, mesh filters).
- Storage Capacity: Measurement of storage tank size (5000 L, 3000 L, or 1500 L) and the material of the tank.
- Water Usage Patterns: Documentation of how harvested rainwater is utilized, including domestic purposes (drinking, cooking, washing), gardening, and livestock.

- Maintenance Practices and Perceived Challenges: Information on cleaning frequency, filter replacement, and challenges related to water quality, system maintenance, and seasonal variability.

Technical Assessments

Water Security Metrics:

- Daily Water Availability: Measurement of water availability in liters per capita during both dry and wet seasons to quantify the contribution of RWH systems.
- Storage Reliability: Assessment of the number of months per year the RWH system can provide an adequate water supply, crucial for determining the system's resilience to seasonal droughts.

Water Quality:

- Water samples from 20% of the surveyed systems were tested for key parameters such as pH, turbidity, and microbial contamination.
- The efficiency of first-flush diverters was evaluated by measuring the volume of water diverted and analyzing its quality, following the methods outlined by [11].

4. Data Analysis

- Quantitative Analysis
    - Descriptive Statistics: Used to summarize the characteristics of the RWH systems, including frequencies of different system designs and usage patterns.
- Regression Models:
    - Regression analysis was employed to examine the relationship between tank size and the adequacy of water supply during dry seasons. The impact of income level on the frequency of system maintenance was also assessed using regression models, providing insights into the socio-economic factors influencing RWH sustainability Qualitative Analysis
- Thematic Coding:
    - Qualitative data from household surveys, particularly open-ended questions, were analyzed using thematic coding. This involved identifying recurring themes related to the socio-environmental impacts of RWH, such as reduced dependency on municipal water, improvements in crop yields, and enhanced community resilience.
- Ethical Considerations
    - Informed consent was obtained from all participants before their inclusion in the study.
    - All data were anonymized to protect the privacy of the participating households.

RWH System Design and Usage

The analysis of 20 randomly selected households revealed a variety of RWH system configurations, with a strong preference for specific storage capacities and usage patterns. Below Table 1 represent the Distribution of RWH System Components

Table 1. Distribution of RWH System Components

Component	Percentage of Households	Details
Storage Capacity		
5000 L Tanks	84%	Most common storage size, reflecting household needs for domestic use and small-scale gardening.
1500-3000 L Tanks	16%	These systems are primarily used for domestic purposes
Roof Material		
Corrugated Metal	45%	Predominant choice due to cost-effectiveness and ease of installation.
Asbestos sheets	35%	Found in new houses
Tile	25%	Found in older houses, generally associated with better water quality due to lower runoff contamination.
Gutters		
PVC	92%	Favored for their durability and ease of maintenance.
Metal	8%	Older systems, prone to rust and higher maintenance requirements.
First-Flush		
Yes	78%	Common practice, especially in households aware of water quality concerns.
No	22%	Often due to lack of awareness or perceived additional cost.

