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Development of a Windows-based Tool to Model RWH System

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Abstract

Water scarcity has become a global issue in recent years. Recently, water scarcity has been further exasperated due to climate change. Rainwater harvesting (RWH) technique has been receiving great attention as an alternative water source due to rising water scarcity throughout the world. This paper presents the development of a python-based daily water balance tool to analyse the RWH system performance and optimise a potential rainwater tank size. The developed tool performs three different tasks, namely, reliability, sensitivity, and economic analyses. In the first step, the tool calculates the reliability of a particular size tank, connected with a particular roof area to fulfill the expected rainwater demand. Secondly, three distinct years (climate conditions) are considered in the sensitivity analysis to account for climate variability: a dry year, an average year, and a wet year. Finally, the tool calculates net present values (NPV) and benefit-cost ratios (BCR) to assess the cost-effectiveness of the proposed rainwater tank system. The developed tool is user-friendly that will make decision-making process for end-users simple, effective, and informed. It will facilitate the end-users to perform a cost-benefit assessment and eventually will encourage many people/organizations to optimise and install a feasible RWH system.

Keywords: Rainwater tank, daily water balance model, reliability, water security, economic analysis

1. INTRODUCTION

Water is one of the most precious natural resources on earth. Growing water demand, population growth, and climate change have made water supply systems under pressure in many countries across the globe. This has resulted in the identification and making use of alternative freshwater sources that can meet the growing demand of water (Hafizi et al., 2018). Water authorities are taking several steps to address this issue, including demand control and finding alternate water sources such as RWH, greywater and wastewater reuse, and desalination. RWH is receiving the greatest attention among all these alternative sources. It is the third largest source of water in Australia after surface water and groundwater (Alim et al., 2020). Over the last two decades, modelling tools and methodologies have been developed to evaluate the assessment and design of RWH system. The size and features of the contributing catchment, the amount of rainfall, and the system's demand are related to the performance of a RWH system (Campisano et al., 2017). RWH evaluation models are widely used as a design tool to evaluate the volume of storage needed to balance these inflows and outflows, ensuring that the water demand is satisfied for a specific house or building (Semaan et al., 2020). Several approaches can be used in RWH system tank design, optimisation, and performance evaluation, for instance, the design storm approach (Vaes et al., 2001), the analytical probabilistic or stochastics approach (Basinger et al., 2010) and continuous mass balance simulation approach (Fewkes et al., 2000). Among these approaches, the mass balance modelling approach has been widely used by many researchers to optimise the size of rainwater tank and to analyse the water savings and/or stormwater management benefits of a RWH system. (Toosi et al., 2020).

Water efficiency modelling approaches within RWH tools have been widely shown to give accurate representations when daily time step intervals are used. However, RWH tools can be manipulated to use a wide range of time steps with selection based on the resolution of data available. The selection of the most appropriate modelling tool and the simulation parameters depends on the objective of the analysis. Several studies described in this paper suggest a trend toward increasing complexity and detail within RWH models. The choice of the best appropriate modelling tool and simulation settings is determined by the study's goal. RWH models are becoming more complicated and detailed, according to the studies included in this analysis. Several research used a daily water balance modelling technique to determine a suitable rainwater tank size depending on local variables such as Campisano et al. (2012) for Sicily, Imteaz et al. (2011) for Australia, Londra et al. (2018) for Greece and Karim et al. (2021) for Bangladesh. Rainwater tank design tools have been widely investigated among many researchers in different regions globally

Based on the several studies presented above, it can be easily argued that most of the studies previously conducted were focused on a specific geographic location (s). Only a few studies considered reliability, water savings, sensitivity, and economic analysis together. Australia is a big continent with highly variable rainfall from location to location, hence, different cities will have different optimum rainwater tank sizes for a given water demand. To overcome this gap, a rainwater simulation tool is created to assist in the evaluation of RWH system performance as well as the determination of the optimal tank size for any given site. With a single source of information about a given site, the tool can generate reliability, water savings, sensitivity, and economic analysis together for various tank sizes. Further, the results are generated in separate excel files with visual graphs for greater insights and in-depth comparison. Additionally, users may even generate all the above-mentioned analyses for different tank sizes. The main objective of this paper is to provide an overview of the methodology used to develop rainwater simulation model and present a case study for the optimization of tank size based on four households in Sydney. Finally, three different types of analyses are performed by the tool (reliability and water savings, sensitivity and economic analysis) to make the decision-making process for end-users simple, effective, and informed. The remainder of the paper is organised as follows: a flowchart in section 2 shows the logical steps to calculate the reliability, water saving, and economic parameters of a RWH system. The overview of the created tool's window interfaces is shown in section 3. Section 4 contains conclusions and recommendations for future research.

