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Article

Adaptation climate change through application of green infrastructure household scale rainwater harvesting in tropical coastal areas based fuzzy logic

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Abstract: Freshwater problems in coastal areas include the process of salt intrusion which occurs due to decreasing groundwater levels below sea level which can cause an increase in salt levels in groundwater so that the water cannot be used for water purposes, human consumption and agricultural needs. The main objective of this research is to implementation of RWH to fulfill clean water needs in tropical coastal area in Tanah Merah Village, Indragiri Hilir Regency, with the aim of providing clean water to coastal communities. The approach method used based on fuzzy logic (FL). The model input data includes the effective area of the house's roof, annual rainfall, roof runoff coefficient, and water consumption based on the number of families. The BWS III Sumatera provided the rainfall data for this research, which was collected from the Keritang rainfall monitoring station during 2015 and 2021. The research findings show that FL based on household scale RWH technology is used to supply clean water in tropical coastal areas that the largest rainwater contribution for the 144 m^2 house type for the number of residents in a house of four people with a tank capacity of 29 m^2 is 99.45%.

Keywords: adaptation; climate change; rainwater harvesting; tank capacity; tropical coastal area; fuzzy logic

1. Introduction

Global warming can also increase water temperatures and disrupt freshwater quality, especially in coastal areas that have high evapotranspiration levels. Apart from the problems above, according to the IPCC specifically, climate change can have an impact on water resource management and can affect resilience to RWH at the household scale. As an illustration, such as irregular rainfall patterns, the climate can cause changes in rainfall patterns which will reduce the effectiveness of rainwater harvesting, thereby reducing the availability of clean water in several areas. One example of an action plan recommendation from the IPCC is the application of adaptive green technology to handle the impact of climate change on sustainable water resource management through the implementation of RWH on a household scale. The Global Water Partnership (GWP) initiative supports the implementation of Integrated Water Resources Management (IWRM), including in coastal areas. This approach helps countries manage water resources adaptively in the face of changing rainfall patterns due to climate change. Relevance for Rain Water Harvesting (RWH): Adaptation of RWH technology to suit variations in local rainfall patterns, development of rainwater storage strategies in more intense but irregular rainy seasons and research on how to increase the efficiency of RWH systems through integrated water management.

The United Nations Environment Program (UNEP) in 2011 suggested that RWH could be one solution to overcome the problem of lack of clean water that occurs in many regions throughout the world based on geographical characteristics, namely tropical regions with average annual rainfall ranging from 2000–3000 mm. However, Riau's coastal areas can experience quite high rainfall of between 3000–4000 mm per year, and in the dry season, Riau's rainfall tends to be low with an average of 100–300 mm per month. RWH infrastructure is an important element to encourage sustainable coastal development. By managing stormwater effectively, conserving water resources, and promoting ecological balance, these strategies contribute to more resilient and environmentally friendly coastal ecosystems. It is important for government, society and industry to collaborate and take proactive steps to implement these practices. By doing this, coastal areas can achieve sustainable development while preserving their water resources for future generations.

Rainwater Harvesting refers to the collection and storage of rainwater for later use. This involves capturing rainwater from roofs, surfaces, and catchment areas and directing it to a storage system, such as a tank or underground reservoir. This collected rainwater can then be used for various purposes such as irrigation, gardening and household needs. RWH statistics that highlight the positive impact of rainwater harvesting. In the United States, an estimated five billion gallons of rainwater can be extracted from one inch of rainfall over a one-acre area. According to the Environmental Protection Agency (EPA), rainwater collection can reduce the average household's water use by up to 50%. An Australian study found that households that had rainwater tanks reduced their average primary water consumption by around 24%. In Singapore, the "Active, Beautiful, Clean Water" program aims to implement rainwater harvesting systems across the country, with the aim of meeting 10% of national water needs by 2020.

Several supporting literature studies have shown that RWHs have significant potential to increase water availability for both domestic and non-domestic needs. RWH is the process of collecting and storing rainwater for future use. Traditionally, this practice simply involves collecting rainwater in containers or storage tanks. However, as technology advances, modern RWH systems have become more sophisticated and efficient. These systems usually integrate various components such as roofs, gutters, filters and storage tanks to utilize and store rainwater effectively. RWH management has been around for several centuries and continues to evolve over time. These practices vary depending on factors such as culture, climate change and water pressures. RWH practices have been widely applied in various parts of the world, including in Africa and have been used to meet the need for clean water and increase food in sustainable socio-economic development (Verschuren et al., 2000).

Radonic et al. (2018) remarks that a relaunch of small scale RWH practice for residential use in urban areas is observed globally, encouraged by water policies, water-pricing schemes, and climate change strategies (Chubaka., 2018; Domenech et al., 2011; Meehan et al., 2015). Previous studies have described the RWH system from the perspectives of saving water and using rainwater as an alternative supply for potable and non-potable use (Antoniou et al., 2014; Mendez et al., 2011; Morales et al., 2012; Palla et al., 2011; Palla et al., 2012; Vialle et al., 2011; Villareal et al., 2005; Ward et al., 2012). This concept has been improved over several centuries as indicated by the advancement of different types of the tank and hydraulic engineering, thereby, showing a substantial nexus between culture, climate crisis, and water stress. Furthermore, it has been implemented in Ethiopia (Taffere et al., 2016), Australia (Van der Steren et al., 2013), Bangladesh (Karim et al., 2015), Brazil (Ghisi et al., 2009), Germany (Schuetze et al., 2013), Greece (Sazakli et al., 2007), Zimbabwe (Motsi et al., 2012), United Kingdom (Roebuck et al., 2011), USA (Jones et al., 2009), India (Stout et al., 2009), Jordan (Abdulla et al., 2009), Italy (Notaro et al., 2016), Korea (Kim et al., 2009), Mexico (Mendiola et al., 2015), Namibia (Woltersdorf et al., 2015), South Africa (Kahinda et al., 2007), Portugal (Ng et al., 2016), Sweden (Villareal et al., 2005) and Taiwan (Liauw et al., 2004).

The complexity and uncertain effectiveness of large-scale adaptation methods, coupled with an understanding of the impact of local decision-making processes on place-based vulnerability, enable locals to develop community strategies and practices. This allows them to avoid tragedies and confront challenges such as water scarcity, as well as apply traditional practices and patterns (Aguiar et al., 2018; Amundsen et al., 2018; Corfee et al., 2011; Fewkes, 2000; Fewkes and Butler, 2000; Fuhr et al., 2018; Joleha et al., 2019a; Roebuck et al., 2010; Walker et al., 2011). Local wisdom was observed to be applied in the implementation of RWH in communities, as indicated by the adoption of a 200-liter reservoir to meet the daily drinking and cooking water needs estimated at 18 liters per day. This was necessary due to a drought, which was the longest experienced by the community in the past six years from 2015 to 2020. Rainfall recording data from BWS III in Bunga Raya (Siak) rainfall station showed that there was no rain for 26 consecutive days starting from 11 February to 8 March 2015. This underscores the importance of implementing RWH as a strategy for managing water scarcity in the region. Local wisdom was observed to be applied in the implementation of RWH in communities, as indicated by the adoption of a 200-liter reservoir to meet the daily drinking and cooking water needs estimated at 18 liters per day. This was necessary due to a drought, which was the longest experienced by the community in the past six years from 2015 to 2020. Rainfall recording data from BWS III in Bunga Raya (Siak) rainfall station showed that there was no rain for 26 consecutive days starting from 11 February to 8 March 2015. This underscores the importance of implementing RWH as a strategy for managing water scarcity in the region.

Sustainable water management is very important to ensure the availability of sufficient water for coastal communities. One way that can be done is to apply RWH Technology as part of Green Infrastructure to determine the dimensions/capacity of household scale rainwater storage tanks. This can ensure that the collected rainwater can be stored properly and can be used when needed. In this way, household water needs can be met properly and water availability can be increased significantly. The Long Term Development Plan (RPJP) of Riau Province for 2005–2025 to fulfill clean water needs mostly still relies on dug wells (30%), rainwater (30%), rivers, lakes and Regional Drinking Water Company (PDAM) services. Specifically for water needs in Indragiri Hilir Regency based on the 2005–2025 Riau Province RPJP, some people depend on rainwater, but surface water is generally brackish and contains high levels of organic matter and iron. The Riau Provincial Government has carried out a clean water management program with the help of the Central government in partnership with the private sector such as PDAM, but PDAM distribution itself cannot reach the islands in coastal areas. Freshwater problems in coastal areas, such as in Tanah Merah Village, Indragiri Hilir Regency, Riau Province in Indonesia include the process of salt intrusion which occurs due to decreasing groundwater levels below sea level which can cause an increase in salt levels in groundwater so that the water cannot be used for water purposes. human consumption and agricultural needs.

