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Modeling of Rainwater Harvesting System

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Abstract Sepaku District, located in Penajam Paser Utara Regency, East Kalimantan, Indonesia, faces a major challenge in providing clean water due to the limited availability of water sources. One of the alternative solutions that can be offered to overcome this problem is the application of rainwater harvesting technology using the Gama Rain Filter (GRF), designed to improve the quality of rainwater for non-domestic use. This study aims to simulate various scenarios of storage capacity to determine the duration of water availability in the rainwater harvesting installation. PowerSim software was used in this dynamic system modeling to simulate various scenarios of rainwater use. The variables influencing this model included rainfall, building roof area, storage capacity, and daily water consumption. This model considered three different scenarios of storage capacity: 1200 L, 2200 L, and 5500 L. This model helped illustrate complex cause-and-effect relationships within the water supply system and helped examine its impact on the efficiency of rainwater harvesting in meeting water demands. The software displayed technical data, water demand calculations, and potential rainwater supply based on historical rainfall data. The results of the simulation showed that rainwater harvesting technology significantly reduces reliance on groundwater sources and pipe water from the regional water utility (Perumdam) if it is effectively designed, properly applied, and well accepted by the community.

Keywords Modeling, PowerSim, Rainwater Harvesting, Dynamic System

1. Introduction

Water is essential for life and socio-economic development, yet it is becoming increasingly vulnerable due to population growth, climate change, global warming, and recurrent droughts [1]. Besides being a basic human need, water is also classified as a natural resource with distinct characteristics that set it apart from other resources. Water is a renewable and dynamic resource, as its availability is continuously replenished through the natural hydrological cycle. The primary source of freshwater is rainfall, which typically occurs seasonally throughout the year. Due to these characteristics, water holds significant potential in supporting both ecosystem sustainability and human activities [2].

Clean water plays a vital role in daily life, serving basic needs such as drinking, bathing, cooking, washing, and various other activities [3]. It is a fundamental human need for survival. The availability, quality, and sustainability of the water supply have a substantial impact on human well-being and everyday living [4]. Beyond households, water supports various sectors, including agriculture, industry, and municipal services. However, rapid population growth, intensive human activities, inadequate management, and climate change have intensified pressures on water availability and sustainability [5].

The global water crisis is a major environmental challenge with widespread social, economic, and ecological impacts, and addressing it requires accurate assessment of hydrological parameters, particularly rainfall [6]. The demand for clean water fluctuates annually, influenced primarily by population growth. As the population grows, the need for clean water becomes increasingly complex [7]. Water supply inequality persists, as densely populated areas often face shortages or poor-quality access despite adequate supply elsewhere [8].

Sepaku District, which is part of Penajam Paser Utara Regency, faces major challenges in providing access to clean water, particularly amid the development of Indonesia's new capital city, Nusantara (IKN). As a consequence of this infrastructure development, access to traditional water sources, such as rivers and wells, has been increasingly limited. To overcome this issue, it is essential that sustainable alternatives for water supply be provided, one of which is the application of rainwater harvesting system. However, to ensure this system's effectiveness, it is necessary to use a simulation-based approach to analyzing the interaction among various variables that influence water availability and demand.

Rainfall intensity and distribution are key factors in understanding hydrological cycles and their influence on environmental processes. Their spatial and temporal variability strongly shape precipitation patterns, which are often uneven across regions and seasons [9]. Continuous rainfall typically occurs under stable large-scale atmospheric circulation conditions [10]. This highlights rainwater's potential as an underutilized clean water source, especially in areas with limited access and high rainfall [11].

Rooftop rainwater harvesting, as a nature-based solution, has attracted global interest because of its diverse potential benefits [12]. In Indonesia, abundant year-round rainfall makes rainwater a sustainable, cost-effective water source and helps reduce urban flooding by easing pressure on drainage and water infrastructure. From a disaster risk management perspective, this offers added value, particularly during periods of high-intensity rainfall [13]. Moreover, RWH systems play an important role in securing a reliable water supply in regions with abundant precipitation [14].