2. METHODOLOGY

A python-based daily water balance model was developed considering inputs like daily rainfall, roof area, losses due to leakage, spillage, and evaporation, tank volume and water uses. The basic idea underlying the model is that the rainfall falling on a roof area initially discharges to a first flush device and then to the rainwater tank. Water is drawn from the rainwater tank for the intended use. Three different combinations of water use were considered: (i) toilet and laundry; (ii) irrigation; and (iii) a combination of a toilet, laundry, and irrigation (combined use). Daily runoff volume is calculated by multiplying the daily rainfall amount with the contributing roof area and deducting the losses (e.g. leakage, spilling, and evaporation). Generated runoff is diverted to the connected available storage tank. The available storage capacity is compared with the cumulative runoff. If the accumulated runoff is greater than the available storage volume, excess water is removed from the cumulative runoff. The amount of water use(s) is deducted from the daily accumulated/stored runoff volume if enough water is available in the tank. The model calculates daily rainwater use, daily water storage in the tank, and daily overflow. In addition, the model also calculates accumulated annual rainwater use and accumulated annual overflow. The methodology flowchart in Figure 1 demonstrates the logical steps to calculate the reliability, water saving, and economic parameters of a RWH system. A similar daily water balance approach was used in several previous studies, for example, by Fewkes (1999), Goh et al. (2021), and Khan et al. (2021).

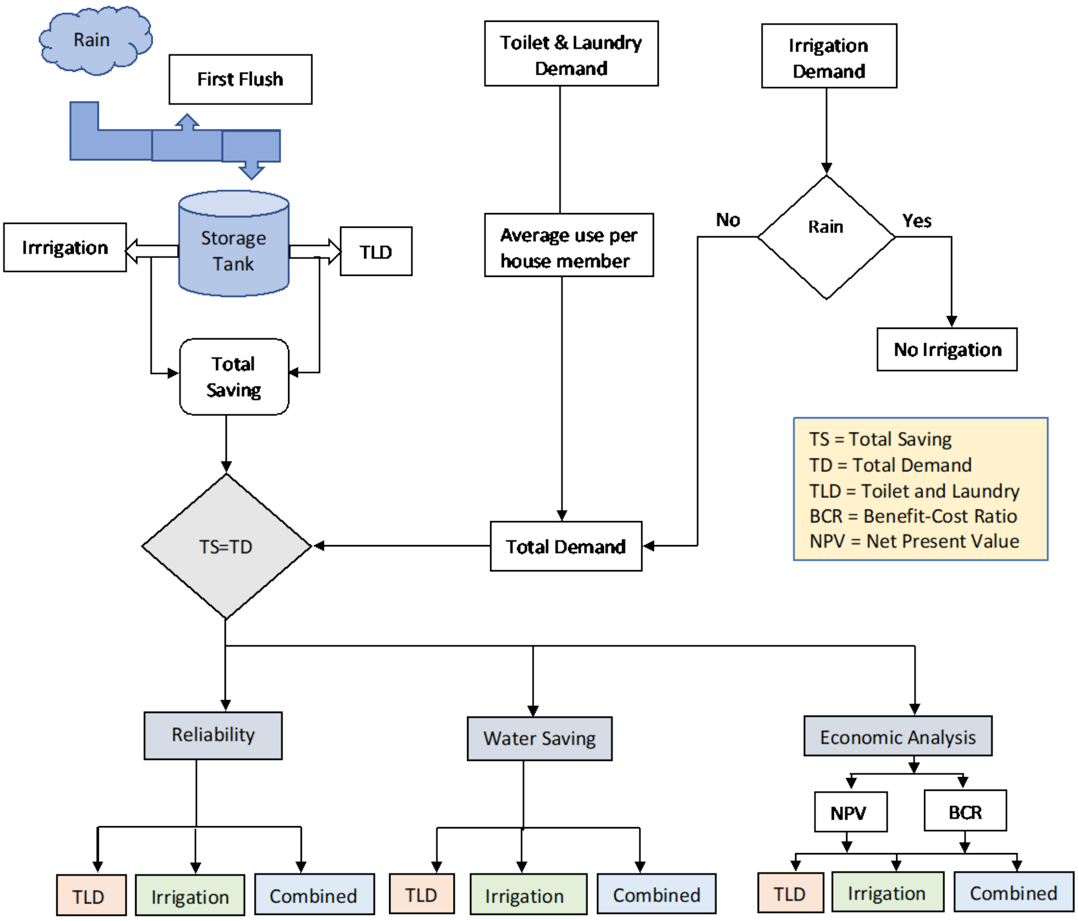

Figure 1. Flowchart showing the adopted methodology of the daily water balance model.

