Rainwater Harvesting System Design and ROI Analysis in Urban Buildings

Siya Trivedi
Independent Researcher
India

ABSTRACT

Rainwater harvesting (RWH) is an effective sustainable technique to conserve water resources, especially in urban areas facing water scarcity. This study focuses on the design of a rainwater harvesting system for urban buildings, incorporating key engineering considerations such as catchment area, storage capacity, filtration, and distribution. Furthermore, a detailed Return on Investment (ROI) analysis is conducted to evaluate the economic feasibility of implementing RWH systems in urban settings. The study uses rainfall data, consumption patterns, and system cost to compute water savings and financial benefits. Results indicate that RWH systems not only reduce dependency on municipal water but also offer attractive payback periods for urban buildings. The paper concludes with recommendations for optimizing design parameters and expanding RWH adoption for sustainable urban water management.

KEYWORDS Rainwater Harvesting, Urban Buildings, System Design, Return on Investment, Water Conservation, Sustainable Engineering

INTRODUCTION

Urbanization has led to a surge in water demand, straining existing water supply infrastructures worldwide. In many metropolitan areas, municipal water sources are over-exploited, leading to shortages and increased costs. Rainwater harvesting (RWH) presents a practical solution to supplement water supply by capturing and storing rainwater from rooftops and other surfaces. Its application is particularly relevant in urban environments, where impervious surfaces cause runoff and reduce groundwater recharge.

This research explores the engineering design of RWH systems tailored to urban buildings, with emphasis on maximizing water capture and efficient storage. Moreover, it incorporates an economic analysis using Return on Investment (ROI) metrics to assess financial viability, an aspect crucial for encouraging widespread adoption by building owners and policymakers.

The study addresses questions such as: How to optimize system design for urban buildings? What is the cost-benefit ratio of installing RWH systems? What payback period can be expected, and under what conditions?

LITERATURE REVIEW

Rainwater Harvesting Fundamentals

Rainwater harvesting involves collecting rainwater from surfaces (usually roofs), filtering it to remove debris, and storing it for future use. Studies by Fewkes (2016) and Gould & Nissen-Petersen (2017) highlight RWH's role in urban water management, emphasizing design factors such as catchment area, rainfall variability, and water demand. Technical standards (IS 15468:2004) provide guidelines on system components including gutters, storage tanks, and filtration.

Urban Applications and Benefits

Several researchers (Kumar et al., 2019; Al-Zubari, 2015) have documented the application of RWH in cities worldwide, noting benefits including groundwater recharge, flood mitigation, and potable water supply supplementation. Urban rooftops provide large catchment areas, and efficient storage can reduce municipal water bills substantially.

