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Design and Development of the Dual Atmospheric and Rainwater Harvesting Tower for Water Security in Highland Communities

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ABSTRACT

Background/Objectives: Access to clean water remains limited in remote highland communities in Thailand due to insufficient infrastructure and seasonal variability, despite relatively high annual rainfall. At the same time, frequent fog occurrence in mountainous regions represents an underutilized atmospheric water resource. This study presents the design and development of the Dual Atmospheric and Rainwater Harvesting Tower, an integrated system that combines fog and rainwater harvesting to support decentralized water supply in remote communities.

Methods: A design and development approach was adopted to conceptualize a passive water-harvesting system integrating atmospheric moisture capture, rainwater collection, and basic water treatment functions. The system architecture was developed based on the selection of locally available materials and low-cost components to ensure suitability for community-based implementation. The proposed configuration incorporates fog collection elements, a rainwater capture unit, and a multi-stage passive filtration process for preliminary water treatment.

Results: The design process produced a fully integrated system architecture that enables dual-source water harvesting within a single passive structure. The final design demonstrates the feasibility of combining fog and rainfall capture with decentralized filtration and simple water-quality indication in a unified framework. The system is engineered to operate without external energy input while prioritizing affordability, structural simplicity, and adaptability to highland environmental conditions.

Conclusions: The Dual Atmospheric and Rainwater Harvesting Tower provides a design and development framework for integrating atmospheric water harvesting and basic treatment processes for community-level applications. The proposed system offers a conceptually scalable approach to improving water accessibility in highland regions. Further work will focus on prototype construction and field validation to assess operational performance and environmental robustness under real-world conditions.

Keywords: *Atmospheric water collection; Rural water supply; Climate resilience; Sustainable engineering; Community-based technology; Water resource management*

1. INTRODUCTION

Although Thailand receives an average annual rainfall of approximately 1,200–1,600 mm, reliable access to clean water remains a persistent challenge in many highland communities. Mountainous settlements, particularly in northern regions, are frequently characterized by inadequate water infrastructure, including limited piped distribution systems and insufficient storage capacity. As a result, local water supply systems remain highly dependent on seasonal streams, shallow groundwater, or external water delivery, all of which are vulnerable to prolonged dry periods and seasonal variability. These constraints have been further exacerbated by climate change, which has increased rainfall irregularity and intensified drought conditions, thereby reducing the reliability of conventional freshwater sources in remote areas.

In contrast, highland regions above approximately 800 meters frequently experience persistent fog formation, particularly during nighttime and early morning conditions. Fog consists of suspended microscopic water droplets and represents a distributed atmospheric moisture resource that remains largely untapped in Thailand. International studies have demonstrated the potential of fog harvesting technologies, particularly mesh-based systems, in capturing atmospheric water in fog-prone regions such as Chile, Morocco, and Peru, where they have been used as supplementary water sources in arid and semi-arid environments. These studies confirm that atmospheric water harvesting can serve as a viable decentralized water supply strategy under suitable environmental conditions.

Despite this potential, fog harvesting applications in Thailand remain at an early and fragmented stage. Existing implementations are primarily experimental and typically focus on single-source fog collection systems. Many of these systems rely on imported materials, lack design standardization, and are not optimized for long-term deployment in rural community contexts. In addition, current designs rarely integrate complementary water sources or incorporate decentralized treatment and maintenance considerations, which limits their scalability and operational sustainability in remote highland environments. This reveals a critical gap between existing fog harvesting prototypes and the practical requirements of community-level water security systems.

To address this limitation, this study is grounded in the concept of integrated atmospheric water harvesting within a community-oriented engineering framework. The proposed system combines fog collection and rainwater harvesting within a unified passive structure to enhance water capture across varying seasonal conditions. In addition, the design incorporates low-cost, locally available materials to improve accessibility, reduce dependency on external supply chains, and support long-term maintainability in resource-constrained settings. Rather than focusing on standalone fog harvesting efficiency, the system emphasizes functional integration as a strategy for improving practical deplorability in rural highland environments.