Rainwater harvesting captures rain from surfaces like roofs and roads, storing it in tanks or reservoirs to provide an alternative clean water source, especially in areas with limited networks, poor surface water, or scarce groundwater [15]. Beyond addressing water scarcity, RWH provides additional benefits, including groundwater recharge, reduced energy consumption, flood and drought mitigation, improved water quality, and the sustainable use of naturally clean and minimally polluted rainwater [16]. From an economic perspective, the implementation of RWH can lower water bills and reduce infrastructure maintenance costs, thereby making it a feasible and sustainable solution [17].

Properly harvested rooftop rainwater may, in some cases, surpass municipal water in quality [18]. Rainwater harvesting systems are increasingly popular for non-potable uses, with storage capacity depending on rainfall patterns, catchment characteristics, roof area, and water demand [19]. The effectiveness of RWH systems depends on the catchment area size, storage capacity, rainfall intensity, and collection efficiency, with rooftop harvesting being the most common method [20]. Consequently, a larger the catchment area, the greater the volume of water that can be collected.

Rainfall characteristics greatly influence the potential for rainwater harvesting. Regions with high and evenly distributed rainfall have greater potential than those with seasonal precipitation. However, climate change may cause unstable supply, making it essential to design systems that are efficient in both wet and dry seasons [21]. Proper maintenance and the use of safe, durable materials are essential in rainwater harvesting systems to prevent contamination and maintain water quality [22].

The performance of RWH systems depends on storage capacity and roof area, with effectiveness varying between urban and park settings due to differences in water demand, collection area, and storage potential [23]. In urban areas, a majority of buildings typically feature sloped roof designs, which functionally offer greater potential to optimally drain and collect rainwater. Therefore, applying rainwater harvesting system in urban environments is considered more effective in reducing surface runoff and mitigating flood risks [24].

This study aims to simulate various scenarios of storage tank capacity and to determine the duration and effectiveness of the consumption from water stored in the rainwater harvesting installations. Furthermore, dynamic system modeling using Powersim software serves as the primary tool for analyzing the temporal behavior of these systems and an effective tool for simulating various scenarios [25]. The dynamic system model supports decision-making by enabling policymakers to analyze complex systems, formulate efficient long-term water management strategies, and visualize dynamic interactions and feedback loops between subsystems through the use of stock-and-flow diagrams [26]. Generally, a dynamic system model consists of several steps: identifying the existing problems, selecting the main variables that influence the system, formulating mathematical equations to represent system behavior, and defining the simulation time frame [27]. By understanding the interaction between stocks and flows, the dynamic system model is capable of detecting critical points or limitations within the system, while also helping formulate more optimal and sustainable water management strategies [28]. With its ability to analyze various feedback loops, to determine relationships between elements, and to make predictions, researchers can improve the accuracy of the water system model being developed, while also simplifying the model by reducing the number of variables used [29].

PowerSim software is employed to build a dynamic system model that can evaluate how factors such as rainfall patterns, roofs as catchment area, storage capacity, and water use rate contribute to the sustainability of the RWH system. In a rainwater harvesting system, the quantity of water that can be collected is extremely dependent on several key factors: catchment area (such as building roofs), rainfall intensity and frequency, and the efficiency of the capture and storage system. A larger catchment area increases the potential volume of water that can be collected. By utilizing PowerSim software, dynamic system models can be applied more practically and interactively. Users gain the flexibility to conduct various experiments and scenario analyses on the developed model without relying on time-consuming and costly real-world trials. Powersim, therefore, serves as a strategic tool that supports systemic decision-making with efficiency, accuracy, and a long-term perspective [30].

In the context of rainwater management and utilization, the application of Causal Loop Diagrams (CLDs) is markedly relevant as this application involves multiple interrelated factors, including environmental, technical, social, and public policy aspects. For instance, CLDs can be used to model the relationships between rainfall, storage capacity, community behavior in harvesting rainwater, and urban spatial planning policies. Through this holistic mapping, the most effective intervention points can be identified to enhance the efficiency of rainwater utilization and ensure the long-term availability of clean water [31].

Therefore, to ensure that the results of the analysis are more comprehensive and applicable, a deep understanding of the structure of the analyzed system is required, and involving stakeholders to validate the relationships between variables. This can be achieved through the use of an approach called Casual Loop Diagram integrated with other methods such as dynamic system simulation, quantitative modeling, or community-based participatory approaches [31].