It is reported that RWHs are safe, cheap, and have the potential to become a popular solution for the availability of clean water. It is based on the assertion that water and its sources can be protected and the quality of life of communities can be achieved through the implementation of low budget and easy solutions using simple technology and based on local conditions and practices. Therefore, this research focuses on developing an integrated approach to RWHs in a coastal context. Research conducted on Merbau Island, Meranti Regency, Riau Province highlights the need for a RWH system that considers factors such as roof area, roof type, and number of households to provide clean water for those who do not have access to reliable clean water. Source (Joleha et al., 2019b). RWH system performance can be expressed using tank reliability and efficiency indicators. Storage tank reliability can be expressed in units of time or volume (Fewkess et al., 1999). In this study, the reliability of the storage tank is expressed in units of time which represent the number of days the water needs are met using the RWH system.

The artificial intelligence (AI) and machine learning models, sometimes known as black-box or data-driven models, are based on time series data (Bikmukhametov et al., 2004; Gonzalez et al., 2004). These models can capture the complex non-linear relations between input and output variables during forecasting (Li et al., 1999). Also, these models are flexible enough to predict hydrological problems with high efficiency (Bouktif et al., 1999; Latif et al., 1999). Machine learning and artificial intelligence models have become very popular in recent decade (Elbeltagi et al., 2023; Mirzania et al., 2023; Saroughi et al., 2023; Sterpin et al., 2021). Fuzzy logic (FL) branch of AI was introduced by Professor Lofti Ahmed Zadeh, University of California at Berkeley, in 1965 (Bai et al., 2006; Zadeh, 1965) through his paper Fuzzy sets. His work was not recognized until Dr. EH Mamdani, Professor at the University of London, practically applied the concept of fuzzy logic to control an automatic steam engine in 1974 (Bogardi et al., 1983; Mamdani et al., 1974). Since the beginning of the application of FL in the field of hydrology (Mujumdar et al., 2008; Simonovic et al., 2008) a large number of investigations have been carried out, and today, FL has turned into a useful approach in water resources assessment and hydrological analysis. Hydrology is often susceptible to uncertainty caused by a lack of data, natural causes (e.g., climate) and imprecision in modeling. System limitations and initial conditions also give rise to uncertainty. In addition, the stress potential in the system cannot be clearly identified in many hydrological studies. FL allows us to consider handling all fuzziness (or ambiguity) in hydrology (Sugeno et al., 1983). In order to employ a systems approach, it is necessary to change the fundamental understanding of physical reality under consideration (Wang et al., 1992). New researchers have focused on the application of fuzzy logic-based techniques for modeling vagueness within the water resource systems. So far in the literature, many research contributions have been made for dealing with the vagueness in water resources systems which include fuzziness, bias, ambiguity and deficiency of sample data (De Campos et al., 1993).

Fuzzy rule-based modelling is an extension of the concept of FL. The main difference in fuzzy logic and fuzzy rule-based modelling is that FL is used for systems with feedback and FL is used for systems without feedback. Feedback process (Bardossy et al., 1995, 1991). The idea of applying FL in modelling hydrological systems is relatively fresh and innovative (Bardosy et al., 1990). Some areas of application of FL in hydrology include: fuzzy-based regression (Kojiri et al., 1988; Ozelkan et al., 2000), hydrological forecasting (Hundecha et al., 2001), hydrological modeling (Fewkess et al., 1999), regional water resources management (Bogardi et al., 2004, 1982), reservoir operation planning (Nachtnebel et al., 1986; Simonovic et al., 1992), water resources risk assessment (Shrestha et al., 1996) and so on. From the early application of fuzzy logic to hydrology (Teegavarapu et al., 1999), a large amount of research has been pursued and, at present, fuzzy logic has become a practical tool in hydrologic analysis and water resources decision making. In this paper, the main areas of applications in hydrology and water resources are highlighted. The main objective of this research is to implementation of green infrastructure RWH scale household in Tanah Merah Village, Indragiri Hilir Regency, with the aim of providing clean water to coastal communities based on FL.

2. Material and methods

2.1. Study area and data collection

The research location is administratively located in Tanah Merah Village, Indragiri Hilir Regency, Riau Province, Indonesia, which geographically has an area of 136.92 km^2 with a population of 14,143 people. Tanah Merah Village is characterized by an area that is approximately 93% lowland, namely river sediment areas, swamp areas with peat soil, brackish areas with an average height of approximately 0–3 m above sea level. With these high topographic conditions, the area is influenced by tides, and from a physiographic perspective the river area forms several tributaries to form groups of islands. The map location of research is presented in **Figure 1**.

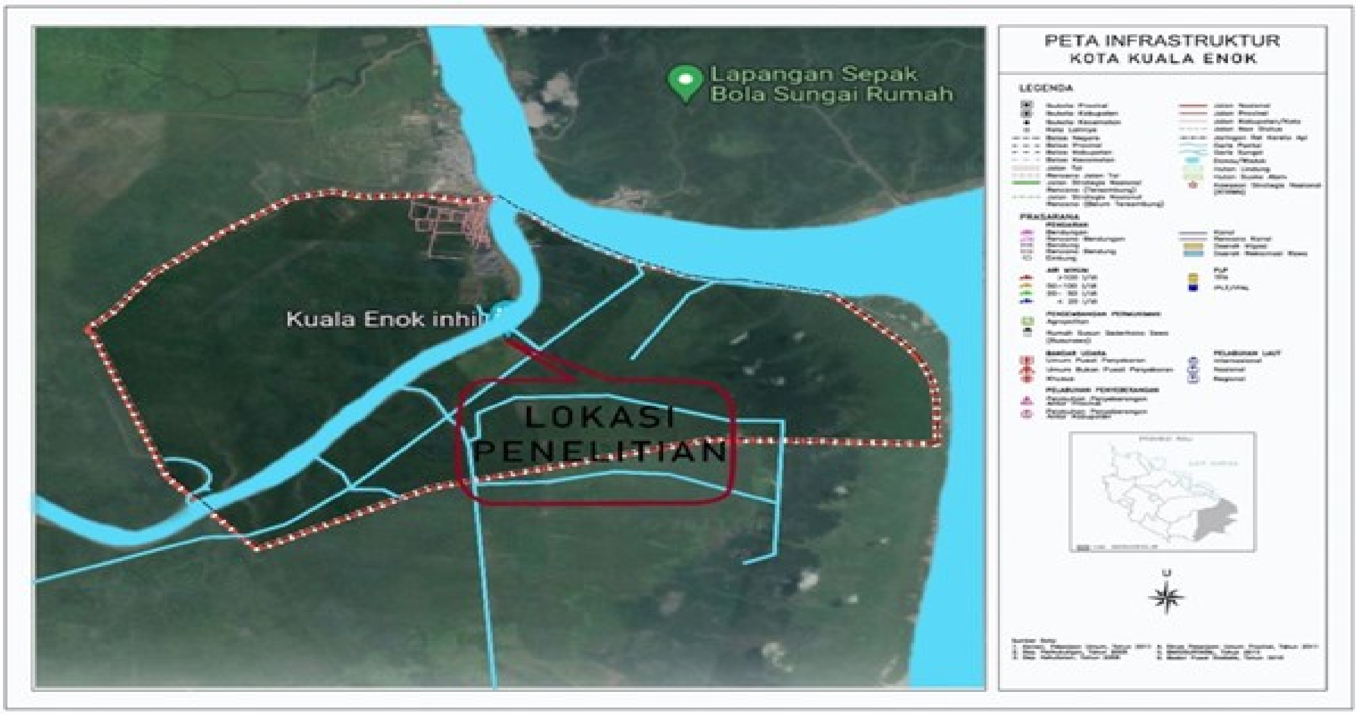


Figure 1. Map location of research.

2.2. Data collection

Secondary data in the form of rainfall data from the Keritang Rainfall Station, Indragiri downstream district for 2015–2020 sourced from the BWS III Sumatra, Pekanbaru city and data on clean water needs for Tanah Merah District refers to the Central Statistics Agency (BPS) of Indragiri Hilir Regency 2022.

2.3. Rain water harvesting system

The Rainwater Harvesting (RWH) system used is simple and involves using the roof as the catchment area, pipes as the flow system, and tanks as the storage system. Fewkess (2000) reported that the performance of the RWH system is highly determined by the capacity of the ground tanks used. The capacity of the ground tank is a crucial element that determines the overall functionality and cost of the system. Its performance is typically subject to the characteristics of the catchment area, the potential rainfall, and the water needs. The simple RWH system applied is described in the following **Figure 2**.

