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# ASSESSING RAINWATER HARVESTING OPTIONS IN TERESA, RIZAL: INCORPORATING USER PREFERENCES WITH MULTI-CRITERIA DECISION ANALYSIS

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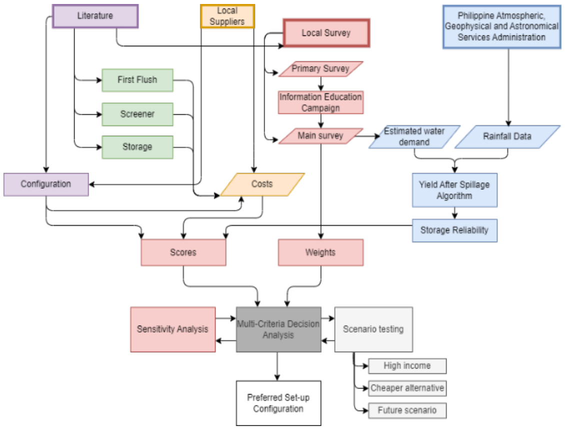
### Research Flowchart Methodology



Abstract

Water scarcity has emerged as a critical global challenge, necessitating the exploration of alternative water sources. Rainwater harvesting (RWH) presents a promising solution, given its abundance and ease of collection. Despite the Philippines' ample rainfall, RWH remains underutilized, capturing merely 6% of the annual precipitation. To bolster RWH adoption, this study aims to investigate residents' preferences for alternative water systems, with a specific focus on cost-effectiveness and reliability. By addressing these factors, we aim to identify key strategies for promoting and implementing RWH to mitigate water scarcity and foster sustainable water management practices in the Philippines. Preferences of rural residents (n = 185) in Teresa, Rizal on RWH alternative was then evaluated using a multi-criteria decision analysis. The main criteria assessed were reliability, cost, adoption factors, and benefits. The analysis involved assessing and converting the scores into Yield After Spillage (YAS) to establish rainfall reliability. The study employed Multi-criteria Decision Analysis (MCDA) to compare and evaluate various alternatives based on different factors, which were subsequently ranked under different scenarios. The study found that Alternative P10, a 1,000L plastic tank with a 20L first flush, exhibited the highest utility score among the assessed alternatives, with a score of 0.617. Notably, Alternative F30, featuring a 3,000L ferrocement tank with a 200L first flush, closely followed with a utility score of 0.614. The study employed the Jonckheere-Terpstra test and Kendall's tau with a significance level of 0.05 to determine the significance of these criteria concerning increasing income. The criteria of price, maintenance, and durability were identified as statistically significant (p-values: 0.007, 0.031, and 0.005, respectively) as residents' income increased. Consequently, residents with higher incomes placed greater importance on Alternative F50, a 5,000L ferrocement tank, due to its alignment with these influential criteria. Moreover, given the potential impacts of changing rainfall patterns and growing water demands, implementing larger storage tanks, like Alternative F50, is advisable to enhance future water sustainability in Teresa, Rizal.

*Keywords:* Water Sustainability, Rainwater harvesting, Rainwater Reliability, Multi-criteria decision analysis, Yield after spillage algorithm

## 1.0 INTRODUCTION

Water scarcity remains a pressing global challenge, affecting approximately 71% or 4.3 billion individuals worldwide for a significant period each year [1]. In the Philippines, the eastern region of Metro Manila experienced a severe water scarcity issue in March 2019, attributed to historically low water levels in the La Mesa Dam over the past 12 years [2]. With the Philippine population reaching 100 million in 2015, accompanied by a growth rate of 1.72 from 2010 to 2015, the water demand in Metro Manila is projected to escalate to 800 million liters per day by 2025 [3]. Addressing the impending water stress resulting from population growth and increasing water demands necessitates an exploration of alternative water sources.

Compounded by the effects of climate change, regions across Asia are facing further water scarcity, with decreasing rainfall intensity and more frequent rainfall extremes [4],[5],[6]. Climate change's impact on rivers and watersheds is expected to lead to extended drought periods, reducing water supply during peak usage times [7].

In the Philippines, limited locally available rainwater harvesting (RWH) systems prevail, with commercial tanks and filters proving financially prohibitive for rural average income earners. The adoption of RWH systems in Southeast Asian countries, including the Philippines, remains inadequately explored [8]. In some areas, low-cost RWH systems have been implemented successfully, such as the example in Bangladesh, where a ferrocement tank with 4.8 $m^3$ of storage costs approximately 9600 Php (170 USD) [9]. Nevertheless, previous studies often assume that users do not have access to piped water, neglecting the potential integration of RWH with existing water sources.

In rural areas of the Philippines, water access is primarily reliant on groundwater pumping, contributing to rapid depletion and various ecological challenges, including seawater intrusion, land subsidence, reduced stream flow, loss of springs, and ecological degradation [10]. To address these issues and promote RWH adoption, it is essential to investigate whether residents in rural areas would consider alternative water systems based on cost and reliability factors. Such insights are critical in encouraging the widespread adoption of rainwater harvesting systems, ultimately contributing to improved water supply and sustainability in the country.

This research aims to bridge the existing knowledge gap by utilizing a multi-criteria decision analysis to incorporate the informed choices of rural residents in selecting a rainwater harvesting system that aligns with their needs and preferences. By investigating attitudes, perceptions, and potential practices related to rainwater harvesting, this study seeks to enhance the adoption of sustainable water solutions in the rural areas of the Philippines. The implications of this research hope to positively impact the livelihoods and water security of rural communities facing water scarcity challenges. Additionally, the local government can benefit significantly from the study's recommendations, as implementing the suggested alternatives can contribute to more effective and sustainable water management practices in the region.