Stock and Flow Diagram is a visual tool used in system dynamics to illustrate how a system changes over time. One of the significant advantages of this diagram is its ability to provide a more structured and detailed representation of a system compared to a standard Causal Loop Diagram (CLD). This diagram is useful in the computer modeling process because it helps create simulation equations easily and visualize the interaction among variables in the system more systematically [29].

The study on this dynamic system, developed using PowerSim, is expected to provide insights for planning and optimizing rainwater utilization as an alternative clean water source that is non-potable and intended for non-domestic purposes. The application of a simulation-based RWH system will help improve the effectiveness of clean water management policies in the Sepaku region. In addition, the simulation results can serve as a reference for policymakers in formulating strategies to enhance the adoption of rainwater harvesting technology.

2. Materials and Methods

This study applied a quantitative approach with dynamic system simulation methods to model a rainwater harvesting system. The study was conducted in Sepaku District, which holds a strategic position because it is connected to the development of the new capital of Indonesia, Nusantara (IKN). This study was conducted in three stages: preparation, modeling and analysis.

Preparation stage began with a literature review and data collection. The data included clean water demand and the potential availability of rainwater. The data covered primary and secondary data required for rainwater harvesting system modeling. Primary data were collected through field observation and survey of public facilities in seven locations for this study, including information on the size and type of building roof, sources of clean water used, and the capacity of water tanks available in the market. Secondary data were collected from relevant institutions and official sources, encompassing demographic and social conditions, climatic characteristics, administrative divisions, monthly rainfall, and the total number of rainy days in the Sepaku District. The integration of these datasets provided the foundation for developing and simulating accurate dynamic system models that represent the actual conditions of the research location.

The data were analyzed after all of the required data had been completely collected. This stage included two main components: calculating the demands of clean water and analyzing potential rainwater availability. The demands of clean water are defined as the volume of water required to meet the needs of the population in a specific area [32]. In this study, water demands focus on non-domestic purposes that support the operation of public service facilities, as stated by Simanjuntak [33].

The potential availability of rainwater was analyzed to assess how much rainwater was utilized to meet this demand. This calculation was based on monthly rainfall data, the catchment area (building roof), and the runoff coefficient value, following the approach outlined by Ramadhayanti and Helda [34] (Equation 1). These two aspects are important for developing a rainwater harvesting system model. Water volume was calculated by multiplying rainfall by the flow coefficient and the roof surface area serving as the catchment area. The value of produced discharge was then used in simulations, factoring daily consumption reductions – that is, the amount of water used each day [35]. This approach allows for a more realistic estimation of water availability based on physical characteristics and user needs.

$$Q = (a \times I \times A) \times \frac{1}{1000} \qquad (1)$$

Notes:
Q = Incoming water discharge (m^3/month)
I = Monthly rainfall (mm/month)
A = Building roof area (m^2)
a = Runoff Coefficient

Stochastic rainfall generators are designed to perform rapid and computationally efficient simulations, enabling the analysis of rainfall variability and associated uncertainties across large ensembles. By applying an empirical approach, they simplify the complex physical processes of rainfall formation while still capturing essential precipitation patterns [36].

Stochastic rainfall models are extensively employed in catchment modeling, water resources analysis, and flood assessment studies [37]. Rainfall projection data were generated using a stochastic modeling approach, which is widely used to analyze phenomena characterized by high uncertainty, particularly in the natural sciences and technology [38]. The development of stochastic models in hydrology can be traced back to the 1950s, beginning with the work of Barnes (1954), who generated a 1,000-year sequence of independent synthetic annual inflows to support reservoir design on the Upper Yarra River in Australia. Building on this foundation, Thomas and Fiering (1962) introduced the first stochastic model capable of reproducing key statistical properties of natural hydrological processes [39]. Monte Carlo analysis is extensively applied in disaster modeling, particularly for estimating potential losses and assessing risks. As a probabilistic simulation technique, it generates random samples from predefined probability distributions of input variables and performs repeated iterations to approximate the probability distribution of outcomes [40]. Within Monte Carlo applications, the Thomas-Fiering model demonstrates distinct strengths compared to alternative time-series approaches. Its key advantages lie in its straightforward structure, ability to capture temporal patterns, uncertainty, and flow variability, established adoption in hydrological research, and interpretability, which facilitates meaningful insights into the physical mechanisms underlying flow dynamics [41].