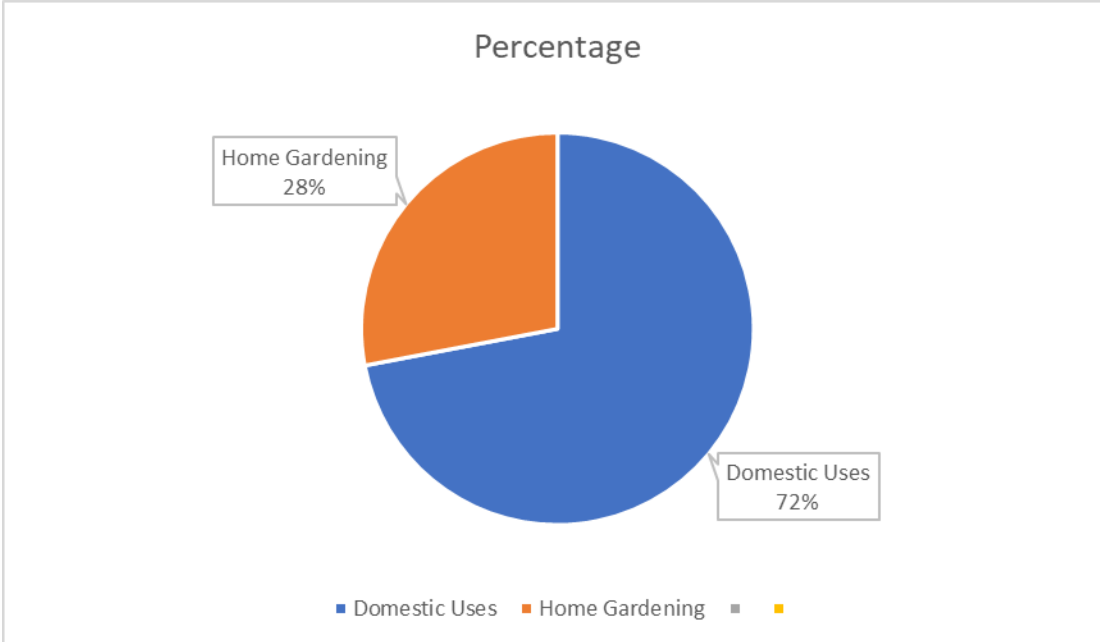


Fig. 2. Primary Uses of Harvested Rainwater

The above pie chart illustrates the distribution of rainwater use among surveyed households. According to the data, 72% of uses are for domestic uses and 28% are for home gardening. If we discuss the tank capacity, the prevalence of 5000-liter tanks indicates that this is the most common size in both wet and dry zones. The dominance of corrugated metal roofs and PVC gutters reflects a balance between cost, availability, and ease of installation. The adoption of first-flush diverters in a significant number of households highlights an increasing awareness of water quality issues.

Water Security Outcomes

The study assessed the effectiveness of RWH systems in enhancing household water security, focusing on daily water access and the duration of water availability throughout the year. Table 2 represents the impact of RWH on daily water access

Table 2. Impact of RWH on Daily Water Access

Water Source	**Average Daily Access (Liters/Capita)**	**Percentage Change**
RWH Households	45	+35%
Non-RWH Households	30	

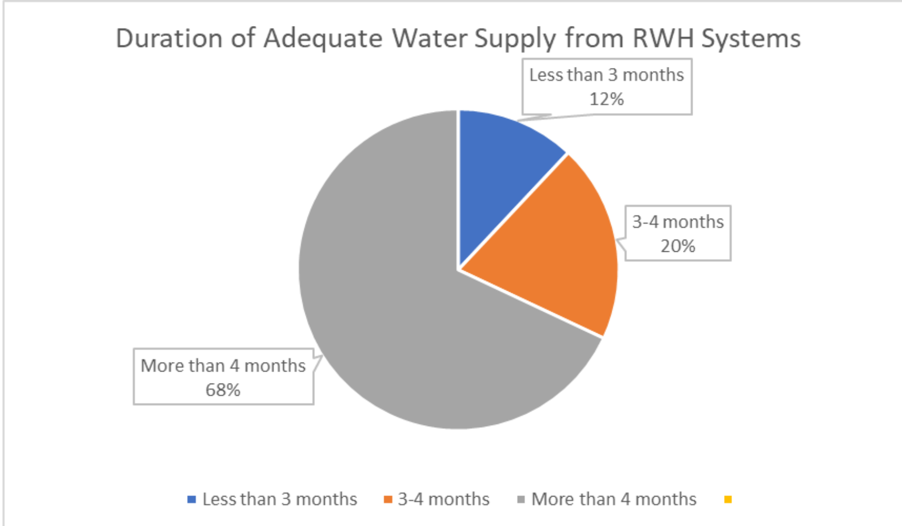


Fig. 3. Duration of Adequate Water Supply from RWH Systems

The above pie chart illustrates the distribution of households based on the number of months with adequate water supply. According to the data, 12% of uses Less than 3 months, 20% of use 3-4 months and 68% are More than 4 months. The results indicate that RWH systems significantly improve daily water access by 35% compared to households without RWH. who reported a 30-40% increase in daily water access for Sri Lankan households with RWH systems. The majority of households (68%) reported that their RWH systems provide an adequate water supply for more than 4 months annually, highlighting the crucial role of RWH in mitigating seasonal water scarcity.