## 2.0 METHODOLOGY

### 2.1 Area Location

The study area is the Municipality of Teresa (Figure 1), situated approximately 32 km away from the capital city, Manila, at coordinates 14.57033, 121.22255. According to the Philippine Statistics Authority (2015), this region is home to 57,755 individuals, residing in 13,411 households, and spread across 18.61 $km^2$ of land. Notably, 43% of the population falls within the lower middle-income bracket, with a monthly household income ranging from Php 21,914 to 43,828 (approximately 400-750 USD). In terms of water availability, certain barangays in the area experience significant water interruptions, enduring 10-14 hours of water scarcity every day. Moreover, some barangays rely on private water operators for their water supply. This location thus serves as a pertinent site for investigating residents' preferences regarding alternative water systems and the potential adoption of rainwater harvesting to address water scarcity challenges since they are on the look for alternative water systems in filling their water needs.

**Figure 1:** Location of area relative to the capital city of Manila **(Google, 2023)**

### 2.2 Data Collection

The methodology employed in this research encompassed the collection of five key datasets, comprising information on historical rainfall patterns, water demand estimation, costs of various system components, system configurations, and survey weights. To determine past rainfall patterns, daily rainfall data spanning from 1999 to 2019 were obtained from rainfall stations in Boso-Boso and Mt. Oro, administered by the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA).

The estimation of water demand was derived from the preliminary survey, enabling a comprehensive understanding of the required water quantity. For determining system costs, local suppliers in proximity to the study area were consulted, and transportation costs were considered if materials and systems needed to be sourced from nearby locations.

System configurations, encompassing outdoor, underground, above ground, or indoor setups, were identified through extensive literature reviews [22]. Moreover, material selection played a crucial role in defining the configuration of the rainwater harvesting (RWH) system. Additional features of the system, including first flush mechanisms, screeners, diverters, and filters, were also incorporated. Figure 2 shows the four alternatives that was chosen for the study, with their name followed by the acronym in parenthesis accordingly 1-Metal tank (M), 2-Ferrocement tank (F), 3-Plastic tank (P) and 4-Commercial tank (C). Sizes for these configurations were determined based on their maximum and minimum capacity that residents are willing to use and are outlined in Table 1 as storage sizes.

**Table 1:** Alternatives that were selected based on the resident's preferences

| Alternative | Reference | Filters | First flush / efficiency | Storage Sizes | Symbol* |
|---|---|---|---|---|---|
| Metal tank (M) | Kinkade-Levario (2007), Avis (2014) | Plastic Inline filter | 90% | 500L, 1000L, 1500L | M5, M10, M15 |
| Ferrocement tank (F) | DOST (Taguig) Project | Angled screen and first flush | 200L Plastic drum first flush | 1000L, 3000L, 5000L | F10, F30, F50 |
| Plastic tank (P) | PCIEERD Project | Angled screen and first flush | 20L | 200L, 400L, 600L, 1000L | P2, P4, P6, P10 |
| Built-in Commercial Plastic tank (C) | Weida Philippines Inc. | Integrated first flush with a basket filter | 25L | 700L | C7 |

*Symbol: The number that follows the letter signifies the size in hundreds of L, i.e. M5 is a Metal storage tank with a size of 500L

In establishing the significance of each factor, weights were assigned based on user preferences gathered through a survey. The research aims to present an analysis of residents' preferences for alternative water systems and their willingness to adopt rainwater harvesting practices in the study area.

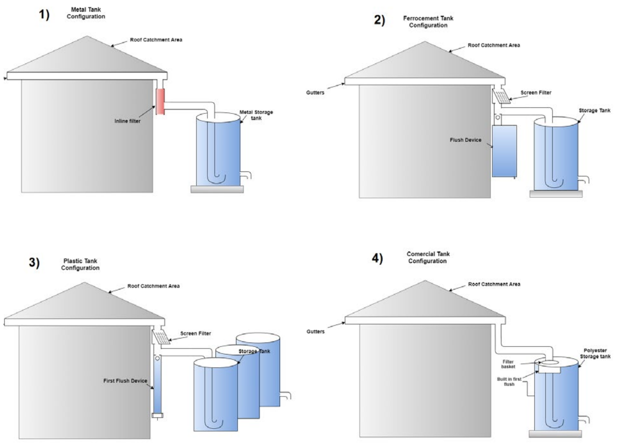


**Figure 2:** Configuration of the different alternatives.

Local alternatives obtained from the survey are presented in Table 1. These alternatives were initially introduced in the preliminary survey, where respondents were asked to select from metal, cement, or plastic tanks as their storage options. The first alternative is a metal tank with a plastic inline filter, available in three sizes differentiated by cost, with the highest option priced at 20,000 pesos for the storage tank alone.

A cost-effective ferrocement tank was chosen as another alternative, available in various sizes, including larger options such as 5,000 L, and potentially reaching up to 40,000 L [24]. To act as a filter, options for an angled screen and a 200L plastic first flush were introduced. Angled screens are designed to filter out leaves and large debris, preventing their entry into the storage tank. The first flush, or roof washer, isolates the initial volume of rainfall, diverting it away from the tanks.

The third option involves plastic drums, serving as the most economical alternative and easily accessible in the local area. The survey revealed that an average of 1.7 drums per household were already available and used for water storage when the main water supply is unavailable. This alternative envisions fewer purchases for households if they can repurpose their existing plastic drums. Accompanied by an angled filter and a 20L first flush [21], this alternative provides a practical and cost-effective option for residents.

Finally, the study explored a commercially available tank as an alternative, featuring a built-in filter basket and a 25L first flush. This option requires minimal assembly and construction and is readily purchasable by individuals.

## 2.3 Survey Collection

To gauge the preferences and insights of the local community, a two-step survey approach was employed. Initially, a preliminary survey was conducted, involving 20 selected individuals from the local area. Specific questions were formulated to ascertain the factors they deemed important, and open-ended questions were included to elicit direct problems and concerns foreseen by the residents. Through this preliminary survey, factors perceived as unimportant by the residents were identified and subsequently eliminated from the main survey.

