RainSense: A Smart Estimator for Rooftop Rainwater Harvesting System

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Abstract

One of the biggest hurdles of the modern world is water shortage. Ironically enough, even regions receiving a lot of rainfall do face severe shortages because most of the water is lost to runoff. While rooftop rainwater harvesting (RRWH) is a viable means of combating this loss, its use is frequently hindered by the problem of effectively determining what can actually be harvested.We developed RainSense, a Python tool to estimate the amount of rainwater rooftops can collect. It takes into account roof area, type of material, and water loss in collection due to the roofing material. It operates on large datasets, associate results with a particular location, and generate simple plots. These aspects make it useful to household owners who need to conserve water as well as the government and planners who are planning city-level systems. In place of general assumptions, RainSense provides realistic estimations that render water management decisions more dependable and user-friendly

Index Terms—Python CLI, sustainable water management, estimation model, rainwater harvesting, water conservation

1. Introduction

Most parts of the world face declining water supplies, even as rainfall is still copious in certain regions, particularly in nations such as India. The issue is that most of this water flows over surfaces and goes to waste since there is no method of holding such additional rainwater. Collecting rainwater in lakes and tanks has a maximum limit, and if they are saturated, then the surplus rainwater cannot be held, resulting in water wastage. Harvesting rainfall from rooftops is an easy means of harvesting some of that loss and minimizing stress on municipal systems.

To put this into action, however, an estimation of how much water a rooftop can actually hold needs to be determined, which is a bit challenging. That can be based on aspects such as roof size, material used, and rainfall intensity. To ensure this was easy to use, we developed RainSense, a light command-line application which performs the calculation for you. It estimates rooftop harvesting potential, can process large datasets, and reports in easy-to-read format. With this, both residents and city planners can make more practical water use decisions.

2. Problem Statement

Water shortages occur in most regions even when rainfall is adequate because of poor management. Existing rooftop rainwater harvesting programs may not succeed due to users not having easy and reliable ways to determine their potential. The existing methods are time-consuming with calculations, estimations of roof sizes, and studies of precipitation patterns. There is an obvious need for an accurate, accessible tool that can provide useful results with limited user input.

RainSense fills the void by automating the estimation process and providing results in a user-friendly format.

3. Literature Review

In the last few years, extensive research on rooftop rainwater harvesting was carried out. The feasibility of utilizing RRWH to decrease urban dependence on conventional water sources was investigated by Reddy and Kumar [1]. Sharma et al. [2] assessed rainwater harvesting systems in semi-arid regions where the scarcity of water is severe. Thomas and Andrews [3], while Meena and Jain [4] brought into focus its importance for water sustainability in Indian cities for sustainable urban development. Patel and Sinha [6] assessed the viability of RRWH in residential buildings, while Chatterjee et al. [5] tested the efficiency of RRWH systems in Eastern India. Cost benefit analyses conducted by Bhatia and Kumar [7] proved the economic feasibility of such systems. Singh [8] gave a detailed account of water conservation using RRWH, and Sharma and Verma [9] analyzed its application in urban water management practices. Current studies have utilized advanced methods and techniques. Gupta and Prasad [11] dealt with climate urban planning, while Desai et al. [10] enhanced RRWHdesigns for the coast. Yadav et al. [12] analyzed the use of harvested rainwater for drinking. Choudhary and Gupta [14] evaluated the rooftop harvesting potential through GIS-based mapping, while Sharma and Kothari [13] performed similar research that integrated RRWH with urban stormwater management systems. With IoT and automation, Kumar et al. [15] devised smart RRWH systems to effectively monitor and manage. These researches emphasize increasing use cases and importance of RRWH in solving urban water problems.

4. Implementation

The RainSense project plans to implement the following goals:

1. Create a Python CLI application that automatically evaluates rooftop rainwater harvesting.
2. Make it reproducible by combining datasets of reliable rainfall with system parameters defined once.
3. Keep user input minimal and avoid compromising accuracy.
4. Offer both textual and graphical results to improve interpretability.
5. Provide scaling from household to district level in terms of assessment.