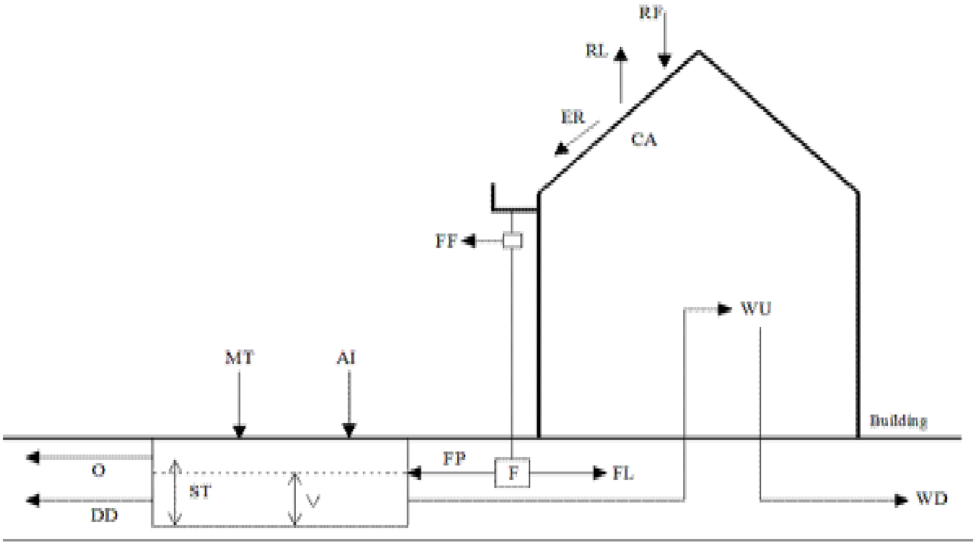


Figure 2. The simple RWH system.

2.4. Behaviour model

The basic model that can be used to comprehensively describe a supply, discharge, and run-off system can be analogized with an urban hydrological cycle. The potential rainfall is calculated based on the concept of water balance. Water balance simulation is used to explain the operational algorithm of storage tanks in RWH systems. Simply put, the changes in volume within the storage tank can be expressed using the water balance concept.

$$V_t = V_{t-1} + Q_t - D_t - E_t - L_t \tag{1}$$

where $0 \leq V_T \leq \mathrm{S}$, V_t is the volume of storage at time t (m^3), V_{t-1} is the volume of storage at time $t - 1$ (m^3), Q_t is the volume inflow into storage during time interval t (m^3), D_t is the release or demand during time interval t (m^3), E_t is the evaporation (m^3), L_t is other losses (m^3), and S is the storage capacity (m^3).

If the storage tank used is located below the ground surface due to the influence of evaporation and other losses, the mathematical formulation is obtained as follows:

$$\begin{gathered} V_t = V_{t-1} + Q_t - D_t \\ 0 < v_t < S \end{gathered} \tag{2}$$

where ΔS is the change in storage.

2.5. The storage tank capacity

The volume of water collected in the storage tank within a certain time period will be equal to the volume of water at the previous time added to the inflow and subtracted by the outflow at a specific time. A behavioural model (behavioural analysis) simulates an algorithm of the operational system of the volume within the storage based on the concept of mass balance over a specific time interval. The RWH cycle at the household scale using a behavioural model approach is presented as in **Figure 3**.

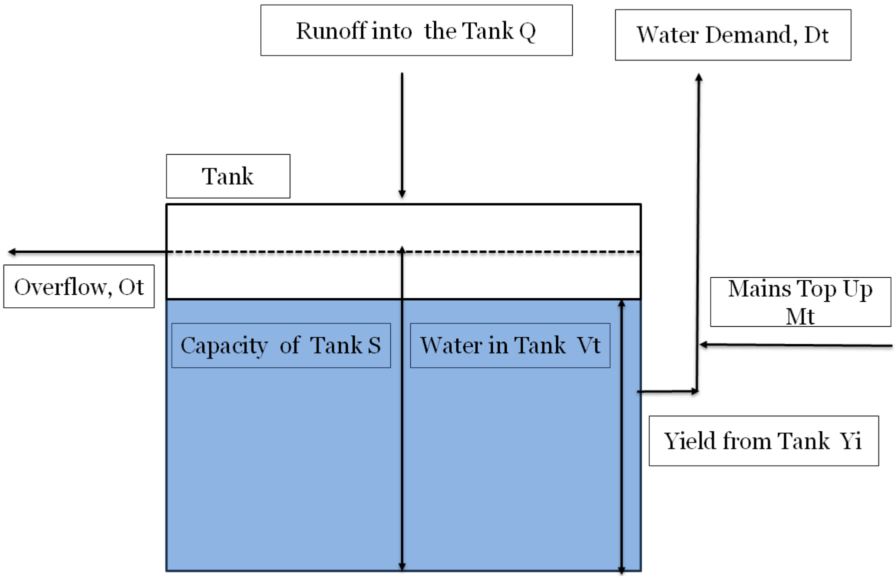


Figure 3. The RWH cycle at the household scale using a behavioural model approach.

The rainwater harvesting process at the household scale using a behavioural model approach is described by the volume of water in the storage tank at day t and the volume of water at day $t + 1$. If the storage tank used is located below the ground surface due to the influence of evaporation and other losses volume of water at day t and volume of water at day $t + 1$, the mathematical formulation are obtained as follows:

$$V_t = V_{t-1} + Q_t - D_t \text{ and } V_{t+1} = V_t + Q_{t+1} + D_{t+1} \tag{3}$$

where V_t is volume of storage on day t (m^3), V_{t-1} is volume of storage on day $t + 1$ (m^3), Q_t is discharge on day t (m^3/day) and D_t is water demand on day t (m^3). V_{t+1} is volume of storage on day $t + 1$ (m^3), V_t is volume of storage on day t (m^3), Q_{t+1} is discharge on day $t + 1$ (m^3/day) and D_{t+1} is water demand on day $t + 1$ (m^3).

The effective rainfall volume is obtained by multiplying the rainfall depth with the catchment area and the runoff coefficient

$$E_R = R_t \times A \times C \tag{4}$$

where E_R is the effective runoff (m^3), R_t is the rainfall depth (mm), A is the catchment area (m^2), and C is the runoff coefficient.

The relationship between for the water volume on day t, the water volume on day $t + 1$ until the water volume on day $(t + n)$ in the storage tank expressed mathematical formulations are obtained as follows:

$$V_t = V_{t-1} + C \times A \times R_t - D_t \text{ at time } t \tag{5}$$

$$V_{t+1} = V_t + C \times A \times R_{t+1} - D_{t+1} \text{ at time } (t + 1) \tag{6}$$

$$V_{t+n} = V_t + C \times A \times R_{t+n} - D_{t+1} \text{ at time } (t + n) \tag{7}$$

2.6. Fuzzy logic model

In order to apply FL technique to a practical application problem, the following steps are to be followed:

a. Fuzzification—this step involves the conversion of crisp data or classical data into fuzzy set data or the membership functions (MFs)
b. Fuzzy inference process—this process consists of combining MFs along with the fuzzy control rules to obtain the fuzzy output
c. Defuzzification—this process is the reverse process of fuzzification. It involves the conversion of the fuzzy output into crisp output along with associated rules. The complete fuzzy logic system workflow is presented as in **Figure 4**.

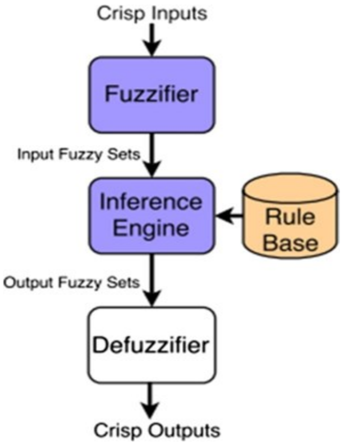


Figure 4. Workflow of a fuzzy logic system (Bhattacharjee et al., 1999).

Machines are capable of processing crisp data such as the binary system ('0' or '1') and can be facilitated to handle uncertain linguistic data such as 'high' and 'low' if the crisp input and output are converted to linguistic variables along with the fuzzy components. Moreover, both the crispinput and the crisp output have to be converted to fuzzy data. All of these conversions are carried out by the first step—fuzzification.

The second step is the fuzzy inference process (FIS) where membership functions (MFs) are combined with the control rules in order to derive the fuzzy control output, andthe outputs are arranged into a table format called as the 'lookup table.' In FIS, the important is the fuzzy control rules. Those rules are as similar as that of human being's inference and intuition to the course of action. Various methods such as mean of maximum (MOM) or center of gravity(COG) are been used to work out the related control output,and each one of the control output must be arranged into a table format called lookup table.

For a real-life application, a fuzzy control output must bechosen from the lookup table developed in the previous stepbased on the present input. Further, that fuzzy control outputmust be transformed from the linguistic variable form to thesharp or crisp variable and perform the control operator. The process is known as defuzzification or step 3.

Real-life applications are usually associated with input variables having more than one dimension. In such cases, one needs to develop the membership functions for each dimensional variable separately and the similar operation needs to be carried out if the system consists of multiple output variables. To summarize, the fuzzy system modeling is a chain of crisp-fuzzy-crisp transformation used to derive results for an actual working system. The initial input and the final out-put must necessarily be crisp variables; however, the transitional stage is a fuzzy inference process, where the linguistic. variables are used to derive the outputs. The motive why there is need to transform a sharp or crisp variable to a fuzzy variable is that, from the principle of fuzzy system process or a human's inference or intuition, no absolutely crisp variable exists in our factual world.