The main survey, targeting the residents of Teresa, Rizal, was conducted online to ensure broader participation and accessibility. The online survey questionnaire comprised a comprehensive set of 45 questions and was supplemented by an Information Education Campaign (IEC). The IEC component aimed to educate and inform respondents about various aspects of rainwater harvesting (RWH) systems. In order to validate the credibility and comprehension of participants, validation questions were strategically incorporated into the survey. Out of the 329 total respondents, 184 individuals were deemed valid and considered for analysis, ensuring the reliability and accuracy of the collected data. By implementing this survey collection approach, the study aims to obtain robust and representative insights into residents' perspectives on alternative water systems, specifically focusing on their attitudes towards rainwater harvesting in the study area.

## 2.4 Rainfall Reliability

The study utilized the Yield after Spillage (YAS) algorithm, represented by Eq. 1, as the primary water balance model [11]. This algorithm, based on the rational method, calculates the usable rainfall for the system by considering the smaller value between the current water demand and the remaining storage volume from the previous time step. The final volume is obtained by adding the additional rainwater runoff collected to the current storage volume and subtracting the water demand, resulting in the system's yield. The simulations were conducted using Microsoft Excel and Google Sheets, where custom functions were incorporated and implemented on a VBA-enabled sheet, operating on a daily time step.

$$Y_t = min\begin{Bmatrix} D_t \\ V_{t-1} \end{Bmatrix}$$
$$V_t = \min\begin{Bmatrix} V_{t-1} + Q_t - Y_t \\ S - Y_t \end{Bmatrix} \quad \textbf{Eq. (1)}$$

The key output of the YAS algorithm is storage reliability, which assesses the capacity of a given storage size to meet household demand. Storage reliability is determined by dividing the number of time intervals in which the demand was fully satisfied by the volume of the tank, by the total number of time intervals.

In modeling future climate change scenarios, historical data relied on predicted future rainfall data provided by PAGASA. This approach enables insights into the potential performance of the rainwater harvesting (RWH) system under future climate conditions, serving as a basis for selecting appropriate alternatives. By employing the YAS algorithm and evaluating storage reliability, this research offers valuable assessments of rainwater harvesting system efficiency and reliability, considering present and future conditions, and contributes to informed decision-making for sustainable water management in the study area.

## 2.5 Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) is a powerful tool widely used in environmental studies, including terrain site evaluation and contaminated sediment relocation [12]. This approach effectively analyzes diverse streams of information, consolidating them into a single basis for evaluation, providing valuable decision support. MCDA has been successfully applied in various fields such as site prioritization, environmental remediation, environmental impact assessment, stakeholder involvement, and natural resource planning. By employing MCDA as a framework, stakeholders can systematically weigh pros and cons concerning their environmental options, facilitating well-informed decision-making [12].

The MCDA framework comprised four main categories: reliability, total cost, adoptability, and benefits. Factors such as water reliability, system costs, water savings, and stormwater reduction were identified as crucial criteria in evaluating rainwater harvesting (RWH) systems [13],[14],[15]. Formulas delineated in Table 2 were applied to applicable categories and to each alternative, ensuring a standardized evaluation for comparative analysis. The preliminary survey served to confirm these criteria, which may vary based on user preferences. Weights derived from the main survey were then utilized to determine the most preferred alternative, while values of the alternatives were evaluated based on quantifiable variables or user preferences.

This study aims to assess respondents' preferences and attitudes towards rainwater harvesting systems, ultimately contributing to a higher adoption rate when implementing these systems in the field. By exploring preferences across income brackets and various scenarios, the research ensures that alternatives are ranked based on their assigned importance. Moreover, the study incorporates a future scenario that considers the effects of climate change when selecting alternatives, enhancing the robustness and relevance of the findings. Through the application of MCDA, this research aims to provide valuable insights for promoting the widespread adoption of sustainable rainwater harvesting systems, fostering enhanced water management practices in the study area.

### *2.5.1 Weight Assignment*

To determine the weights for the different criteria, survey participants were requested to score each criterion on a scale of 1 to 4. This scale was designed for user convenience, especially for those expected to respond via mobile phone. The median score of each criterion was then identified as the corresponding weight. These weights were subsequently transformed using the expected value approach [16], ensuring a robust and a sound representation of the respondents' preferences.

**Table 2:** Formulas used for scoring different criteria

| Criteria | Formula |
|---|---|
| Reliability [17] | $r \text{ is } \begin{Bmatrix} 0, & D_t > Y_t \\ 1, & D_t \le Y_t \end{Bmatrix}$<br>$R = \frac{\sum_i^n r}{n}(100)$<br>*R* is the reliability, *n* is the total number of time intervals, *Dt* is Demand for time interval t and $Y_t$ is Yield from storage for interval t |
| Water Savings | $T_{saved} = \frac{\sum_i^n Y_a}{\sum_i^n Y_{max}}$<br>With $Y_a$ as the yield of the alternative and $Y_{max}$ as the yield of the highest storage alternative |
| Water storage as an emergency water supply | $e = \begin{Bmatrix} 1, V_t > D_t \\ 0, otherwise \end{Bmatrix},$<br>$E = \frac{\sum_{i=1}^n e}{n}$<br>With $D_t$ as the emergency water consumption for a household and $V_{t-1}$ as the water stored from the previous time interval |

| | |
|---|---|
| Stormwater retention [19] | $f = \begin{cases} Q_t + V_{t-1} - S, Q_t + V_{t-1} > S \\ 0, otherwise \end{cases}$<br>$F = 1 - \frac{\sum_i^n f}{\sum_i^n Q_t}$<br>With $f$ as the daily overflow, $Q_t$ as the overflow without an RWH, $S$ is the storage size and $V$ as water stored |