Among these, the Thomas-Fiering method was specifically developed to address the limitations of short hydrological data records. Situated within the broader framework of time-series analysis, this empirical stochastic model derives event probabilities from historical observations and experimental evidence [42], [43]. This method enables the generation of synthetic data based on historical statistics, allowing for the projections of future rainfall by taking seasonal patterns and intertemporal correlations into account (Equation 2). The reliability of this method makes it an important tool supporting long-term analysis of water resource availability, particularly in the context of climate change and uncertainty of historical data [23].

$$X_{1,b} = X'_b + [(r_b \times \delta_b)/(\delta_b - 1)] \times \left(q_{i,b-1} - X'_{b-1}\right) + \left(t_{i,b} \times \delta_b \times \sqrt{(1 - r_b)^2}\right) \quad (2)$$

Notes:
$X_{1,}$ = Generated rainfall for month b in year I
$X_{1,,}$ X'_{b-1} = Average rainfall for month b and month b-1
r_b = Correlation coefficient for month b
δ_b, δ_{b-1} = Standard deviation for month b and month b-1
$t_{i,}$ = Random number for month b
$q_{i,-1}$ = Rainfall for year I and month b-1

The modeling stage in this study aims to simulate the effectiveness of the rainwater harvesting system as an alternative solution for clean water supply in Sepaku District, Penajam Paser Utara Regency. The modeling considers rainfall fluctuations as well as the challenges faced by the region in distributing clean water. To support this process, PowerSim Studio 10 software was used, which enables dynamic system modeling based on causal loop diagrams and stock-flow diagrams. This software was designed to visualize, simulate and predict the performance of RWH system under various policy scenarios and environmental conditions. The modeling process was conducted systematically, starting with the identification of key variables such as rainfall, roof area, the efficiency of water catchment, storage capacity, and clean water demand in public facilities. The seasonal variability in the modified Thomas-Fiering method was represented by two main seasons, namely the wet and dry seasons, based on observed rainfall patterns in the study area. Extreme events and climate change projections were not explicitly incorporated in this version of the model.

Next, to illustrate the relationship between variables, a causal diagram was developed, followed by a stock and flow diagram model using PowerSim. The model was then verified through a testing process to ensure that there were no logical or computational errors. The last step involved simulating scenarios based on the variations of storage tank capacity to predict the duration of the stored water usage. This served as the basis for evaluating the effectiveness of the designed system.

The analysis stage in this study was the processing of the outputs of the dynamic system model that had been developed. The output data were visualized in the form of graphs to show the extent to which clean water needs were met and the estimated duration of stored water usage based on various simulation scenarios. The analysis was performed by comparing the model outputs between two different sources of water supply: rainwater harvesting and water services provided by the Regional Water Utility (Perumdam). This comparison aimed to evaluate the effectiveness of the rainwater harvesting system in meeting the water demand in public facilities. Furthermore, the duration of water usage provided by RWH system was estimated based on the available storage capacity. The results of this analysis demonstrated the potential contribution of rainwater harvesting systems in supporting water security in the research locations.

Dynamic system modeling is the approach used to understand, analyze, and predict the behaviors of a complex system that continuously changes over a certain period of time. Through this model, water availability can be projected based on historical rainfall data. In the process of modeling, data and components involved in the model were classified into five main categories, i.e., demand subsystem, supply subsystem, variables, and scenarios.

a) Demand Subsystem

This subsystem represents the demand for clean water by the population, considering the following:

1. The number of occupants
2. The types of buildings occupied
3. Daily needs for clean water

This subsystem represents the clean water demand arising from the basic needs of the community within the region.

b) Supply Subsystem

This subsystem encompasses all components influencing the volume of rainwater stored and utilized by the community. These components include:

1. Monthly rainfall
2. Number of rainy days per month
3. Roof Area
4. Runoff Coefficient
5. Tank Capacity
6. Stored rainwater
7. Clean water availability
8. Water Supply by Perumdam.