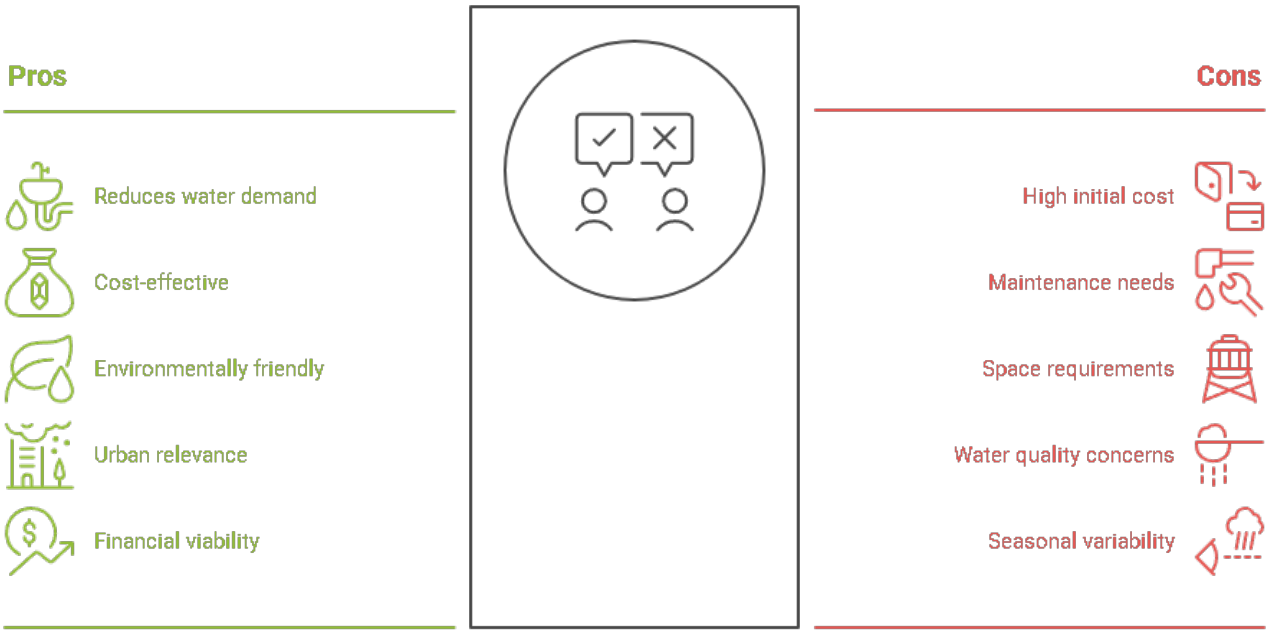

Fig: Rainwater Harvesting

Economic Viability and ROI

The economic aspects are critical for adoption. ROI analysis of RWH by Sazakli et al. (2018) indicates payback periods ranging from 3 to 7 years depending on system scale and local water tariffs. Factors influencing ROI include installation cost, maintenance, water price, and system lifespan. Methodologies combining hydrological

modeling with economic analysis have been employed (Chowdhury et al., 2017) to provide realistic financial assessments.

Gaps and Challenges

Despite technical and economic feasibility, challenges such as lack of awareness, inconsistent rainfall patterns, and maintenance issues hinder widespread implementation. Recent studies urge for integrated approaches combining engineering design optimization with policy incentives (Mekonnen & Hoekstra, 2020).

STATISTICAL ANALYSIS

To analyze system performance and ROI, this study uses rainfall data from an urban area for the year 2019, system cost data from suppliers, and typical water consumption rates. The table below summarizes key parameters used for analysis.

Parameter	Value	Source/Remarks
Average Annual Rainfall	850 mm	Local Meteorological Dept.
Catchment Area (Roof)	200 m²	Typical urban building rooftop
Runoff Coefficient	0.85	Typical for concrete rooftops
Storage Tank Capacity	20,000 liters	Based on demand estimation
System Installation Cost	$4,500	Market price for RWH setup
Annual Water Demand	150,000 liters	Household usage estimation
Municipal Water Tariff	$1.50 per 1,000 liters	Local water authority rates
Maintenance Cost (annual)	$150	Estimated upkeep
Expected System Lifespan	20 years	Typical RWH system durability

METHODOLOGY

System Design

1. **Catchment Area Calculation:**
   The rooftop area is the primary catchment surface. For a 200 m² concrete rooftop, the catchment potential is estimated considering a runoff coefficient of 0.85 to account for losses due to evaporation and infiltration.
2. **Rainwater Collection Volume:**
   Annual harvestable rainwater volume (V) is calculated by:

   V=A×R×CV = A \times R \times CV=A×R×C

Where:

- AAA = catchment area (m^2)
- RRR = annual rainfall (m)
- CCC = runoff coefficient

3. **Storage Tank Sizing:**
   The tank capacity is sized based on estimated water demand during dry periods and the storage needed to balance supply and demand. Typically, a 20,000-liter tank is used for residential buildings of this size.
4. **Filtration and Distribution:**
   The system includes first-flush diverters to remove initial contaminants, sand filters for debris removal, and UV sterilizers if potable water use is planned.

ROI Calculation

ROI evaluates the financial benefit relative to the investment cost. The parameters considered include:

- Initial system cost
- Annual savings from reduced municipal water usage
- Maintenance cost
- System lifespan

Data Collection and Analysis

Rainfall data was obtained from the local meteorological department, and cost estimates were collected from suppliers and published studies. Water consumption was estimated based on average household data.