### 2.5.2 Criteria Scoring for the Alternatives

The evaluation of various criteria involved diverse measurement approaches. Reliability was measured directly through the formula in Table 1. While the benefit criteria were measured through three parameters namely, water savings, water as an emergency water supply and through storm water retention (Table 1)

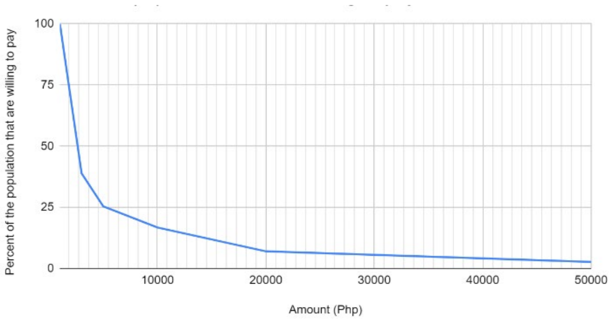


**Figure 3:** Alternatives scores overall and sum of utility scores derived from the survey

The costs criteria were conducted directly based on the survey results and an interpolation approach. This computation was carried out by considering the number of respondents willing to spend a particular price for the RWH configuration, as depicted in Figure 3. A score of 100% indicates that all respondents are willing to pay the specified amount for the ability to collect and store rainwater, while a score of 0% signifies that none of the population is willing to invest in such a price for rainwater harvesting. The resulting score is obtained as a ratio compared to the highest-scoring alternative. The underlying aim of this function is to minimize cost [17], where a higher score suggests that the alternative is likely more affordable and cost-effective.

The adoptability criteria were gauged using a direct rating scale [16], allowing respondents to express their preferences explicitly. The assessment of color was determined by the alternative's tank capacity to maintain water colorless, influenced by the filter and tank material [20]. Meanwhile, the presence of dirt was measured based on the type and size of the filter [20]. Installation scoring depended on the construction complexity of each alternative, while maintenance scoring considered the frequency of system checks and operational upkeep. Shipping was evaluated by considering the distance and ease of transportation for each system alternative. Space criteria involved measuring the area occupied by each alternative, with the largest area resulting in the lowest score, as users would have less available space for it [21]. Durability was assessed in comparison to the ideal lifespan of water storage tanks, set at 50 years.

To standardize the scores, further transformations were performed by converting each score into a 0 to 1 range. This transformation involved dividing each score by the highest-scoring alternative, enabling a comparative and normalized assessment across all criteria.

### 2.6 Scenario Building

For this study, three distinct scenarios were developed to comprehensively explore various aspects of the rainwater harvesting (RWH) system preferences.

Income Bracket-based Scenario 1: In this scenario, the researchers considered the shifting of weights for the criteria based on the income bracket of the participants. To determine the criteria relevant to each income group, statistical analyses such as the Jonckheere-Terpstra test and Kendall's tau were utilized, with a significance level of 0.05. By identifying the criteria deemed more important to specific income groups, higher ranks and higher corresponding weights were assigned to these criteria. This approach allowed for a nuanced understanding of how income influences preferences for alternative water systems, thus providing valuable insights for tailored RWH adoption strategies.

Lower Cost Alternatives – Scenario 2: In this scenario, the researchers explored alternatives that closely aligned with the budget constraints of the residents. This involved introducing new alternatives that offer cost-effective solutions without compromising the essential functionalities of the RWH system. By identifying and prioritizing lower-cost alternatives, the study aimed to present financially viable options that resonate with the local community's needs and financial capacity. These alternatives have an asterisk (*) in their symbol signifying and that these are low-cost alternatives.

Climate Change Impact – Scenario 3: In this scenario, the researchers considered the potential effects of climate change, leading to an increase in rainfall volume and water demand [26]. By integrating this aspect, the study aimed to project the performance and adaptability of the RWH systems in the face of changing climate conditions. This forward-looking approach enabled the identification of alternatives that could effectively address future water scarcity challenges, contributing to more resilient and sustainable water management practices.

## 3.0 RESULTS AND DISCUSSION

### 3.1 Survey Results

During the months of January to April, there is little rainfall to be expected on average, [23] see Figure 4. As PAGASA states, the local area is to expect decreased rainfall in the months December to February, while a steep increase in rainfall for the months September to November. With little expected rainfall for January to April, for an average household with a roof area of 65 m$^2$, this value averages to only 1.65 m$^3$ per month, which is too little and would only supply two days of the household's non-potable water. Thus, it is not recommended that RWH be used during the dry season. World Bank (2012) mentioned that rainwater catchment systems are best used for areas with well-distributed rainfall. The study then assumes that RWH will only be utilized during the wet season. This includes the months of June to November where a more abundant rainfall is expected [23].

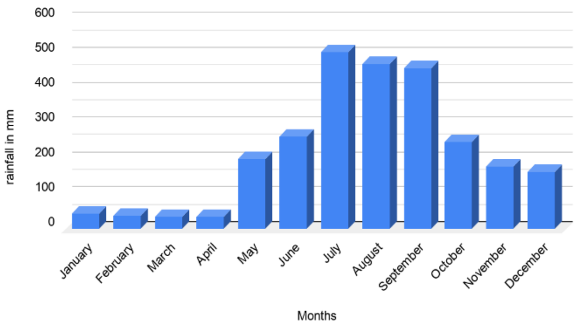


**Figure 4:** Monthly average rainfall for the simulation (20-year data)

The average age of the participants was 29.9 years, with an average roof area of 65.88 m$^2$. The average per capita water consumption was recorded at 132.98 L, and the average household size was 5.54 individuals (Table 3). These variables played a significant role in the simulation process, where they were used to assess the reliability of the different alternatives in capturing rainwater supply to meet household demand effectively.