Accordingly, this study presents the design and development of the Dual Atmospheric and Rainwater Harvesting Tower as an integrated atmospheric water harvesting system for highland communities. The objectives of this study are: (1) to develop a passive dual-source water harvesting system integrating fog and rainfall capture; (2) to incorporate low-cost filtration and basic water quality indication suitable for rural applications; and (3) to evaluate the feasibility of using locally available materials to support community-based implementation and maintenance. The remainder of this paper is structured as follows: Section 2 describes the system design and methodological framework; Section 3 presents the development of the proposed structure; and Section 4 discusses the implications of the design for decentralized water security in highland environments.

2. LITERATURE REVIEW

Decentralized water-harvesting technologies have gained increasing attention as potential solutions for addressing water scarcity in remote and resource-limited regions. Among these approaches, fog harvesting has been widely investigated as a passive atmospheric water collection strategy suitable for fog-prone environments. Mesh-based collectors have been shown to capture airborne moisture effectively without external energy input, making them particularly suitable for offgrid applications (Abdul-Wahab et al., 2020). Subsequent developments have focused on improving collection efficiency through structural optimization, including multi-layer meshes, enhanced surface geometries, and three-dimensional configurations that promote droplet nucleation and drainage (Azad et al., 2018). Collectively, these studies establish fog harvesting as a technically feasible approach for supplementary water supply in suitable climatic conditions.

In parallel, biomimetic design principles have been widely adopted to enhance the performance of water-harvesting systems. Natural organisms such as the Namib Desert beetle, spider silk, and hydrophilic plant surfaces demonstrate efficient mechanisms for capturing and transporting water droplets under low-energy conditions. Engineering studies have translated these mechanisms into artificial surfaces by manipulating wettability gradients, surface texture, and structural geometry to improve condensation and directional water transport (Malik et al., 2016; Gurera & Bhushan, 2020). This body of work highlights the role of bio-inspired design in improving passive water collection efficiency, particularly in atmospheric harvesting systems.

Despite these advancements, most existing fog harvesting systems remain limited in scope, focusing primarily on singlesource atmospheric water collection without addressing broader water security requirements. Seasonal variability in water availability is often not adequately considered, and system designs are typically decoupled from complementary water sources such as rainfall (Lee et al., 2021). Furthermore, issues related to water treatment and long-term operational sustainability are frequently treated as separate research domains rather than being integrated into system-level design frameworks (Al-Kharsa et al., 2022). In rural deployment contexts, sustainability is strongly influenced by local maintainability, material accessibility, and community participation, with studies emphasizing the importance of low-cost and locally adaptable construction materials such as bamboo-based structures (Gatóo et al., 2016; Mishra et al., 2021; Silviana et al., 2021).

Recent research has also highlighted the growing importance of decentralized water-quality monitoring in low-resource environments. While conventional laboratory-based testing remains the standard for accurate water assessment, it is often impractical in remote communities. As an alternative, biosensor-based approaches, including bioluminescent microbial indicators, have been explored for rapid and visually interpretable water-quality assessment (Cevenini et al., 2018; Girotti et al., 2020). However, their integration into small-scale atmospheric water-harvesting systems remains limited.

Overall, existing literature demonstrates significant progress in fog harvesting, biomimetic surface engineering, rainwater collection, filtration technologies, and decentralized water-quality monitoring. However, these components are largely developed in isolation, with limited research addressing their integration into a unified, community-oriented system. This fragmentation highlights a critical research gap in the development of multi-source, low-cost, and maintainable atmospheric water-harvesting systems. To address this gap, this study proposes the Dual Atmospheric and Rainwater Harvesting Tower, an integrated framework that combines fog and rainwater harvesting, passive filtration, and basic water-quality indication within a single community-adaptable structure for enhancing water security in highland regions.