Table 3.Socio-Environmental Impacts of RWH Adoption

Impact	Percentage Change/Improvement
Reduced Municipal Dependency	35%
Increased Garden Productivity	18-25%

Above Table 3.Socio-Environmental Impacts of RWH Adoption of RWH in that area.The data reveal that RWH adoption leads to a significant reduction in municipal water dependency, which alleviates pressure on centralized water supply systems. The increase in home garden productivity underscores the potential of RWH to enhance household food security and income

4.1 Challenges and Recommendations

While RWH systems offer numerous benefits, several challenges need to be addressed to ensure their long-term sustainability and widespread adoption. Below Table 4 represent about the Challenges and Recommendations for RWH Implementation

Table 4. Challenges and Recommendations for RWH Implementation

Challenge	Recommendation
High Initial Costs	Provide targeted subsidies or micro-financing options for low-income households.
Maintenance Requirements	Conduct regular training programs on system maintenance and water quality monitoring.
Water Quality Concerns	Promote the use of first-flush diverters and proper filtration systems.
Space Constraints	Encourage the integration of RWH systems into building designs and urban planning.
Climate Change Impacts	Design RWH systems to be resilient to climate change by incorporating flexible storage capacities and adaptive strategies.

Overcoming these challenges requires a multi-faceted approach involving policy support, community engagement, technical training, and innovative design solutions. By addressing these issues, RWH systems can be scaled up to play a more significant role in enhancing water security and promoting sustainable development in water-stressed regions

5. Discussion

The findings of this study highlight the significant potential of rooftop rainwater harvesting (RWH) systems in addressing water security challenges and promoting socio-environmental resilience in Sri Lanka's dry zone, particularly in the Polpithigama area of the Kurunegala District. The results demonstrate that RWH systems not only enhance household water availability but also contribute to broader environmental and social benefits.

Effectiveness of RWH Systems

The analysis revealed that households with RWH systems experienced a 35% improvement in daily water access compared to non-RWH households. This underscores the capacity of RWH systems to mitigate seasonal water shortages, with 68% of surveyed households reporting adequate water supply for more than four months annually. The prevalence of 5,000-liter storage tanks reflects an optimal balance between affordability and functionality for domestic use and small-scale gardening. Additionally, the adoption of first-flush diverters by 78% of households indicates growing awareness of water quality issues, which is crucial for ensuring the safety and usability of harvested rainwater.

Socio-Environmental Impacts

The socio-environmental benefits of RWH adoption are evident in several key areas:

- Reduced Municipal Dependency: A 35% reduction in reliance on centralized water supply systems alleviates pressure on limited municipal resources.
- Enhanced Garden Productivity: The observed 18–25% increase in home garden productivity highlights the role of RWH in improving household food security and supplementary income generation.
- Challenges and Areas for Improvement
- Despite their benefits, several challenges hinder the widespread adoption and sustainability of RWH systems:
- High Initial Costs: The upfront investment required for system installation remains a barrier for low-income households.
- Maintenance Issues: Limited knowledge and irregular maintenance practices can compromise system efficiency and water quality.
- Water Quality Concerns: Households without first-flush diverters or proper filtration systems face heightened risks of contamination.
- Climate Change Impacts: Variability in rainfall patterns due to climate change necessitates adaptive system designs with flexible storage capacities.

Addressing these challenges requires targeted interventions, including subsidies or micro-financing options, community training programs, and policy integration to encourage RWH adoption in urban planning and building designs.

7 Conclusion

This study underscores the critical role of rooftop rainwater harvesting systems in enhancing water security and fostering socio-environmental resilience in Sri Lanka's dry zone. By improving daily water access, reducing dependency on municipal supplies, and supporting groundwater recharge, RWH systems offer a sustainable solution to the region's persistent water challenges. Moreover, their contribution to home gardening productivity highlights their potential to improve livelihoods and food security. However, to fully realize these benefits, it is essential to address the identified challenges through a multi-faceted approach involving financial incentives, technical training, and policy support. Designing climate-resilient RWH systems with adaptive storage capacities will further enhance their effectiveness in the face of changing climatic conditions. In conclusion, promoting the widespread adoption of RWH systems can significantly contribute to sustainable water management practices while fostering a harmonious relationship between humans and the environment.

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