2.7. Description fuzzy logic model for RWH

Fuzzy logic is a very useful tool in dealing with problems involving uncertainty and variability, especially in water resource management, such as rainwater harvesting (RWH) systems at the household scale. Fuzzy logic models enable more flexible and effective decisions when dealing with changing variables, such as rainfall patterns, water needs, and environmental conditions. The following is a detailed explanation of the three main steps of fuzzy logic—fuzzification, inference process, and defuzzification—and their application in managing household rainwater harvesting system

Fuzzification is the first step in fuzzy logic, which converts definite input values (crisp input) into a fuzzy set that defines input uncertainty in the form of degrees of membership to certain fuzzy categories. How it Works: In the context of a household RWH system, inputs such as rainfall, household water requirements, and storage tank capacity are converted into fuzzy values. Each input is grouped into fuzzy categories such as "low," "medium," and "high." Each category has a membership function, which describes the degree to which an input value falls into a particular category. Application Example: For example, rainfall can be categorized as "low" (if rainfall < 50 mm), "medium" (50–100 mm), and "high" (>100 mm). If the rainfall measured in the household is 75 mm, then the degree of membership may be 0.5 in the "medium" category and 0.3 in the "high" category. Likewise, the capacity of rainwater storage tanks can be categorized as "full", "half full", and "empty" depending on the level of water filling. Benefits: Fuzzification allows the system to work with input that is uncertain or variable. This is especially useful in RWH, where rainfall is irregular and the harvestable water capacity varies.

The inference process is the stage where fuzzy logic rules are applied to the fuzzy set of fuzzification to produce a fuzzy output. This process involves the use of "if-then" rules, where various combinations of input conditions will result in a particular decision. How it Works: In a household rainwater harvesting system, the inference rule can be:

If rainfall is "high" and the tank capacity is "half full", then store more water.

If rainfall is "low" and the tank capacity is "empty", then save water use.

If rainfall is "moderate" and water demand is "high", then optimize the use of stored water.

These rules combine input conditions to produce an output in the form of an action that needs to be taken. At this stage, the results of several rules will be evaluated, and the resulting output is still in fuzzy form.

Application Example: For example, if the rainfall is moderate and the tank capacity is at half full, the inference system can decide that the rainwater that falls should be stored more optimally. If rainfall is low but household water demand is high, then inference decisions may result in actions to conserve available water. Benefits: The inference process enables the use of various combinations of input conditions to produce smarter and more informed decisions, considering variability in household water availability and demand. This helps households manage water efficiently, especially during dry seasons or irregular rainfall patterns.

Defuzzification is the final stage that changes the fuzzy output from the inference process back into a definite value (crisp output) that can be used as a real decision or action taken. The result is a numerical value that guides actions that must be taken in water management. How it Works: After the fuzzy output is obtained from the inference process, defuzzification will convert it into a firm value that can be used. A commonly used defuzzification method is the centroid method, which calculates the weighted average of the fuzzy values to obtain a firm value. Application Example: After going through inference, the system might produce a fuzzy output such as "save water usage". The defuzzification process will convert these results into specific numbers, for example "water usage savings of up to 20%". The system can then regulate water distribution automatically or provide recommendations to household residents to reduce water consumption. In another example, if the tank capacity is nearing full and rainfall is predicted to be high, the defuzzification output might direct the rainwater flow to be diverted to the drainage system to prevent overflow. Benefits: Defuzzification provides concrete results and can be implemented in real life in household rainwater management. These can be specific numbers regarding the volume of water that can be saved, the volume of water that needs to be used, or warnings about saving water.

3. Result material and discussion

3.1. Existing conditions infrastructure of RWH

Expanding the study to other coastal areas would strengthen the conclusions by referring to the Research Road Map that has been carried out by previous researchers in Coastal Areas in Riau Province

a. Joleha et al. (2019b) A research conducted in Merbau Island, Meranti Regency, Riau Province highlighted the need for the RWH system that takes into account factors such as the roof area, roof type, and number of households to provide clean water for those without access to a reliable clean water source.

b. Suprayogi et al. (2022), the successful implementation of Rain Water Harvesting (RWH) on a household scale to a village scale has been implemented in Kampung Rempak Village, Siak District, Riau Province: The results and discussion regarding the full-scale physical model and simulation, conducted using the spreadsheet excel program with tank capacity 12.5 m^3 and dimension of tank 4.5 m × 2 m × 1.4 m, showed that the simple RWH household scale system is 39% reliable based on time. It was also discovered that the risk of failure water resources RWH household scale was 61%. If the water usage is reduced by 1000 liters per day, then the risk of failure of the RWH system at the household scale is 22%. Therefore, it is recommended that the reliability of this technology be further integrated into the tank system devices in individual households. This is expected to ensure adequate adaptation to the actual environmental conditions, potentially supporting the sustainable provision of clean water in a tropical swamp area.

This means that in 2022, the rainwater contributed 64.93% of the water needs, requiring an additional 35.07% from a clean water source other than rain. From the simulation results with rainfall data input from 2016 to 2022 for a roof area of 90 m^2, it was found that the required tank capacity for a household with four family members in the tropical swamp area is 12.5 m^3 with dimensions of 4.5 m × 2 m × 1.4 m, as modeled in **Figure 5**.

Figure 5. Fully physical model of RWH household scale in a tropical swamp area.

Risk of failure for the Water Resources RWH Supply:

Testing the reliability of the dry season model. It is important to be reminded that the available water volume always fluctuates, which means that the quantity of water needed by the people may not always be met. As mentioned earlier, the performance related to meeting water needs can be measured using reliability analysis expressed in units of time and volume. It has been observed that the satisfaction of the household-scale RWH system, produced using time-based tank buildings, has the following reliability: (continue the next text according to the available analysis or data). The pattern of the relationship between the analysis results of water availability in the storage tank as a function of time during the dry season period for approximately five months (July, August, September, October, and November) to meet the water needs of a four-person family, amounting to 1000 L/day and 900 L/day, is presented as shown in **Figure 6**.

Figure 6 shows the analysis of water volume as a function of time during the dry season period in June, July, August, and September 2022. The number of times the water needs are met (n) is 119 days out of a total time (N) of 152 days, resulting in a reliability of the full-scale physical model of household-scale RWH system based on time unit (R_t) at 78%. The relationship between the system's reliability, R, is 78% or 0.78, with the failure risk level of the model during the dry season being F at 0.22 or 22%.

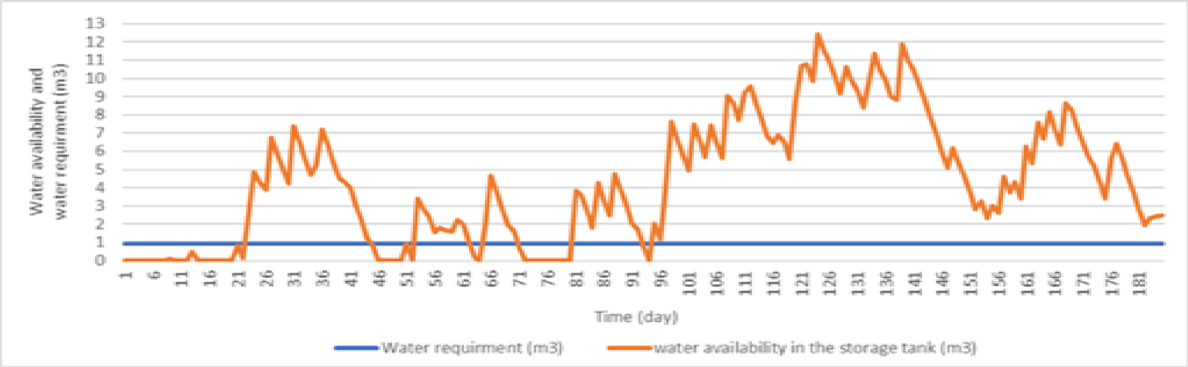


Figure 6. The relationship between water availability and water requirement in the tank as a function for water demand 900 L/day.

To implement the RWH system on a large scale, it is important to consider the various types of costs that will arise. These costs can be divided into initial costs (capital costs) and operational and maintenance costs (O&M costs).

Initial Costs:

a. Planning and Design: Development of RWH implementation plans, including technical studies, design, and environmental impact analysis. These costs may include technical consultation, system design, and water availability analysis.

b. Infrastructure: Costs of building infrastructure such as roof water collectors, pipes, water filters, storage tanks, and water distribution systems. On a larger scale, these costs also include the installation of distribution networks to support multiple buildings or residential areas.

c. Land Acquisition Costs: If land is required for the installation of large tanks or other infrastructure, there are land acquisition costs that must be taken into account.

Operational and Maintenance (O&M) Costs:

a. Tank and Pipeline Maintenance: Costs of ensuring that storage tanks and pipelines remain clean and free from damage.

b. Filter Cleaning: RWH systems require regular cleaning to maintain rainwater filter efficiency

c. Component Replacement: Includes the cost of replacing system parts such as worn filters or pumps.