3. RESEARCH METHODOLOGY

3.1 Research Design

This study adopted an engineering design and prototype development approach to conceptualize and construct an integrated atmospheric water-harvesting system for highland environments. The research integrated principles of fog harvesting, rainwater collection, biomimetic design, and passive structural engineering to develop a system capable of operating without external energy input. The design process included conceptual system development, material selection, prototype fabrication, laboratory-based functional assessment, and field-based environmental observation. This approach was selected to support the development of a context-appropriate water-harvesting system rather than to conduct performance benchmarking against existing technologies.

3.2 Participants / Samples

The system was designed for deployment in highland regions of northern Thailand, particularly areas located above 800 meters above sea level, where fog occurrence is frequent during seasonal cycles. The design considerations were based on typical environmental conditions, including moderate wind flow, high relative humidity, and seasonal variability in atmospheric moisture availability. These parameters were used as boundary conditions for system design and prototype configuration.

For comparative design optimization, variations in mesh aperture size (0.5–2.0 mm) and structural geometry (cylindrical, conical, and spiral configurations) were examined at a conceptual and laboratory simulation level to inform the final prototype design.

3.3 Instruments and Materials

The prototype structure was constructed using bamboo as the primary supporting material due to its availability, low cost, and suitability for community-based maintenance. Atmospheric water capture was facilitated using a multi-layer polyester mesh system designed to enhance droplet interception and drainage efficiency. A passive filtration unit was integrated using layered media, including gravel, sand, and activated carbon, to support preliminary water treatment.

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Measurement instruments included a digital balance for water yield observation, a pH meter, a turbidity meter, and standard environmental monitoring tools such as an anemometer, a hygrometer, and a thermometer for recording ambient conditions. A bioluminescent bacterial module was incorporated as a qualitative indicator for preliminary water quality observation under controlled conditions.

3.4 Data Collection Procedures

The research was conducted in two sequential phases. The first phase involved laboratory-based functional assessment of mesh configurations, structural geometries, and water collection behavior under controlled simulated fog conditions generated using a fine-mist system. Observations focused on comparative water collection behavior under standardized airflow conditions.

The second phase involved field observation of the full-scale prototype under natural environmental conditions in a highland setting. The prototype was deployed during periods of expected fog occurrence, and water collection was monitored under real atmospheric conditions. Environmental variables such as temperature, humidity, wind speed, and wind direction were recorded concurrently to contextualize system behavior.

Water samples were collected pre- and post-filtration to observe changes in basic physicochemical characteristics, including pH and turbidity, as part of system-level functional assessment.

3.5 Data Analysis

Data were analysed using descriptive statistical methods to summarize system behaviour under laboratory and field conditions. Water collection data and environmental parameters were expressed in terms of mean values and variability. Comparative analysis was used to examine relative differences in performance across design configurations at a conceptual evaluation level. All analyses were conducted using Microsoft Excel. The analytical approach was intended to support prototype-level assessment and design refinement rather than statistical hypothesis testing.

4. RESULTS

The development of the Dual Atmospheric and Rainwater Harvesting Tower resulted in a completely integrated design of a passive dual-source water-harvesting system. The final conceptual configuration combines fog harvesting, rainwater collection, passive filtration, and basic water-quality indication within a single structural framework, as shown in Figure 1.

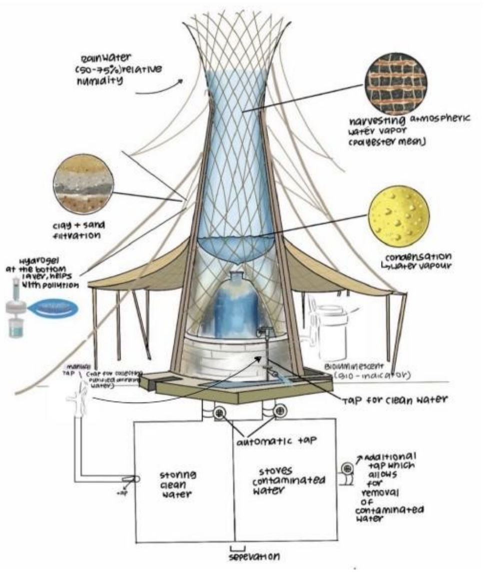

Figure 1. *Conceptual design of the Dual Atmospheric and Rainwater Harvesting Tower.*