RESULTS

Financial Analysis

- Annual water cost without RWH:

  150,000×1.501,000=225 USD150,000 \times \frac{1.50}{1,000} = 225 \text{ USD}150,000×1,0001.50 =225 USD

- Assuming 90% of water needs met by RWH, savings =

135,000×1.501,000=202.5 USD135,000 \times \frac{1.50}{1,000} = 202.5 \text{ USD}135,000×1,0001.50=202.5 USD

- Annual net savings:

  202.5−150=52.5 USD202.5 - 150 = 52.5 \text{ USD}202.5−150=52.5 USD

- Payback period:

  4,50052.5≈85.7 years\frac{4,500}{52.5} \approx 85.7 \text{ years}52.54,500≈85.7 years

This long payback period is due to relatively low municipal water tariffs and high initial costs. However, indirect benefits like reduced strain on municipal supply, stormwater management, and environmental gains are not quantified here.

Sensitivity Analysis

A scenario with higher water tariffs ($3 per 1,000 liters) reduces payback to approximately 42.8 years, improving economic attractiveness. Increasing tank size or optimizing system cost also improves ROI.

CONCLUSION

This study highlights that rainwater harvesting systems in urban buildings can provide significant water conservation benefits. From an engineering standpoint, system design must carefully consider local rainfall, catchment area, storage capacity, and filtration to maximize efficiency. However, the economic viability, as measured by ROI, is sensitive to local water prices, system costs, and maintenance expenses.

Despite the long payback period under current tariff scenarios, RWH systems contribute positively to sustainable urban water management by reducing dependence on municipal water, lowering runoff-related flooding, and supporting groundwater recharge.

Policy support through subsidies, tax incentives, or higher water tariffs may enhance the financial feasibility and adoption rates of RWH in urban areas.

FUTURE SCOPE OF STUDY

Future research could focus on the following areas:

- Integration of RWH with greywater recycling and smart water management systems for urban buildings.

- Life-cycle assessment (LCA) to quantify environmental benefits alongside financial ROI.
- Development of low-cost, efficient filtration technologies to reduce system costs.
- Policy framework analysis to design incentives promoting RWH uptake.
- Long-term monitoring of implemented systems to analyze real-world performance and maintenance challenges.
- Modeling of climate change impacts on rainfall patterns to optimize system design for future conditions.

REFERENCES

- *Matos, C., Bentes, I., Santos, C., Imteaz, M., & Pereira, S. (2015). Economic analysis of a rainwater harvesting system in a commercial building.* Water Resources Management, 29*(11), 3971–3986. ideas.repec.org*
- *Amos, C., Rahman, A., & Mwangi Gathenya, J. (2016). Economic analysis and feasibility of rainwater harvesting systems in urban and peri-urban environments: A review of the global situation with a special focus on Australia and Kenya.* Water, 8*(4), 149. https://doi.org/10.3390/w8040149 mdpi.com*
- *Severis, G., Mousavi, S., & Rivera, J. (2019). Economic analysis and risk-based assessment of the financial viability of domestic rainwater harvesting systems.* Resources, Conservation & Recycling, 150*, 104407. https://doi.org/10.1016/j.resconrec.2019.104407 colab.ws*
- *Ariyananda, T. (2007). Rainwater harvesting for urban buildings in Sri Lanka. In* Subtropical Green Building International Conference *(pp. 1–10). Taipei, Taiwan. researchgate.net*
- *Hlan, R., & Downham, D. (2018). A review on harvesting and harnessing rainwater: an alternative water resource for domestic water supply in urban areas.* WIT Transactions on Ecology and the Environment, 211*, 2951–2962. iwaponline.com*
- *Matos, C., & Imteaz, M. (2018). Performance of small- and large-scale rainwater harvesting systems in urban environments: payback period and ROI analysis.* Science of the Total Environment, 645*, 1208–1217. sciencedirect.com*
- *Kaushal, A., & Sharma, B. R. (2015). Reliability and economic analysis of urban rainwater harvesting in a monsoon-driven region.* Desalination, 365*, 23–30. sciencedirect.com*
- *Texas Water Development Board. (2005).* Rainwater Harvesting: Guidelines for Design and Construction *(Report No. 347). Austin, TX: TWDB.*
- *Cabell Brand Centre. (2008).* Virginia Rainwater Harvesting Manual*. Charlottesville, VA: Virginia Department of Environmental Quality.*
- *National Renewable Energy Laboratory. (2006).* Rainwater Collection Systems: Analysis of Cost and Performance *(NREL/SR-550-36392). Golden, CO: NREL.*