**Table 3** Summary information on the surveyed population

| Surveyed factors | Sample size | Minimum | Maximum | Mean | SD |
|---|---|---|---|---|---|
| Age | 185 | 18 | 60 | 29.90 | 9.90 |
| Roof Area | 156 | 10 | 240 | 65.88 | 69.1 |
| Liters per capita | 174 | 20.55 | 328.73 | 132.98 | 64.0 |
| Household members | 185 | 1 | 32 | 5.54 | 2.1 |

Approximately two-thirds of the respondents reported facing challenges with low water supply and frequent water interruptions, while only one-third stated having no problems with their current water source. When considering rainwater harvesting (RWH) systems, the respondents identified two main concerns. Firstly, they expressed worries about the potential for RWH systems to become breeding grounds for mosquitos. Secondly, there were reservations about the perceived cleanliness of the water produced by these systems.

The tropical climate of the Pacific regions, as indicated in the evaluation of ADB's (Asian Development Bank) population-weighted average key dimensions [2020], can lead to increased health impacts from water-borne diseases. Given this context, the prevalence of mosquitos in the area poses a serious threat that needs to be carefully managed by RWH alternatives.

Survey respondents revealed their preferences for the primary uses of RWH systems, with flushing toilets, plant watering, and general cleaning ranking as the most preferred purposes; as chosen by more than 50% of respondents. When it comes to the location of storage tanks, respondents indicated a preference for having the tanks outside of the house (36.1%), followed by the option of having no available space for a water tank (27.8%). Understanding these preferences can help tailor the implementation of RWH systems to better suit the residents' needs and maximize their adoption in the study area.

## 3.2 Weights

Table 4 presents the weights derived from both the general scenario and the high-income scenario. In the high-income scenario, residents with higher income displayed a greater preference for the benefits criteria. Consequently, the weights were adjusted accordingly to reflect their preferences.

**Table 4:** Weight summary for the overall vs scenario 1 (high-income scenario) using the expected value approach [16]

| Criteria | Sub criteria | Overall | Scenario 1 |
|---|---|---|---|
| Reliability | | 0.250 | 0.16 |
| Cost | | 0.250 | 0.16 |
| Adoptability | Color | 0.036 | 0.035 |
| | Dirt | 0.036 | 0.007 |
| | Installation | 0.036 | 0.035 |
| | Maintenance | 0.036 | 0.035 |
| | Availability | 0.036 | 0.007 |
| | Space | 0.036 | 0.007 |
| | Durability | 0.036 | 0.035 |
| Benefits | Cost Savings | 0.111 | 0.231 |
| | Emergency | 0.111 | 0.231 |
| | Flood retention | 0.028 | 0.058 |
| **Total** | | **1** | **1** |

For the general case, equal weights were allocated to the four main criteria, as the results indicated a similar level of importance after being ranked. These balanced weights ensure that each criterion is given due consideration based on the preferences of the residents. By employing this approach, the study aims to present a fair and comprehensive evaluation of the alternatives, considering all relevant factors according to the preferences of the surveyed population.

## 3.3 Scoring Results

The scores for the alternatives are depicted in Figure 5, representing a combination of the overall weights from Table 4 and the rating scales created for each criterion. Based on Figure 6, the alternative P10 obtained the highest utility (0.617), closely followed by the alternative F30 (0.614). Alternative P10 comprises multiple plastic tanks with a total capacity of 1,000 liters, which is smaller compared to F30's 3,000 liters and F50's 5,000 liters. However, smaller storage tanks offer the advantage of reducing water quality degradation by minimizing the detention period [25]. The scores for P10 ranged from 0.44 to 0.72, while F30's scores ranged from 0.25 to 0.86, indicating that P10 has more balanced values for all the criteria compared to F30, which exhibited more extreme scores. This well-rounded scoring pattern made P10 slightly more preferable among the alternatives.