Historical facts and the application of local wisdom culture regarding the use of rainwater on an individual household scale. The people of Tanah Merah, Tanah Merah District, Indragiri Hilir Regency have implemented the practice of harvesting rainwater on an individual household scale for generations to meet the needs for drinking and cooking water consumed daily. day with a quantity of approximately 18 L/day. Based on the results of the field survey, it was also reported that the rules for water availability and demand have not been implemented, both in the rainy season, where rainwater is allowed to run off or infiltration, and during the dry season, which has the potential to experience a shortage/deficit of clean water. related to determining the dimensions of individual household scale rainwater storage tanks that ensure continuous and sustainable water use. The condition of RWH buildings on a household/existing scale in Coastal area communities in Tanah Merah Village, Riau

Province is presented in **Figure 7**.

Figure 7. Condition of RWH buildings on a Household/Existing scale in Coastal Area Communities in Tanah Merah Village, Riau Province.

Sourced from rainfall recording data from the BWS III from the Keritang (Indragiri) rainfall station for the month of February from 11–23 February 2015 or for 15 consecutive days there was no rain. Based on the rationale that on 11 February 2015 it is assumed that the storage tank is 200 L full. For the needs of the people in Tanah Merah Village, Tanah Merah District, Indragiri Hilir Regency, who rely on rainwater every day for 8 L of drinking and 10 L of cooking needs, with a total usage of 18 L, we can describe the pattern of the water balance relationship between the availability of water in reservoirs and consumption needs. community rainwater over a period of 13 days. The description of household water availability based on existing RWH buildings is presented in **Figure 8**.

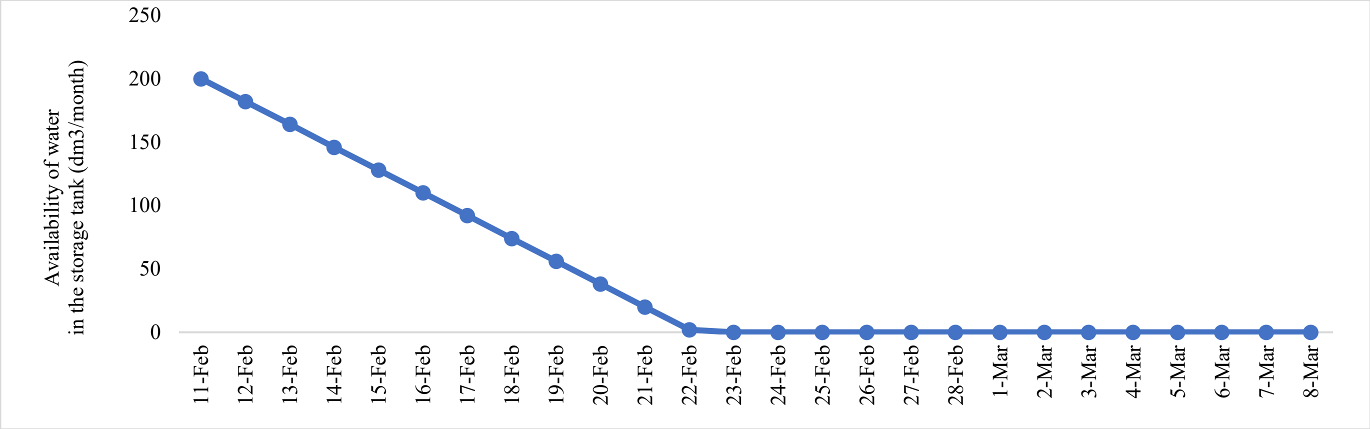


Figure 8. Description of household water availability based on existing RWH buildings.

For conditions resulting from the limited capacity to accommodate household-scale RWH buildings in Tanah Merah Village as described above, there is a high potential for water shortages, especially during the dry season and due to the impact of climate change with a tendency to decrease rainfall intensity. Utilization of drilled water sources built by the government and the private sector, the logical consequence of which is that the community must purchase drilled water for IDR 10,000 per 250 L with the ability to meet water needs for only approximately three days. Especially for drinking and cooking water needs, the community must refinance by purchasing distilled bore water at a price of IDR 5000 per gallon equivalent to 19 L. This condition is certainly very burdensome for the people in Tanah Merah Village who have relatively low incomes.

3.2. Development RWH based fuzzy logic

Design green infrastructure RWH based fuzzy logic

A review of the existing RWH building tank capacity design was carried out by applying Green Infrastructure RWH technology on a household scale based FL for water resource management with input data: the area of the household roof, average rainfall in coastal areas, clean water requirements for household consumption, and the type of roof used in the Coastal Area in Tanah Merah Village, Tanah Merah District, Indragiri Regency. The design green infrastructure RWH based fuzzy logic is presented in **Figure 9**.

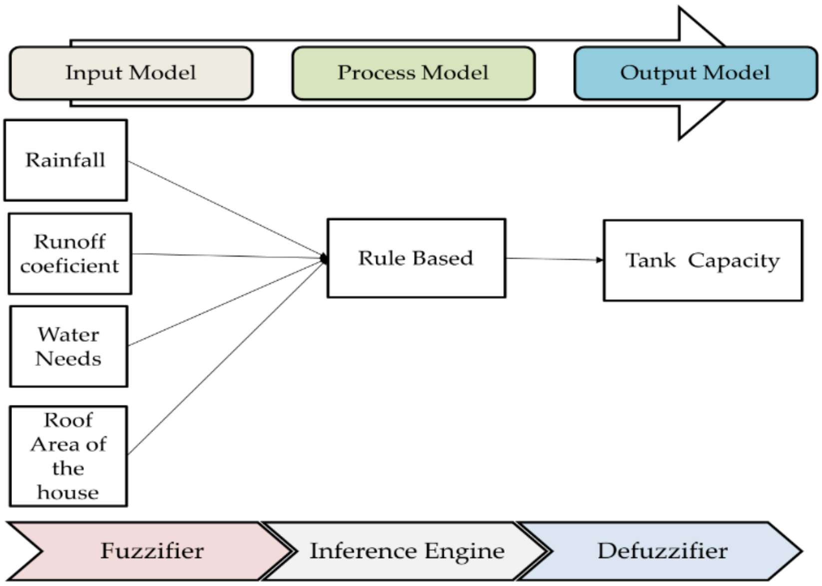


Figure 9. Design green infrastructure RWH based fuzzy logic.

3.3. Input data

3.3.1. Rainfall data

Rainfall data sourced from Keritang rainfall data from the River Basin Center (BWS) III Sumatra. The annual rainfall data Keritang rainfall station 2015–2021 is presented in **Figure 10**.

The rainfall data in **Figure 10** is the annual rainfall from 2015–2021, respectively 2516 mm, 1115.6 mm, 4085.3 mm, 2943 mm, 999.5 mm, 1112 mm, 907 mm. The largest amount of rainfall occurred in 2017 at 4085.3 mm and the smallest amount of rainfall occurred in 2021 at 907 mm. In 2019, especially the month of July, the smallest amount of monthly rainfall was recorded where no rain occurred at all. However, daily rainfall data obtained from BWS III shows that this situation also continued until August. If calculated for June, July and August respectively, the total number of days without rain is 60 days. Conditions like this are quite worrying, because a long period of drought can impact the lives of the local community in Tanah Merah Village, Tanah Merah District, Indragiri Hilir Regency, Riau Province.

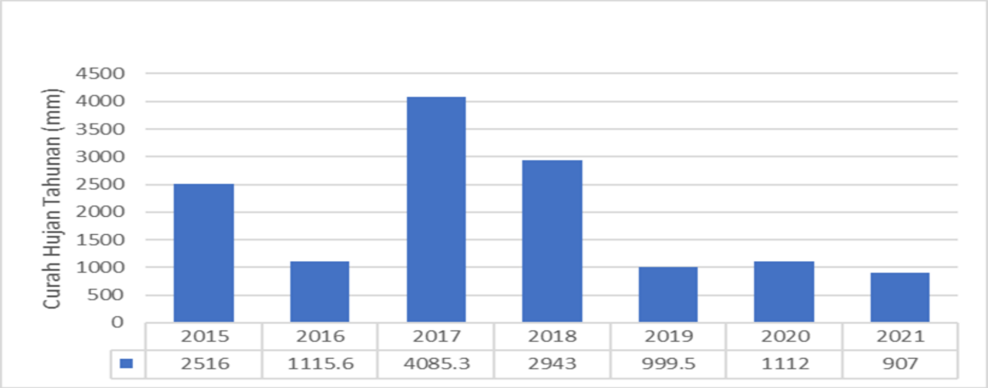


Figure 10. Annual rainfall data Keritang rainfall station 2015–2021.

Source: BWS III Sumatera.