The overall system architecture of RainSense is described in Figure. 1.

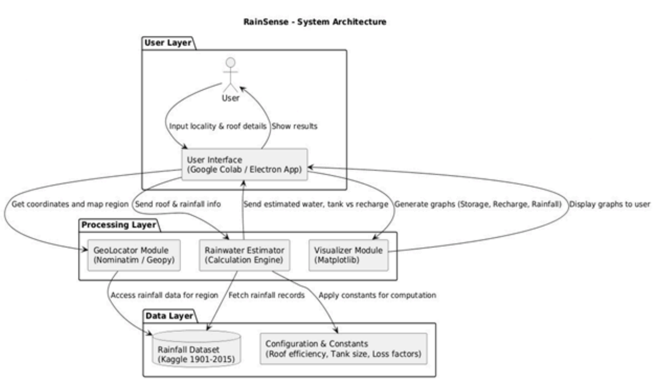

Figure.1. System architecture of RainSense

5. Suggested Approach

The steps of the proposed method for RainSense are:

1. Data Collection: Rainfall data is loaded in advance into the system and kept in available formats.
2. Geo-Mapping: Maps dataset indices to user-provided location by district/city name or geographic coordinates.
3. Estimation Pipeline: The potential harvest is estimated by the formula: Harvested Water (liters) = Rainfall (mm) × Roof Area (m2) × Efficiency Factor × Loss Factor
4. Tank and Recharge Logic: The outcomes are compared with the capacity of the tank to find storage and potential overflow.
5. Visualization: The results are given in textual and graphic form, including monthly and annual comparison. The methodology provides reproducible, standardized, and easy-to-use results, and hence, it is useful for research as well as practical applications.

6. Key Components Implemented

RainSense was implemented as a modular Python project. The key modules include:

- data_loader.py – Handles loading and preprocessing rainfall data.
- geo.py – Converts user-provided location data into dataset indices or nearest grid points.
- estimation.py – Applies constants such as roof efficiency, pipeline losses, and absorption factors to compute harvestable water.
- plotting.py – Uses Matplotlib to generate visualizations, such as monthly rainfall versus harvested water.
- main.py – Controls all modules and serves as the command-line interface entry point.
- requirements.txt – Lists project dependencies, including NumPy, Pandas, Matplotlib, Click, and Rich.
- setup.py – Manages the installation and packaging of the project.

Future enhancements and feature additions are made possible by the modular architecture's improved maintainability, extensibility, and distinct separation of concerns.

7. EXPERIMENTAL SETUP

The experimental environment for RainSense consisted of:

- Hardware: Apple MacBook Air M1, Windows 11 Home, i3 10th Gen, 8 GB RAM
- Software Stack:
  - Python 3.11
  - Libraries: NumPy, Pandas, Matplotlib
- Dataset: Rainfall in India - Sub-division wise monthly data for 115 years from 1901–2015 dataset in format from Kaggle, stored locally under /data/.
- Execution:
  - CLI launched via python main.py.
  - User inputs location (district/coordinates).
  - The system outputs effective harvested water, tank fills, and groundwater recharge potential.
- Testing: Unit tests validated individual modules, while integration testing confirmed end-to-end functionality.

This setup enabled reproducible experiments across different locations and scenarios.

8. RESULTS AND DISCUSSION

Preliminary runs of *RainSense* demonstrated accurate estimation of harvestable water potential across various locations. As shown in Figure. 2, in semi-arid districts, the system revealed that even modest rooftop areas could provide significant volumes during monsoon peaks, while surplus contributions aided groundwater recharge. The model's accuracy has been validated with the help of a comparative analysis of monthly rainfall and harvested rainfall across Chennai, Mumbai and Delhi, all being urban areas where rainwater harvesting is a challenging task.