This subsystem covers all factors that influence the volume of rainwater stored and utilized by the community, contributing to the fulfillment of the clean water needs.

c) Parameters

A parameter is a fixed value used in one model, formula, or system to represent a characteristic, condition, or certain features of the system being analyzed. Parameters of this model are identified as follows:

1. Region
2. Occupants or inhabitants
3. Water Demand
4. Tank capacity with 3 scenarios
5. Roof area
6. Runoff Coefficient

d) Variables

Variables are the key components that represent dynamic change in the system over time. These variables consist of stock, flow, and auxiliary variables, each of which plays a crucial role in explaining the conditions and behaviors of the system.

Variables identified in this study included the following:

1. Monthly rainfall, developed using the modified Thomas-Fiering Stochastic Model
2. Monthly rainy days, developed using the modified Thomas-Fiering Stochastic Model
3. Well water, water discharge produced
4. Water supply by Perumdam, water discharge produced
5. Rainwater storage tanks
6. Well water Storage tanks
7. Perumdam water storage tanks
8. The percentage of demands satisfied by rainwater
9. Storage, all sources used to meet clean water demands
10. Percentage of demands satisfied by all sources
11. Total tanks to store excess rainwater in 3 scenarios
12. Total tanks needed in 3 scenarios to meet the needs of water every month

e) Scenarios

Scenarios prepared in this system were the tank capacity used to store excess rainwater runoff. The following scenarios were used in this study:

1. Capacity of 1200 L
2. Capacity of 2200 L
3. Capacity of 5500 L

These scenarios were designed to analyze the effects of different tank capacities on the ability of the system to collect rainwater captured from the roof surfaces. The selection of these different tank capacities was intended to assess the efficiency and effectiveness of the rainwater harvesting system to help meet the community's daily needs for clean water.

f) Validation

Data validation or verification in the PowerSim simulation was carried out by comparing rainfall data calculated using Microsoft Excel and PowerSim software.

2.1. The Concept and Design of the Model

a) Causal Loop Diagram

A Causal Loop Diagram is a conceptual representation used to visualize the causal relationships and the integration among variables that influence a system.

Figure 1 shows a Causal Loop Diagram created to be developed into a rainwater harvesting system model based on the variables that represent the main objectives of this study.

b) Stock Flow Diagram

This model was formulated in numerical forms and visualized through a flow chart to describe the interaction among the system components (Figure 2). This modeling was based on a Causal Loop Diagram designed using the identified variables and hypothesized flows of the rainwater harvesting system to be developed. The model was developed using PowerSim Studio 10 Software version 10. 14.5555.6.