Figure 1 illustrates the overall system architecture, in which atmospheric moisture and rainfall are collected through separate but integrated pathways. The upper section of the structure is designed for fog interception using a multi-layer mesh system, while the central section facilitates direct rainwater collection through a funnel-based mechanism. Both water sources are directed into a unified collection pathway to support continuous water harvesting under varying environmental conditions.

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The lower section of the system incorporates a passive filtration unit consisting of layered gravel, sand, and activated carbon. This configuration enables preliminary water treatment through physical filtration processes without external energy input. A biological water-quality indicator module is also integrated within the system to provide a qualitative assessment of collected water under low-resource conditions.

The structural framework is based on bamboo as the primary construction material, selected for its availability, low cost, and suitability for community-based fabrication and maintenance. The overall system design emphasizes modularity, allowing adaptation to different site conditions in highland environments. The principal design parameters and system configuration developed in this study are summarized in Table 1.

Table 1. *Key Design Parameters and Functional Configuration of the Dual Atmospheric and Rainwater Harvesting Tower*

Parameter	Configuration	Purpose
Mesh size	0.5–2.0 mm	Optimize droplet capture efficiency
Structure type	Cylindrical / Conical / Spiral	Evaluate airflow interaction
Material	Polyester mesh	Atmospheric water collection
Frame	Bamboo	Structural support & sustainability
Water pathway	Dual-source (fog + rain)	Maximize seasonal water capture
Filtration	Sand + gravel + activated carbon	Passive purification

Overall, the resulting output of this study is an integrated conceptual and structural design of an atmospheric waterharvesting system. The proposed design demonstrates the potential for combining fog harvesting, rainwater collection, and passive treatment mechanisms within a single energy-independent structure intended for decentralized water supply applications in remote highland communities.

The integration of fog harvesting, rainwater collection, and passive treatment within a single structure was guided by the principle of maximizing water availability through multi-source atmospheric water capture while maintaining system simplicity and operational independence. Rather than optimizing individual components in isolation, the design emphasizes system-level integration, where each functional unit contributes to a continuous water collection and treatment pathway under variable environmental conditions. This approach reduces structural redundancy and enhances adaptability to seasonal fluctuations in water availability. The use of passive mechanisms enables operation without external energy input, while the incorporation of locally available materials supports decentralized fabrication and longterm maintainability in resource-constrained highland communities.

5. DISCUSSION

The development of the Dual Atmospheric and Rainwater Harvesting Tower demonstrates the potential for integrating multiple passive water-harvesting and treatment functions within a single structural system. The findings of this study highlight that system-level integration, rather than isolated optimization of individual components, can provide a more context-appropriate approach for addressing water scarcity in highland environments. This aligns with the study's objective of developing a decentralized and low-cost water-harvesting solution suitable for rural deployment.

When compared with previous studies on fog harvesting systems, the proposed design extends beyond conventional meshbased collectors that primarily focus on improving atmospheric water capture efficiency (Abdul-Wahab et al., 2020; Azad et al., 2018). While earlier research has largely emphasized material optimization and aerodynamic enhancement, these systems often remain limited to single-source water collection and do not account for broader water security requirements. In contrast, the integrated design presented in this study combines fog harvesting with rainwater collection, thereby addressing seasonal variability in atmospheric water availability. This multi-source approach responds to a key limitation identified in prior literature, where system performance is typically constrained by dependence on a single environmental input.

The incorporation of biomimetic principles in the design is consistent with existing research that highlights the importance of surface structure, wettability, and geometry in improving water collection efficiency (Malik et al., 2016; Gurera &

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Bhushan, 2020). However, rather than focusing solely on performance enhancement at the material level, this study applies biomimicry at a system level by combining structural design, material selection, and passive flow mechanisms.