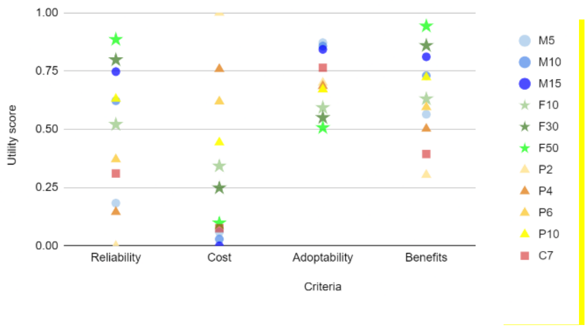


**Figure 5:** Alternatives scores overall and sum of utility scores

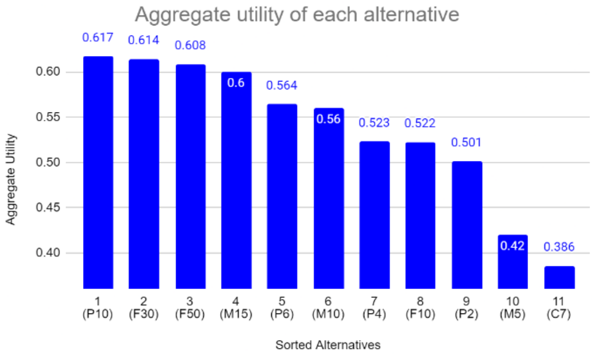
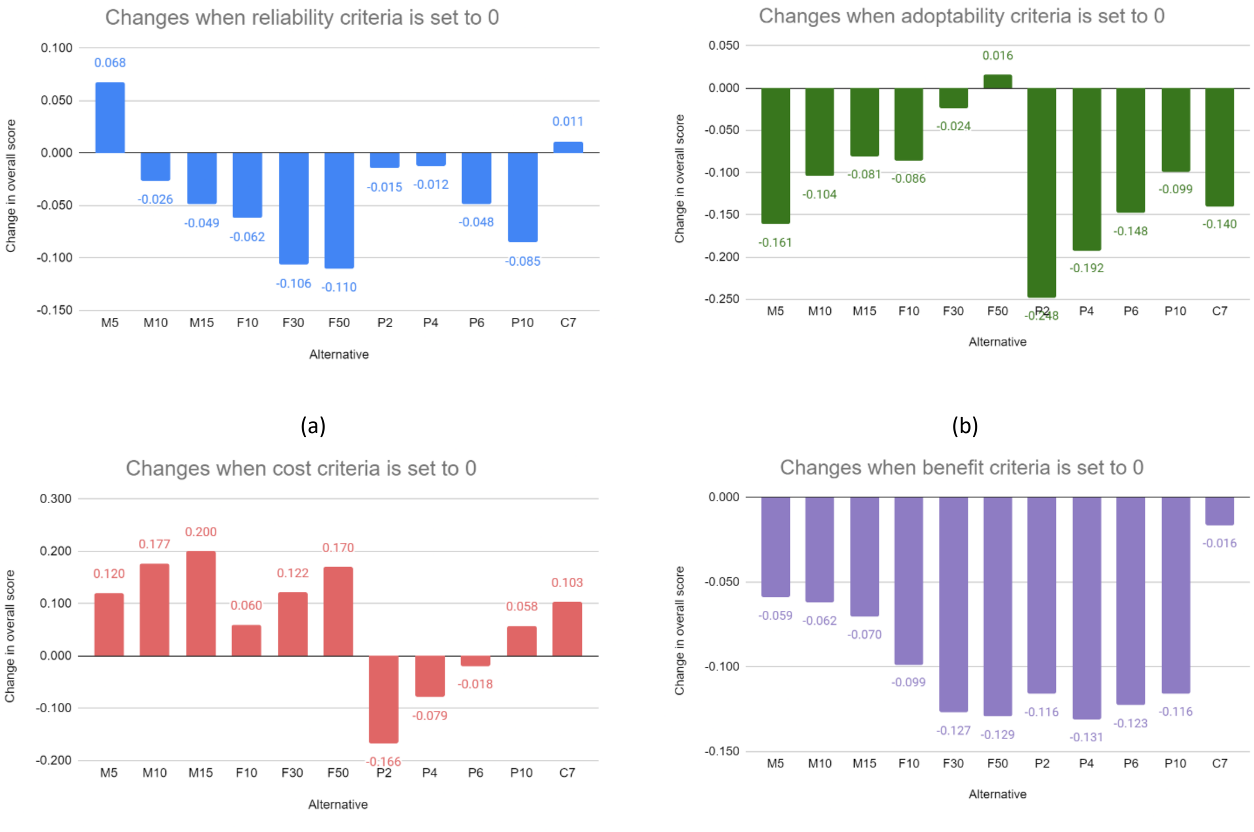


**Figure 6:** Overall scoring of alternatives

The alternative F30 secured the second-highest utility value, with relatively high scores on reliability and benefits (Figure **6**). However, it scored lower in the criteria of cost and adoptability. The combined utility scores indicated that F30 achieved the second-highest score (0.614), while F50 ranked third with a score of 0.608. Ferrocement tanks stand out as one of the most cost-efficient storage options [24], as they can be built using local materials and offer the cheapest cost per volume. Conversely, the alternative C7, a market-available option, scored the lowest overall. This outcome is likely due to its relatively small storage size and higher relative costs, resulting in the lowest overall utility score.



(a) (b)

(C) (D)

**Figure 7:** Changes on the overall score due to varying weights on the criteria (a) reliability, (b) adoptability, (c) cost, and (d) benefits

The sensitivity analysis reveals the potential impact of eliminating a criterion on the ranking of alternatives (Figure 7). When a criterion is removed, the order of preference among alternatives can shift, with either M15 or F50 emerging as the preferred alternative. In most cases, considering only three out of the four criteria leads to M15, the metal tank configuration, being ranked as the most preferred option. This observation emphasizes the significance of each criterion, as their inclusion helps prevent the dominance of a single alternative.

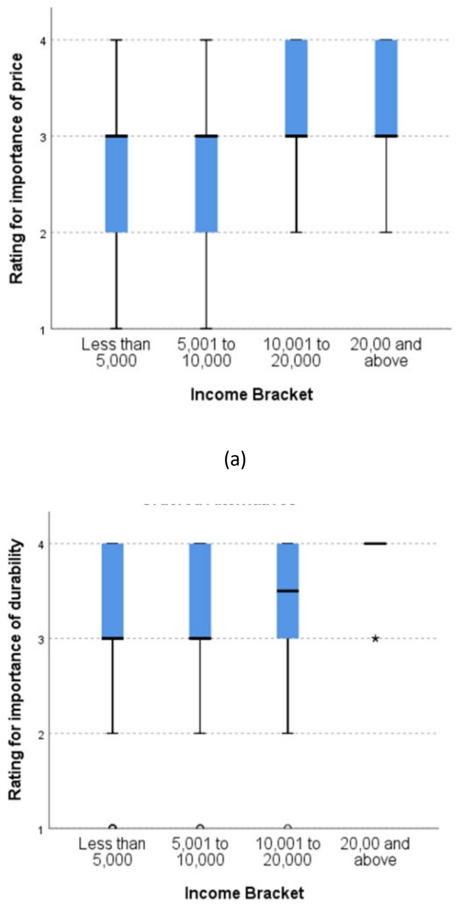
Figure 7 (c) illustrates that as the weight assigned to the cost criterion diminishes, the utility scores shift positively meaning the criteria is pulling their scores down and negatively meaning the alternative is heavily factored by the criteria. As we see, the P2 alternative is significantly favored by cost, when this criterion is removed, the change in its score is negative. This implies that it has lost one of its most valuable assets, while the rest of the alternatives gain scores. This finding suggests that the cost criterion exerts a level of sensitivity, wherein a change in its weight can significantly alter the utility scores and consequently change the preferred alternative. This sensitivity is likely attributed to the current high cost of alternatives, which may be unaffordable for most of the respondents.