3.3.2. Roof area and runoff coefficient of the house

Data identified in the field shows that there are three types of houses with different roof areas and the same type of roof, namely Gable. Rainwater collection, the roof area equipped with rainwater collection channels (gutters) will influence the amount of rainwater that can be collected and channeled to tanks or water storage areas. The composition of the type of house, roof of the house and area of the observed rainwater catchment area is as in **Figure 11** and **Table 1**.

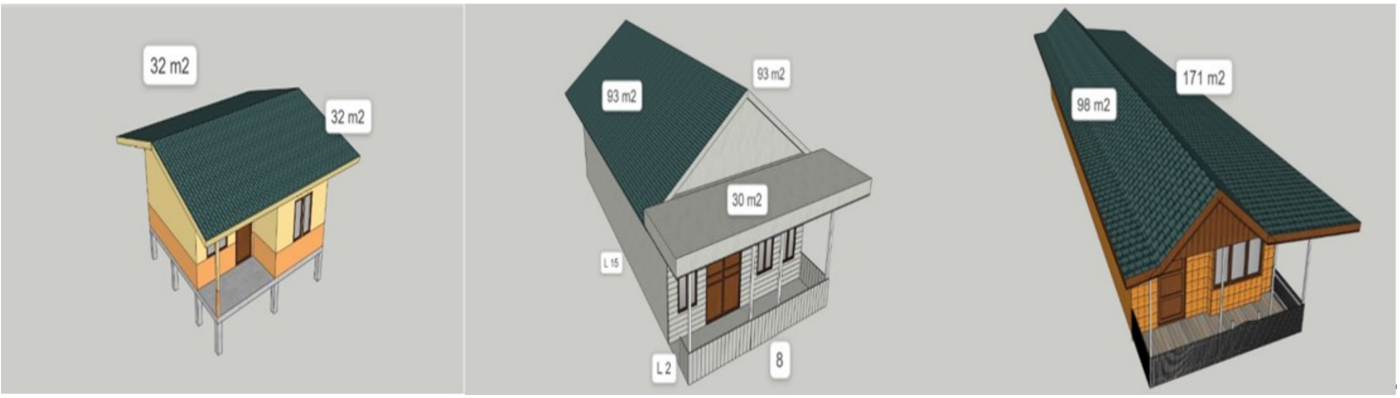


Figure 11. Composition of house type 36 m^2, 136 m^2 and 171 m^2 for roof type gable in Tanah Merah Village.

A runoff coefficient of 0.90 with zinc roof was adopted to account for losses due to roof surface wetting and evaporation which would reduce the amount of rainwater which actually entered the storage tanks (Utami, 2024).

Table 1. Composition of house type, roof type and roof area.

House type (m^2)	Roof type	Roof area (m^2)	
		Left side	Right side
36	Gable	32	32
136	Gable	93	93
144	Gable	171	98

Source: Field observation data, 2024.

3.3.3. Composition of family members

Data on the number of residents in the house based on the results of a field survey in Tanah Merah Village, Tanah Merah sub-district, Indragiri Hilir district has several family members. Data on the number of residents in the house based on the results of a field survey in Tanah Merah Village, Tanah Merah Sub-district, Indragiri Hilir District has several family members. One family tends to consist of four, five to six people for house types of 36 m^2, 136 m^2 and 144 m^2.

3.4. Output data

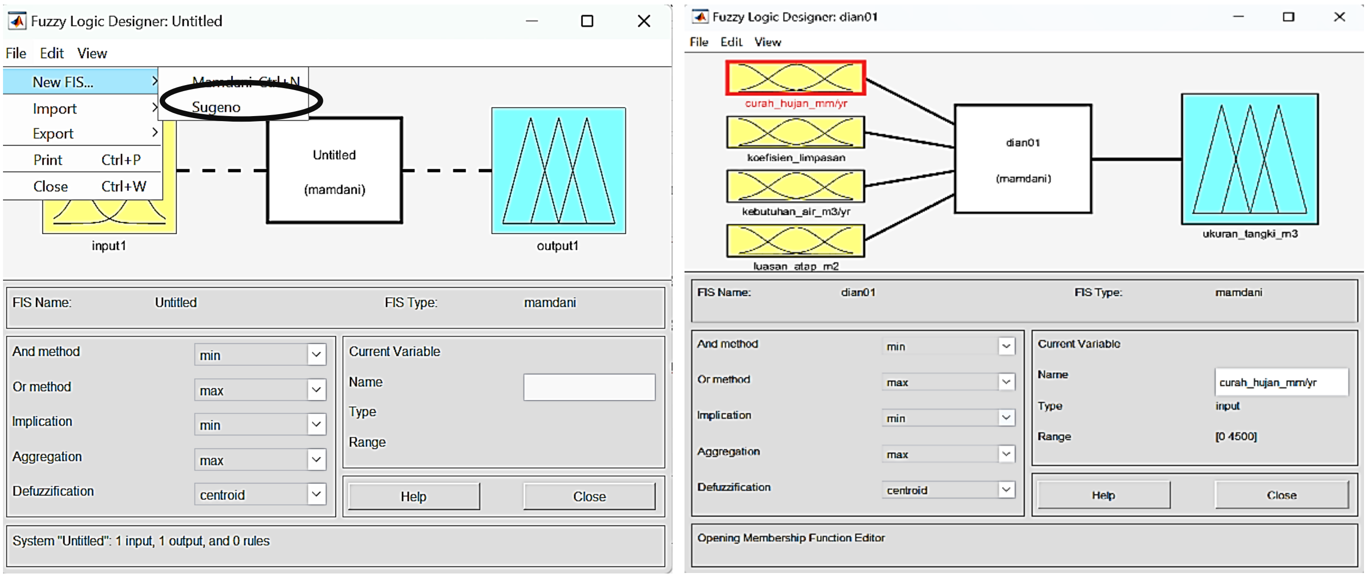
Tank capacity

Water tanks are used to provide water storage for use in many applications such as household scale RWH in coastal areas as a function of rainfall, roof area, number of family members and run off coefficient.

3.5. Analysis tank capacity based fuzzy logic

3.5.1. Fuzzification process

Determining the size of the storage tank using FL begins by determining the FIS used, namely the Mamdani method. The relationship pattern between input: rainfall, runoff coefficient, water needs so roof area of the house using zinc roofs for houses, people in Tanah Merah Village have a runoff coefficient of 0.9 and the output of the Fuzzy Logic model is tank capacity. FIS relationship patterns and output variables: tank capacity is presented fuzzification process using the Matlab Toolbox program which is presented as in **Figure 12** and **Table 2**.



FIS Name: Untitled
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name
Type
Range
System "Untitled": 1 input, 1 output, and 0 rules

FIS Name: dian01
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: curah_hujan_mm/yr
Type: input
Range: [0 4500]
Opening Membership Function Editor

Figure 12. Input and output variables in the fuzzification process using Mamdani method.

Table 2. Input and output variables in the fuzzification process.

Function	Variable Name	Range
Input	Rainfall (mm)	[0–4500]
	Runoff coefficient	[0–1]
	Water needs (m^3)	[0–400]
	Roof area of the house (m^2)	[0–400]
Output	Tank capacity	[0–50]

3.5.2. Membership function process

After determining the input and output variables in fuzzification process of the RWH system, proceed with determining the membership function for each variable. Membership function for each variable in **Table 3**.

Table 3. Membership function for RWH.

Function	Variable	Value	Classification	Domain
Input	Rainfall (mm)	0–1500	Low	[−1500 0 1500]
		1600–3000	Medium	[1125 2250 3375]
		3100–4500	High	[3000 4500 4500]
	Runoff coefficient	0.4–0.5	Small	[−0.4 0 0.4]
		0.5–0.6	Medium	[0.3 0.5 0.7]
		0.75–0.9	Big	[0.6 1 1]
	Water need (m^3)	0–150	Low	[−145 −15 50 150]
		150–250	Medium	[125 200 275]
		250–400	High	[250 350 400 400]
	Roof area of the house (m^2)	0–150	Small	[−145 −15 50 150]
		150–250	Medium	[125 200 275]
		250−400	Big	[250 350 400 400]
Output	Tank capacity	0–15	Small	[−20 0 5 20]
		15–35	Medium	[15 20 30 35]
		35–50	Big	[30 45 50 50]