3. DISCUSSION: OVERVIEW OF WINDOW INTERFACES RAINWATER SIMULATION MODEL BETA V.1

An interactive decision support tool **Rainwater Simulation Model Beta v.1** was developed. Figure 2 shows "**Reliability analysis**" menu of the tool, which is where all of the preliminary data must be entered. Roof area, first flush, runoff coefficient, irrigation demand, toilet, and laundry demand and tank size are all required inputs. By hitting a "Start" button near the annual reliability and water savings analysis button, this window will prompt one to upload the primary input rainfall data file from a saved location. It will also ask for the start and end year if undertaking analysis for many years. In this study, we have used the rainfall data for 75 years with the start year as 1945 and the end year 2019. After selecting the "Start" button, all calculations relating to daily rainwater use, daily water storage in the tank, daily overflow, and total runoff will be calculated. This menu also provides graphical outputs and calculations for reliability, average annual water savings, monthly water demand met, and annual rainfall in an excel file. Each spreadsheet will be created for each tank size. Similarly, there is a monthly water saving and reliability button that runs all of the monthly analyses, such as monthly rainfall and monthly water demand fulfilled.

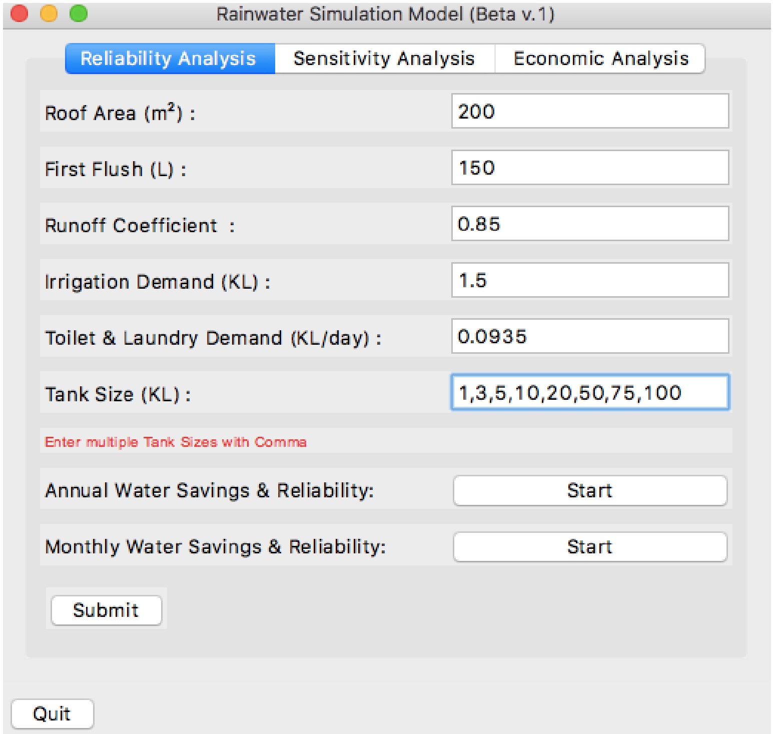

Figure 2. Reliability and water savings analysis menu.

Figure 3 shows the menu for "Sensitivity Analysis". This menu presents yearly rainfall outputs for three selected years: wet, average, and dry. By pressing the "Start" button, computations will begin, and the driest year from 75 years of rainfall data will be displayed on the window, along with rainfall for that year. It will also compute the year's reliability and water savings.