Figure 7 (b) and (d) indeed illustrate a noteworthy trend, where the utility scores of almost all alternatives decrease significantly as the respective criteria are removed. This observation indicates that these criteria have a substantial impact on the overall evaluation and scoring of the alternatives. The decline in utility scores suggests that these criteria carry significant weight and contribute significantly to the overall performance of each alternative.

As such, it is evident that these criteria hold a pivotal position in the decision-making process when selecting the most appropriate rainwater harvesting system for the study area. Acknowledging the importance of these criteria can inform policymakers and stakeholders about the key factors that must be carefully considered to promote the successful adoption and implementation of rainwater harvesting systems, thus ensuring improved water resource management and greater water sustainability in the study area.

### 3.4.1 Scenario 1: High Income

Regarding the participants' income distribution, the survey got 83 participants (45%) reported earning less than 5,000 Php per month (approximately 100 USD), 60 participants (33%) earned between 5,000 to 10,000 Php per month (approximately 100-200 USD), 30 participants (16%) earned between 10,000 to 20,000 Php per month (approximately 200-400 USD), and 11 participants (6%) reported earning more than 20,000 Php per month (approximately 400 USD). Understanding the income distribution is vital for the income bracket-based scenario, where the weights of criteria are adjusted based on different income groups. This data enables a comprehensive analysis of preferences across varying income levels, ultimately contributing to a more tailored and effective approach in promoting rainwater harvesting systems in the study area.



(a)

(b)

**Figure 8** Median ratings for (a) importance of price and (b) durability across income brackets

Scenario 1 assumes that those of higher income bracket have a different of criteria importance thus a different set of weights. Those of higher-income, value the benefits more versus the three other primary criteria. They also gave higher values when considering color of water, system maintenance, installation, and the durability of the system.

Three factors are found to have significant changes across categories of income using the Jonckheere-Terpstra test for ordered alternatives. The study revealed significant correlations between factors such as price and durability to income at a level of 0.01, while maintenance was significant at a level of 0.05. These are the three factors that have higher importance to those with higher income (Figure 9). Some of these changes resulted in weight changes which resulted in a difference in the preferred alternative as shown in Figure 8.

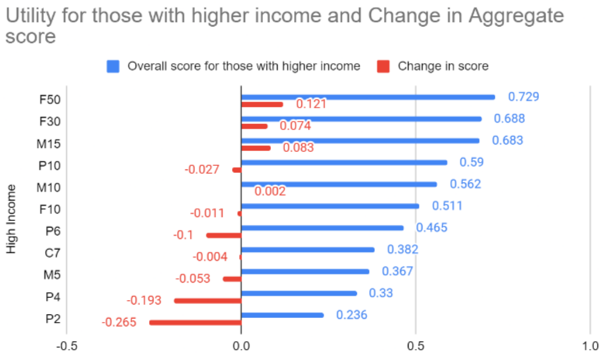


**Figure 9:** Aggregate utility score for those with relatively higher income (above 20 K/mos. or 400 USD)

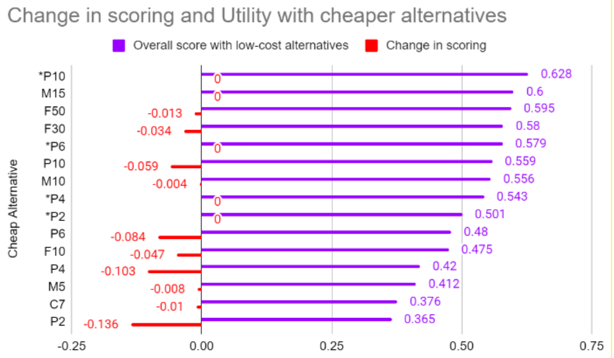
Based on the preferences of individuals with higher income, the study recommends the adoption of larger storage options, such as F50, which obtained the highest benefits score among all the alternatives (Figure 8). This aligns with their preferences and requirements, as they tend to prioritize benefits and consider a larger, more durable system as a viable long-term investment.

Notably, individuals with higher income tend to place greater importance on the price of a water system, as they value durability and long-term use. This sensitivity to price is attributed to their desire for a system that can provide sustained performance and longevity. On the other hand, individuals with lower income tend to prioritize water access over cost, as they focus on meeting their basic water needs without considering the long-term durability of the system.

It is crucial to address the affordability issue for lower income residents, as the current cost of the least expensive alternative in this study already accounts for more than half of their monthly income. Cheaper alternatives that cater to the financial constraints of lower income groups need to be explored to ensure equitable access to rainwater harvesting systems. By identifying and promoting more affordable options, policymakers can foster greater inclusivity and accessibility, making rainwater harvesting systems a viable solution for all income brackets in the study area.

### 3.4.2 Scenario 2: Low-Cost Alternatives

Introducing a cheaper alternative, such as *P10 or a 1,000L plastic tank, resulted in the highest new utility score (Figure 10). This low-cost alternative was developed by assuming that residents either have pre-owned plastic drums or have obtained donated ones. By considering the possibility of pre-existing plastic drums, the cost of the alternative was reduced by 60% compared to the original P10 option. This significant decrease in price enhances its affordability, leading to a higher score in the cost criteria.



* Inexpensive alternatives for residents with pre-existing storage tanks

**Figure 10:** alternatives with the introduction of low-cost

The introduction of this cheaper alternative addresses the affordability concerns raised earlier and has the potential to significantly increase its adoption among the population. Moreover, by allowing residents to repurpose their unused plastic tanks for rainwater harvesting, it not only saves costs but also promotes sustainable practices and reduces waste.