This broader interpretation of biomimicry supports the development of a more holistic and adaptable water-harvesting framework.

In terms of rural applicability, the use of bamboo and other locally available materials addresses a key limitation identified in previous rural water management studies, where reliance on imported or specialized materials restricts long-term sustainability (Mishra et al., 2021; Silviana et al., 2021). By prioritizing locally accessible construction materials, the proposed system enhances the potential for community-based fabrication, repair, and maintenance. This design decision also reduces dependency on external supply chains, which is critical in remote highland regions where logistical constraints often limit infrastructure development.

The integration of passive filtration and a basic biological water-quality indicator further extends the functionality of atmospheric water-harvesting systems. While prior research has explored biosensor technologies for water quality monitoring (Girotti et al., 2020), these approaches are rarely incorporated into small-scale harvesting systems. In this study, the inclusion of a simple, low-cost indicator represents an attempt to bridge the gap between water collection and basic water quality awareness in resource-limited contexts. Although this component does not replace laboratory-grade testing, it provides a preliminary qualitative layer that may support safer water usage decisions in remote communities.

From a systems perspective, the main contribution of this study lies in demonstrating how multiple water-related functions can be consolidated into a unified, passive infrastructure. This integration reduces system fragmentation commonly observed in existing approaches, where harvesting, treatment, and monitoring are treated as separate technological domains. The proposed design therefore shifts the focus from component-level optimization to system-level functionality, which is more aligned with the constraints and needs of decentralized rural environments.

However, several limitations should be acknowledged. First, the current study is based primarily on design development and conceptual validation rather than long-term empirical performance evaluation. As a result, quantitative assessments of water yield efficiency, durability, and seasonal performance under extended field conditions were not fully established. Second, while the system incorporates multiple functional components, the interactions between these components under real environmental variability remain to be systematically evaluated. Third, the bioluminescent water-quality indicator, although conceptually promising, requires further validation in uncontrolled field conditions to assess its stability and reliability.

Future research should therefore focus on full-scale field validation under diverse climatic conditions, including extended monitoring of water yield performance and system durability. Additional studies may also explore optimization of mesh configuration, structural scaling, and integration with community-based management models. Such investigations would help transition the proposed system from a conceptual prototype to a deployable solution for rural water security applications.

In addition, the economic feasibility and lifecycle costs of the proposed system were not evaluated in the present study. Future assessments should consider installation costs, maintenance requirements, and long-term cost effectiveness to support practical implementation in rural communities.

Overall, this study contributes to the growing body of research on decentralized atmospheric water-harvesting systems by proposing an integrated, low-energy, and locally adaptable design framework. The proposed framework provides a conceptual basis for integrating fog harvesting, rainwater collection, passive treatment, and community-based maintenance strategies within a single system intended for remote highland environments.

6. CONCLUSION

The Dual Atmospheric and Rainwater Harvesting Tower was developed as an integrated design and development solution for improving water accessibility in remote highland communities. The study demonstrates the potential for combining fog harvesting, rainwater collection, passive filtration, and basic water-quality indication within a single energyindependent structure. Rather than optimizing individual components in isolation, the design emphasizes system-level integration to address seasonal variability and infrastructure limitations commonly observed in rural environments.

The main contribution of this study lies in the development of a unified atmospheric water-harvesting framework that prioritizes simplicity, affordability, and local adaptability. By incorporating bamboo and other locally available materials, the proposed system supports community-based fabrication and maintenance, reducing reliance on external resources. In addition, the integration of multiple water sources within a passive structure provides a conceptual framework for enhancing decentralized water security in highland regions.