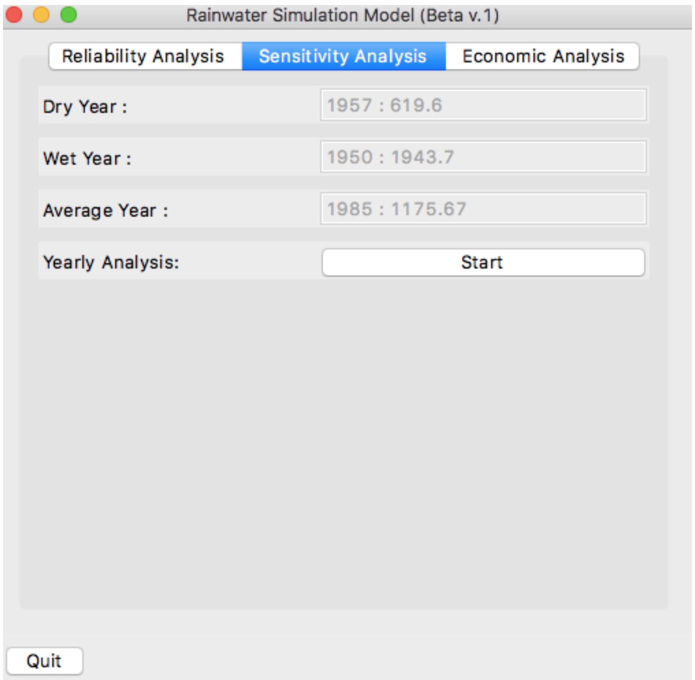

Figure 3. Sensitivity analysis menu for dry, wet, and average years.

Figure 4 shows the menu for "**Economic Analysis**". For the calculations of NPV and BCR, it requires some input data: lifespan of RWH system, water saved over the lifespan, capital investment, maintenance cost yearly, water price, interest rate, and inflation rate. By pressing the "Start" button, the NPV and BCR values for a chosen tank size will be calculated and shown on the window.

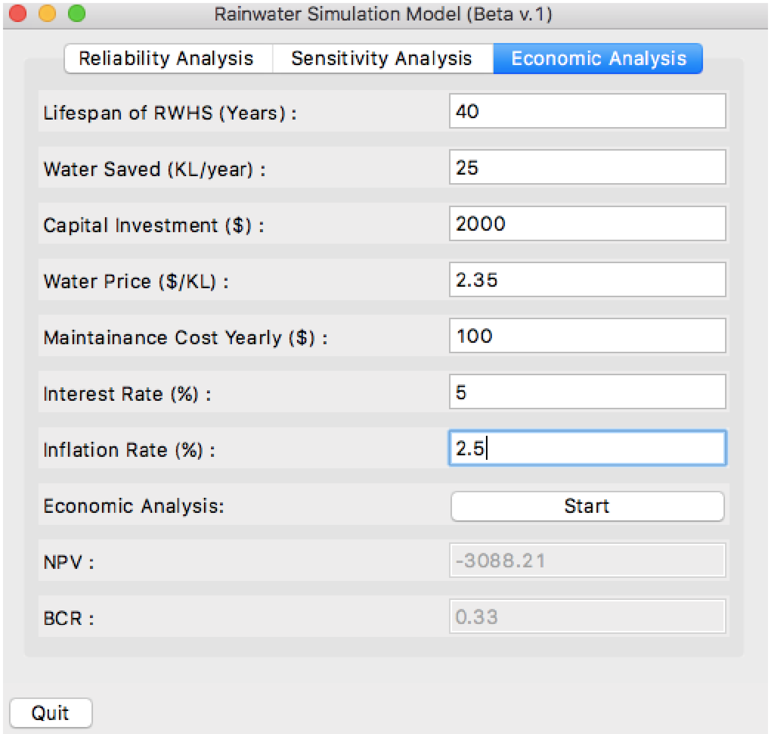

Figure 4. Economic analysis menu provides output in the form of NPV and BCR.

4. CONCLUSIONS

This paper presents the development of a comprehensive interactive decision support tool, which will enable an optimum design of rainwater tank size based on contributing roof area, rainwater demand, and climate conditions. This tool could be used for any geographical location based upon segregated data and also enables the calculation of reliability, water savings, and life cycle costing for a particular tank size. Based on daily rainfall data for a given period of data, the developed tool calculates potential reliability, cumulative water savings, and cumulative overflow losses for a particular tank size, connected with a particular roof area under three different climatic conditions (wet, average and dry). The simple economic analysis function within the decision support tool calculates the cost-effectiveness of any proposed rainwater tank system using NPV and BCR. It will facilitate the end-users to perform a cost-benefit assessment and eventually will encourage many people/organizations to optimise and install a feasible RWH system. The user-friendly tool can be used for the analysis of the effectiveness of a proposed RWH system with different storage volumes with different contributing catchment areas and with different rainfall scenarios. It will allow end-users to choose the best tank size for their RWH system, resulting in the decision-making process made simple, effective, and informed. Guidelines and requirements for the RWH system can eventually be updated for all Australian cities using this application.

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