As cheaper alternatives were introduced into the decision analysis, it became evident that other alternatives could also become preferred so long as they become more affordable. This aligns with the findings presented in Figure 7 (c) regarding the model's sensitivity to cost. Cheaper alternatives hold significant importance in the adoption of rainwater harvesting systems, especially in rural areas where commercial prices for such systems are often prohibitively high. By offering more affordable options, stakeholders can make rainwater harvesting systems more accessible and inclusive for a wider range of residents, regardless of their income levels.

### 3.4.3 Scenario 3: Climate Change

The future scenario involves adjusting rainfall by the portion that PAGASA estimates the mean rainfall to change [23], with a projected decrease of 4.6% from June to August and 3.9% from September to November. Additionally, changes in water demand were expected to rise to 160 LPCD and were factored into the scenario [26]. These adjustments to rainfall intensities and water demand were incorporated into the YAS algorithm using historical data to simulate future conditions.

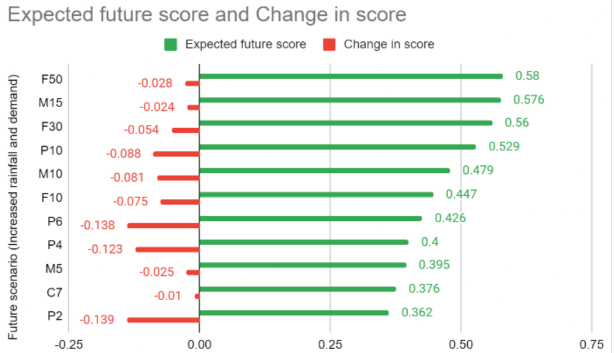


**Figure 11:** Changes in utility from the general aggregate to the expected future scenario (increased rainfall)

The resulting scores of the alternatives under the future scenario showed an overall decrease in utility (Figure 11). This decline in scores indicates that the alternatives become less favorable when considering the projected changes in rainfall and water demand. Notably, the preference shifted towards larger storage tanks, leading to F50 becoming the top-scoring alternative. This change in preference can be attributed to the anticipated increase in future water demand, which renders smaller storage sizes less reliable in meeting the higher demand during peak periods.

The recommendation for larger storage sizes, like F50, aligns with the need to ensure sufficient water supply even during periods of increased demand caused by changes in climate patterns. This finding is consistent with Zhang's (2009) suggestion that rainwater systems should incorporate larger storage capacities to enhance their resilience and adaptability to the impacts of climate change.

### 3.5 Limitations and Bias

The study is limited to the evaluation of alternatives that was based on researchers' interpretation of respondents' ideal systems. To mitigate respondents' bias in not yet having used the system alternatives, researchers relied on respondents' order of importance for each criterion. However, this approach could be further improved by seeking out users who have extensively used different RWH alternatives and having them rate each option based on their experiences.

Another bias of the study is its reliance on the selected alternatives. The decision analysis is heavily influenced by the alternatives chosen, and the results are relative to the other options and could significantly change if a better alternative is introduced or if different options become available in the future. The scores that were generated by the analysis are more of a way to compare alternatives rather than scenarios.

Additionally, the rainwater harvesting systems chosen for this study were limited to those available in the local region, and imported alternatives were not considered. This local focus may affect the generalizability of the findings to other regions or areas with different water supply characteristics and RWH options.

The results of this study are limited to the survey responses from residents, which focused on their needs, preferences, and experiences. While efforts were made to collect accurate rainfall data on a daily interval to represent the system's reliability effectively, the simulations were limited to the rainy months of the year (from June to November). Moreover, this study specifically targeted residential households with water used for non-potable purposes.

## 4.0 CONCLUSION

The findings of this study shed light on the preferences and attitudes of residents in Teresa, Rizal, regarding rainwater harvesting (RWH) systems for non-potable water usage. While most respondents expressed interest in using harvested rainwater for flushing toilets, cleaning, and watering plants, concerns regarding mosquito breeding and water quality were evident.

Among the local alternatives evaluated, the P10 alternative, comprising modular plastic drums with a 20L first flush and easy home installation, emerged as the most favored option. Its utility scores demonstrated a balanced performance, with moderate ratings for reliability, costs, ease of use, and benefits. For respondents with relatively higher income, the F50 alternative, a ferrocement tank with 5,000L storage capacity and a 200L first flush, best aligned with their preferences for durability and system benefits.

Furthermore, the low-cost scenario revealed that cheaper and easily accessible alternatives, such as the *P10 (plastic 1,000L tank with pre-owned drums), garnered high utility scores, making them more favorable in the decision model. This highlights the significance of affordable options in promoting the adoption of RWH systems, especially considering the high prices of other alternatives.

To prepare for climate change scenarios and an anticipated increase in water demand, the alternative F50 proved to be the most suitable choice due to its reliability and larger storage capacity. This larger size helps ensure an adequate supply during periods of high demand, aligning with suggestions that rainwater systems should have larger storage to enhance their resilience to climate change impacts.

It is therefore recommended to promote the adoption of the P10 alternative as a cost-effective and practical RWH system for households in Teresa, Rizal, with its balanced utility scores and ease of installation. For residents with relatively higher income, encourage the use of the F50 alternative, which aligns with their preferences for durability and system benefits. Explore and introduce more affordable alternatives, such as the *P10, to improve accessibility to RWH systems, especially for lower-income residents. It is also important to raise awareness and implement measures to address concerns about mosquito breeding and water quality in RWH systems, ensuring their proper maintenance and usage.

To further enhance the understanding and application of rainwater harvesting systems in rural areas, future research should consider a developed user preference based RWH evaluation tool to other regions and datasets, allowing for broader insights and comparisons across different locations. There must be a conduct of in-depth studies with users who have extensive experience with various RWH alternatives, obtaining firsthand feedback and ratings to refine the decision analysis model. Future researchers must investigate of the possibility of incorporating imported RWH alternatives to provide a wider range of options and better fit the specific needs of different regions. There must also be further exploration on the integration of rainwater harvesting systems for potable water use, as this can offer additional benefits in water conservation and sustainability.

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