From a practical perspective, the proposed design may serve as a low-cost approach for supplementing water supply in fog-prone areas. Future research should focus on full-scale field implementation under diverse environmental conditions to evaluate long-term structural durability, seasonal water-yield variability, and the operational reliability of the integrated filtration and water-quality indication components. Such investigations will be important for advancing the proposed system from a conceptual prototype toward practical deployment in rural water management applications.

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AUTHOR CONTRIBUTIONS

Author	Contribution (CRediT Taxonomy)
P. Jangmeechoke	Conceptualization, Methodology, Data Curation, Writing – Original Draft.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest related to this study.

DATA AVAILABILITY STATEMENT

The data generated and/or analysed during the current study are available from the corresponding author upon reasonable request.

ETHICAL APPROVAL AND CONSENT TO PARTICIPATE

Not applicable. This study does not involve human or animal subjects.

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REFERENCES

Abdul-Wahab, S. A., Al-Damkhi, A. M., Al-Hinai, H., Al-Nabhani, A. K., & Al-Maimani, A. (2020). Assessment of fog-towater harvesting collection in the Dhofar region of Oman. International Journal of Environmental Studies, 77(5), 780–798. https://doi.org/10.1080/00207233.2020.1712215

Al-Kharsa, O., Al-Ghamdi, S. G., & Abdel-Salam, M. S. (2022). Comprehensive review on atmospheric water harvesting: Technology, applications, and challenges. Journal of Cleaner Production, 369, Article 133284. https://doi.org/10.1016/j.jclepro.2022.133284

Azad, M. A. K., Ellerbrok, D., Barthlott, W., & Koch, K. (2018). Fog collecting biomimetic surfaces: Influence of microstructure and wettability on the water collection efficiency. Bioinspiration & Biomimetics, 13(4), Article 046004. https://doi.org/10.1088/1748-3190/aab60d

Cevenini, L., Michelini, E., Calabretta, M. M., & Roda, A. (2018). Bioluminescent microbial biosensors for quantitative and visual detection of water contaminants. Analytical and Bioanalytical Chemistry, 410(3), 1015–1023. https://doi.org/10.1007/s00216-017-0718-4

Gatóo, A., Sharma, B., Bock, M., Mulligan, H., & Ramage, M. H. (2016). Sustainable structures: Bamboo as a principal building material. Proceedings of the Institution of Civil Engineers - Engineering Sustainability, 169(5), 189–196. https://doi.org/10.1680/jensu.15.00015

Girotti, S., Ferri, E. N., Fumo, M. G., & Maiolini, E. (2020). Bioassays and biosensors for ecotoxicity monitoring of water. Analytical and Bioanalytical Chemistry, 412(15), 3501–3515. https://doi.org/10.1007/s00216-020-02568-1

Gurera, D., & Bhushan, B. (2020). Fabric design for fog harvesting inspired by Namib Desert beetle and banana plant. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 378(2167), Article 20190442. https://doi.org/10.1098/rsta.2019.0442

Lee, A., Moon, I., & Kim, S. (2021). Optimization of hybrid water harvesting systems combining rainwater tank and atmospheric fog collectors. Water, 13(9), Article 1245. https://doi.org/10.3390/w13091245

Malik, F. T., Clement, R. M., Gethin, D. T., Krawszik, W., & Parker, A. R. (2016). Nature's sub-micron coating generates a hierarchy of hydrophobicity on the Namib Desert beetle. Scientific Reports, 6(1), Article 23531. https://doi.org/10.1038/srep23531

Mishra, A., Saxena, S., & Sharma, M. (2021). Sustainable rural water management through community participation and local material optimization. Water Resources Management, 35(8), 2411–2428. https://doi.org/10.1007/s11269-021-02834-x

Silviana, S., Darmawan, A., Dalanta, F., Subagio, A., Hermawan, F., & Santoso, H. M. (2021). Superhydrophobic coating derived from geothermal silica to enhance material durability of bamboo using hexamethyldisilazane (HMDS) and trimethylchlorosilane (TMCS). Materials, 14(3), Article 530. https://doi.org/10.3390/ma14030530

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