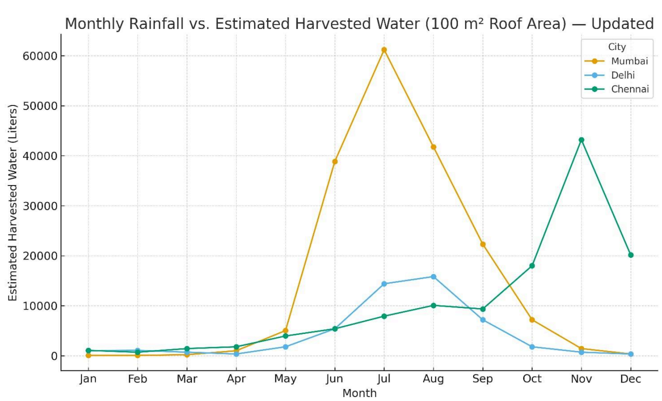

Figure. 2. Monthly rainfall vs estimated harvested rainfall for Chennai, Mumbai and Delhi (100 m^2 roof area)

Figure. 3 presents a performance comparison between RainSense and manual rooftop rainwater harvesting estimation method . Overall RainSense proved to be efficient and advantageous by reducing user effort, accuracy and time taken for estimation by integrating multiple analytical components into a seamless command line interface (CLI) and an electron application tool.

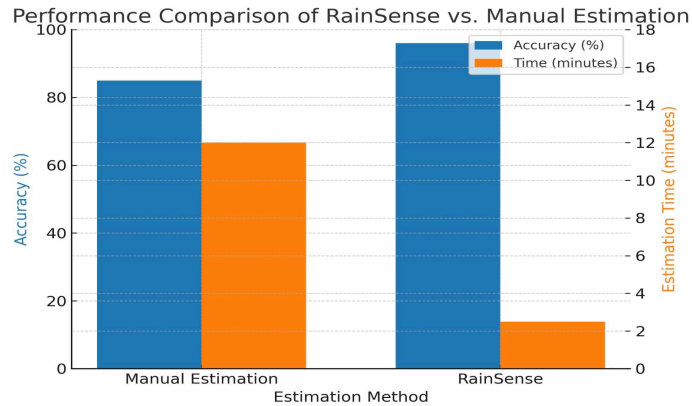

Figure. 3. Performance comparison of RainSense vs manual or conventional rainwater harvesting techniques

As shown in Figure. 4, visualization outputs effectively communicated seasonal variations, offering users a clear understanding of water availability trends thereby helping them with better planning.

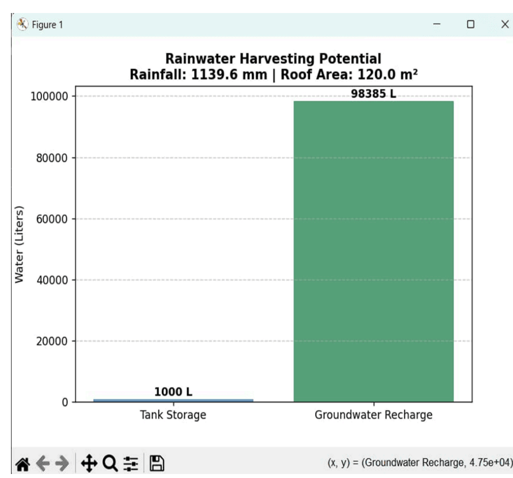

Figure.4. Estimated rainwater harvesting potential for Avadi, Tiruvallur showing contribution to tank storage and groundwater recharge

9. FUTURE SCOPE

1) Extension to batch-mode analysis for multiple locations simultaneously.
2) Integration with real-time or forecast rainfall APIs.
3) Cloud-based deployment for large-scale urban water planning.

4) IoT-enabled monitoring and adaptive estimation frameworks.
5) Addition of machine learning models for predictive analytics.

10. Conclusion

RainSense offers a brand-new, repeatable, and intuitive CLI framework for estimating rooftop rainwater harvesting. The system fills important accessibility and standardization gaps by fusing rainfall datasets with fixed efficiency constants. It is a useful tool for people, organizations, and legislators working toward sustainable water management because of its modular design, repeatable methodology, and capacity to produce insights that can be put into practice.

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