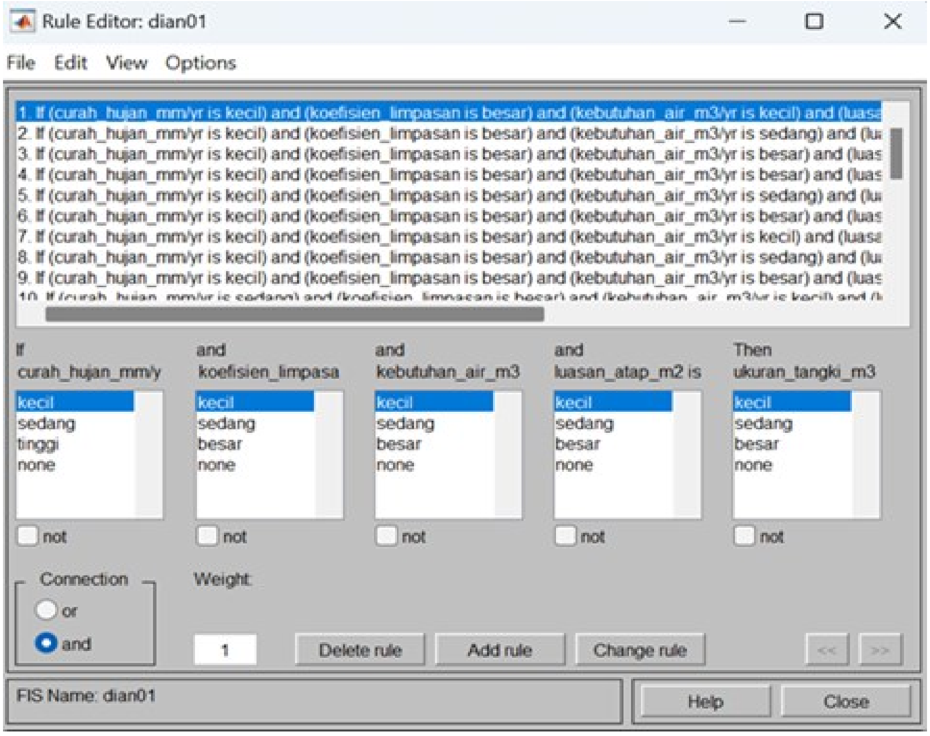
Sources: MATLAB input-output interface.

The membership function has been determined, then the next step is to create fuzzy rules that are useful in determining decisions as a result of the system output. The rules that have been prepared based on analogies that occur in the field can later be used for decision making in determining the required tank capacity based on input data consisting of rainfall, runoff coefficient, water needs so roof area of the house using zinc roofs for houses. The rules for Fuzzification in RWH system is presented in **Table 4**.

Table 4. Rules for fuzzification in RWH system.

			Input		Output
No	**Rainfall**	**Water Use**	**Roof of Area**	**Runoff Coefficient**	**Tank Capacity**
1	Low	Small	Small	High	Small
2	Low	Medium	Small	High	Small
3	Low	Big	Small	High	Small
4	Low	Small	Medium	High	Small
5	Low	Medium	Medium	High	Small
6	Low	Big	Medium	High	Small
7	Low	Small	Big	High	Small
8	Low	Medium	Big	High	Small
9	Low	Big	Big	High	Small
10	Medium	Small	Small	High	Small
11	Medium	Medium	Medium	High	Small
12	Medium	Big	Big	High	Small
13	Medium	Small	Small	High	Medium
14	Medium	Medium	Medium	High	Medium
15	Medium	Big	Big	High	Medium
16	Medium	Small	Small	High	Medium
17	Medium	Medium	Medium	High	Medium
18	Medium	Big	Big	High	Medium
19	High	Small	Small	High	Small
20	High	Medium	Medium	High	Small
21	High	Big	Big	High	Small
22	High	Small	Small	High	Medium
23	High	Medium	Medium	High	Medium
24	High	Big	Big	High	Medium
25	High	Small	Small	High	Big
26	High	Medium	Medium	High	Big
27	High	Big	Big	High	Big

Rules based for fuzzification in the RWH System are arranged, then the number of rules is input via Matlab ToolBox Rule Viewer, the complete results of which are presented in **Figures 13** and **14**.



1. If (curah_hujan_mm/yr is kecil) and (koefisien_limpasan is besar) and (kebutuhan_air_m3/yr is kecil) and (luasa
2. If (curah_hujan_mm/yr is kecil) and (koefisien_limpasan is besar) and (kebutuhan_air_m3/yr is sedang) and (lu
3. If (curah_hujan_mm/yr is kecil) and (koefisien_limpasan is besar) and (kebutuhan_air_m3/yr is besar) and (luas
4. If (curah_hujan_mm/yr is kecil) and (koefisien_limpasan is besar) and (kebutuhan_air_m3/yr is besar) and (luas
5. If (curah_hujan_mm/yr is kecil) and (koefisien_limpasan is besar) and (kebutuhan_air_m3/yr is sedang) and (lu
6. If (curah_hujan_mm/yr is kecil) and (koefisien_limpasan is besar) and (kebutuhan_air_m3/yr is besar) and (luas
7. If (curah_hujan_mm/yr is kecil) and (koefisien_limpasan is besar) and (kebutuhan_air_m3/yr is kecil) and (luasa
8. If (curah_hujan_mm/yr is kecil) and (koefisien_limpasan is besar) and (kebutuhan_air_m3/yr is sedang) and (lu
9. If (curah_hujan_mm/yr is kecil) and (koefisien_limpasan is besar) and (kebutuhan_air_m3/yr is besar) and (luas
10. If (curah_hujan_mm/yr is sedang) and (koefisien_limpasan is besar) and (kebutuhan_air_m3/yr is kecil) and (l

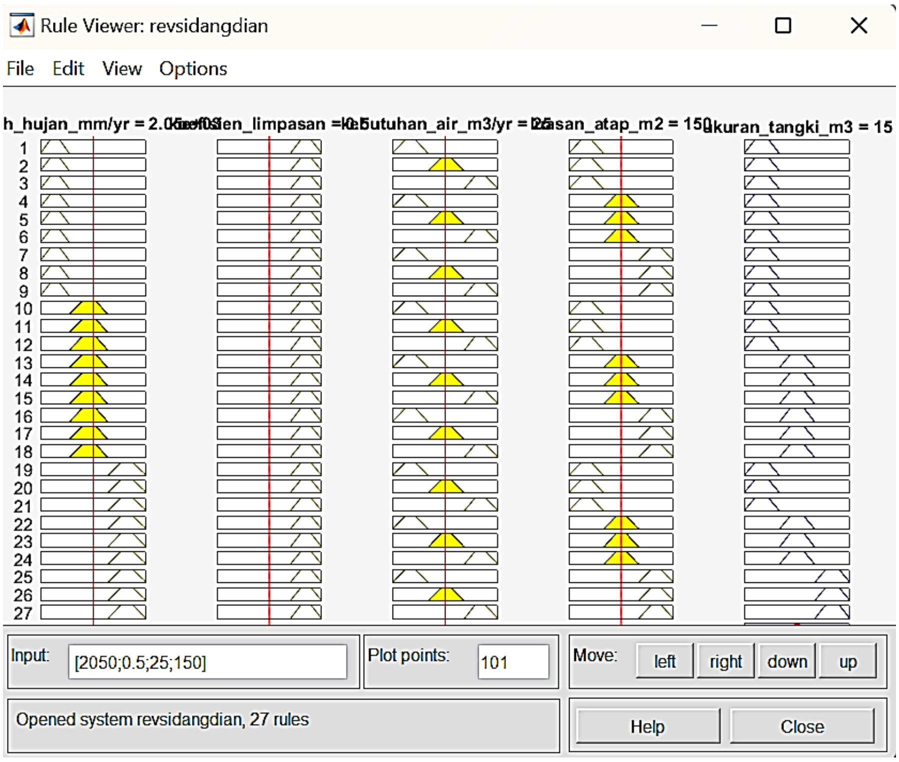
If curah_hujan_mm/y	and koefisien_limpasa	and kebutuhan_air_m3	and luasan_atap_m2 is	Then ukuran_tangki_m3
kecil	kecil	kecil	kecil	kecil
sedang	sedang	sedang	sedang	sedang
tinggi	besar	besar	besar	besar
none	none	none	none	none
☐ not	☐ not	☐ not	☐ not	☐ not

Connection
○ or
● and

Weight: 1

FIS Name: dian01

Figure 13. Rules on fuzzification in RWH systems.



Input: [2050;0.5;25;150]

Plot points: 101

Opened system revsidangdian, 27 rules

Figure 14. Rule view RWH systems.

3.5.3. Scenario analysis tank capacity RWH based fuzzy logic

The people of Tanah Merah Village, Indragiri Hilir District, Riau Province utilize rainwater for daily water use in households for drinking, cooking, rinsing clothes and bathing with a total of approximately 9 L a day per person. The input model (existing water use) is presented in **Table 5**.

Table 5. Input model (existing water use).

Parameter	Value	Sources data
Rainfall	4085 mm/tahun	BWS III Sumatera
Catchment surface: catchment	32 m^2, 93 m^2 and 171 m^2	Primary data
Roof coefficient	0.9	Primary data
Water use	9 L/day/person	Primary data

Increasing the use of rainwater for the rainwater use component is needed to support the need for clean water on a household scale, which was initially only used for drinking, cooking and washing clothes by 9 liters/day/person to 20 L/day/person. The input model (increase water use) is presented in **Table 6**.

Table 6. Input Model (increase water use).

Parameter	Value	Sources data
Rainfall	4085 mm/tahun	BWS III Sumatera
Catchment surface: catchment	32 m^2, 93 m^2 and 171 m^2	Primary data
Roof coefficient	0.9	Primary data
Water use	20 L/day/person	Primary data

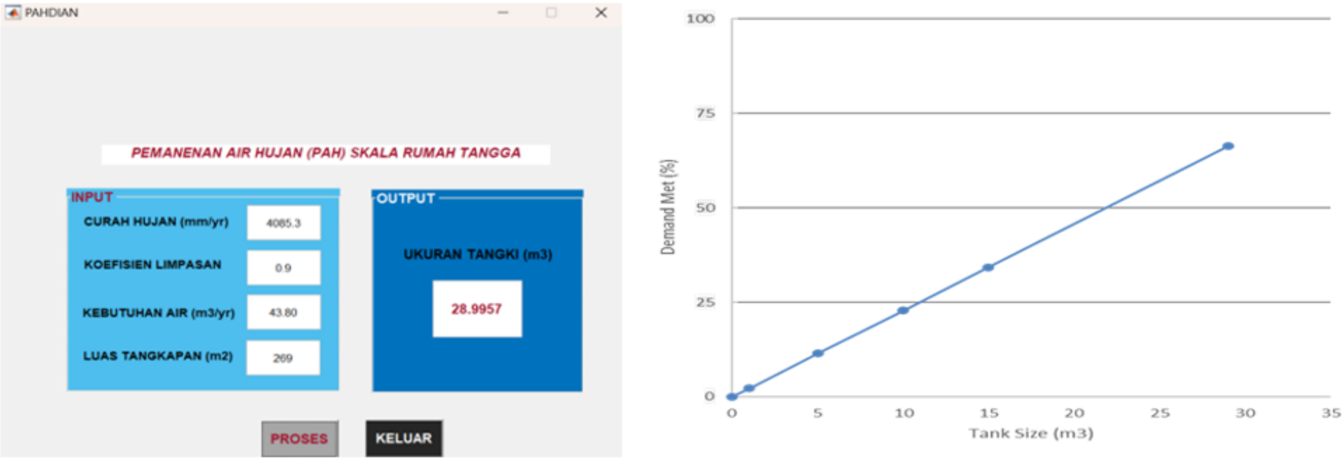
3.5.4. Result tank capacity based fuzzy logic

Water use for analysis of household scale RWH storage tanks in existing conditions for people living in coastal areas is approximately 9 L/person/day (Scenario 1) considering the number of family members, household roof area, daily water needs to obtain the capacity of the tank accommodate household-scale RWH using a Graphical User Interface (GUI) which is then analyzed regarding the contribution of rainfall in efforts to fulfill clean water needs in Tanah Merah Village, Tanah Merah District, Indragiri Hilir Regency, Riau Province, the complete results of which are presented as in **Table 7**.

Table 7. RWH Contribution various type of house and number of family members (Scenario 1).

No	Type of House	Number of Family Members (people)	Roof of Area (m^2)	Daily Water Requirements (m^3/year)	Tank Capacity	Rain Water Harvesting Contribution (%)
1	36 m^2	4	32	13.14	7	53.42
2	36 m^2	5	32	16.43	7	42.74
3	36 m^2	6	32	19.71	7	35.62
4	136 m^2	4	93	13.14	7	53.42
5	136 m^2	5	93	16.43	7	42.74
6	136 m^2	6	93	19.71	7	35.62
7	144 m^2	4	171	13.14	25	190.41
8	144 m^2	5	171	16.43	25	152.33
9	144 m^2	6	171	19.71	25	126.85

The results of the household scale RWH capacity analysis based on fuzzy logic (Scenario 2) for the use of rainwater from 9 L/person/day to 20 L/person/day with various variations in roof area and number of house occupants, the required RWH infrastructure green tank capacity amounting to 25 m^3 for a roof area of 171 m^2, with family members of 4.5 and 6 people with rainfall contribution respectively, 99.45%; 79.45%; and 66.30%. For Scenario 2, by utilizing the community's roof area. water use for analysis of household scale RWH storage tanks in existing conditions for people living in coastal areas is approximately 9 L/person/day, of which water use is increased to 20 L/person/day, the complete results of which are presented as in **Figure 15** and **Table 8**.


PAHDIAN

PEMANENAN AIR HUJAN (PAH) SKALA RUMAH TANGGA

INPUT

CURAH HUJAN (mm/yr): 4085.3

KOEFISIEN LIMPASAN: 0.9

KEBUTUHAN AIR (m3/yr): 43.80

LUAS TANGKAPAN (m2): 269

OUTPUT

UKURAN TANGKI (m3): 28.9957

Figure 15. Input and output process based fuzzy logic.

Sources: Result based GUI RWH.

Table 8. RWH Contribution various type of house and number of family members (Scenario 2).

No	Type of House	Number of Family Members (people)	Roof of Area (m^2)	Daily Water Requirements (m^3/year)	Tank Capacity	Rain Water Harvesting Contribution (%)
1	36 m^2	4	64	13.14	7	24.11
2	36 m^2	5	64	16.43	7	19.18
3	36 m^2	6	64	19.71	7	16.16
4	136 m^2	4	186	13.14	25	85.75
5	136 m^2	5	186	16.43	25	68.49
6	136 m^2	6	186	19.71	25	57.26
7	144 m^2	4	269	13.14	29	99.45
8	144 m^2	5	269	16.43	29	79.45
9	144 m^2	6	269	19.71	29	66.30

Sources: Result analysis using ToolBox MATLAB.

The results of the household scale RWH capacity analysis based on fuzzy logic (Scenario 2) for the use of rainwater from 9 L/person/day to 20 L/person/day with various variations in roof area and number of house occupants, the required RWH infrastructure green tank capacity amounting to 25 m^3 for a roof area of 171 m^2, with family members of 4.5 and 6 people with rainfall contribution respectively, 99.45%; 79.45%; and 66.30%. RWH or rainwater can be applied on two scales, namely the household scale and the communal scale in tropical coastal area based Fuzzy Logic. The following are some of the advantages of household scale RWH when compared to communal scale RWH:

a. Full Control by User

At household scale RWH, each house has full control over the system. Homeowners can monitor water quality, the quantity of water stored, and when and how the water is used, without depending on outside parties.

b. Flexibility in Design

Household-scale RWH systems can be designed according to local needs and conditions, such as the size of the storage tank, the amount of water collected, and the type of filter used. This allows for more appropriate solutions to the specific needs of certain households.

c. Lower Installation and Maintenance Costs

Although there are initial costs for installing an RWH system in a home, these costs are usually lower compared to communal scale RWH which requires large and more complex infrastructure. Apart from that, routine maintenance costs on a household scale are more affordable because the system is simpler.

d. Water Independence

With a household RWH system, each house can be more independent in terms of water needs, especially in areas that often experience water shortages. They do not depend on communal systems or external water distribution.

e. Reducing Pressure on Public Infrastructure

With many households adopting RWH, pressure on communal or public water infrastructure (such as PDAM) can be reduced, especially during the dry season or when water demand increases.

f. Security from Communal Limitations

At a communal scale RWH, if a problem occurs in the system (such as water damage or contamination), the entire community can be affected. Meanwhile, at household scale RWH, the problem will only affect one house, making the risk of widespread impact smaller.

g. Easier to Implement

Installing RWH in individual households is easier to do than organizing and building a large system for a community. There is no need to coordinate with many parties, so the process is faster and more direct.

However, it should be noted that communal-scale RWH has advantages such as lower unit costs and greater storage capacity, which may be more suitable for densely populated areas or communities that wish to share resources

4. Conclusion

The study finds that the largest rainwater contribution comes from a house with a 144 m^2 roof, and the RWH system was able to meet 99.45% of the water needs for a family of four. This shows the potential effectiveness of RWH at the household level in mitigating water scarcity. However, the research also reveals that the existing RWH systems in the village are not sufficient to handle prolonged dry seasons, highlighting the need for improved storage infrastructure and better management practices.

The development of a green infrastructure RWH system based on fuzzy logic offers a promising solution. By considering roof area, rainfall, and water demand, the fuzzy logic model is able to propose optimal tank sizes and systems for continuous water supply. The findings align well with global studies, reinforcing the viability of RWH in mitigating the effects of climate change. Implementation of green infrastructure RWH on a household scale various type of house and number of family members (transformation natural habit community to scientific based water balance) to increase RWH contribution so that is able to overcome global warming which has the potential to increase water temperatures and disrupt the quality of fresh water, which has evapotranspiration high levels and also being proven to be able to overcome the impacts of climate change for sustainable water resource management, especially for communities living in tropical coastal areas Riau Province.

Author contributions: Conceptualization, IS and YY; methodology, IS; software, SA; validation, IS, YY and MM; formal analysis, MF; investigation, FF; resources, IS and MM; data curation, DYPU; writing—original draft preparation, IS and MF; writing—review and editing, EE; visualization, NN; supervision, project administration, YM; funding acquisition, IS, YM and MM. All authors have read and agreed to the published version of the manuscript.

Data availability statement: Data is contained within the article.

Conflicts of interest: The authors declare no conflict of interest.

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