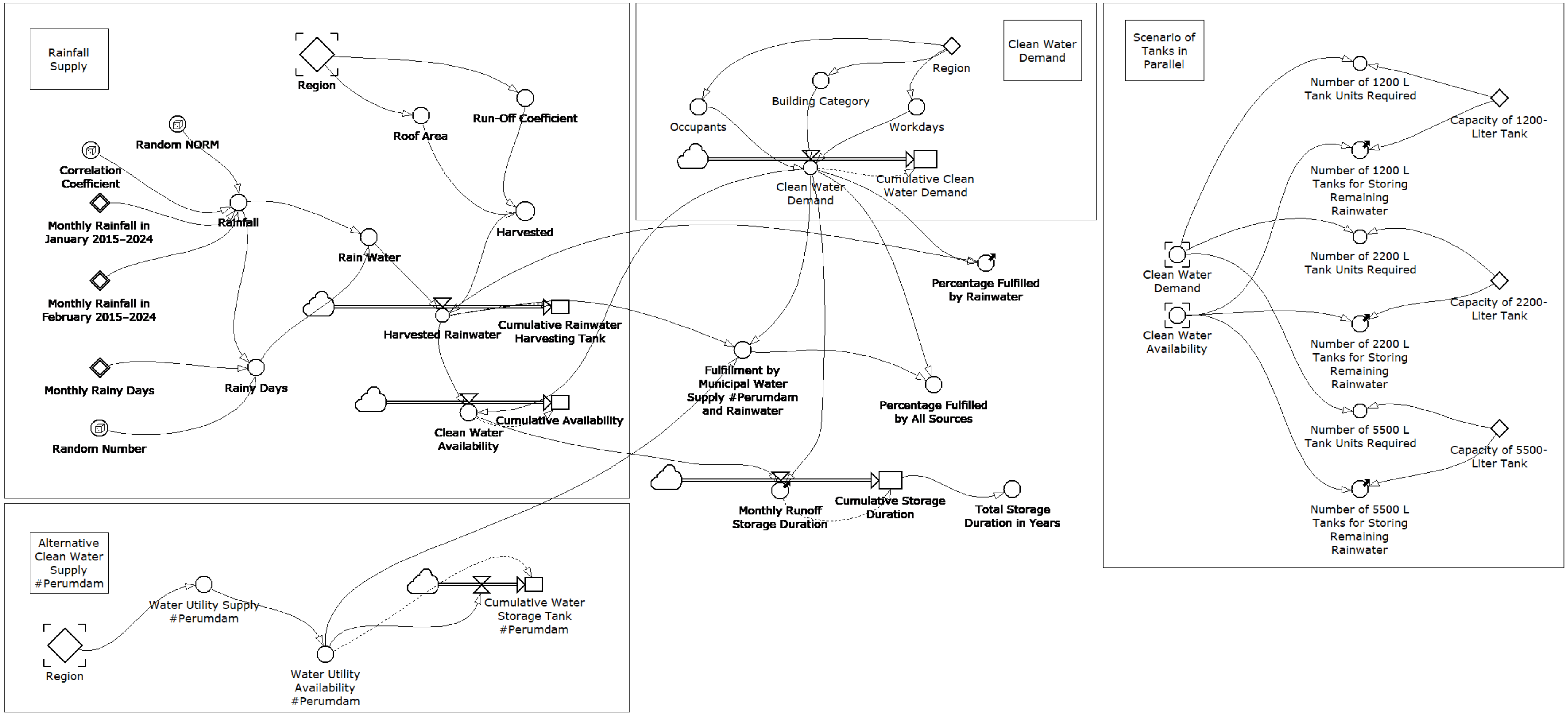


Figure 2. Rainwater Harvesting System to Meet Clean Water Needs in the Selected Areas

This model was developed by referring to the real condition of the research locations, and this was presented in a model using PowerSim Studio 10 Software version 10.14.5555.6. In the model illustrated above, there are a number of interacting and mutually reinforcing subsystems, forming an integrative connection. The reciprocal relationship among these subsystems allows the process to work systematically and continuously, making it possible to project or estimate the system output in the next 20 years.

The stock variables function as storage or accumulation components within the system, including rainwater storage (representing the collected rainfall volume through roof and gutter systems), water availability (the total amount of clean water available from various sources), Perumdam water storage (the volume obtained from the public water supply system), water demand (the total clean water requirement of the community within a specific period), and total storage duration (indicating how long stored water can be used before new supply becomes available). Meanwhile, the flow variables represent the rate of change in the stock variables over time, including harvested rainwater (the amount of rainfall converted into clean water supply), available clean water (the inflow from multiple sources to the consumption system), available Perumdam water (utilized when rainwater is insufficient), clean water demand (the outflow reducing available water due to consumption), and monthly runoff storage duration (representing the average time water is stored before being used or discharged).

The data serving as input for system modeling are presented systematically in Table 1.

The Perumdam variable represents one of the components of the clean water supply incorporated into the modeling. The input variables of Perumdam are shown in Table 2.

The data entered into the PowerSim Software served as a main component used to run the simulation and to generate accurate outputs that reflect the real conditions. Each type of data plays a specific role in modeling the rainwater harvesting system. The data include rainfall and the frequency of rainy days, which affect the volume of water to be stored. In addition, water demand is determined by the type of building and the number of occupants, which influence the rate of consumption. All data were converted and their units were adjusted to match the model structure, allowing consistent analysis in the PowerSim simulation.

This study is unique in that it uses a multi-supply modeling approach to integrate multiple sources of clean water supply, including harvested rainwater and Perumdam water, stored in tanks with different capacities (1200 L, 2200 L, and 5500 L). The model is a long-term dynamic simulation that spans 20 years. The suggested model accounts for seasonal and interannual fluctuations that affect the long-term balance between water availability and demand, in contrast to earlier research that mostly used static analyses or concentrated only on one water source.

Table 1. Input for Modeling

Village/District	Number of Occupants	Types of Buildings	Water Need (L/person.day)	Roof Area (m^2)	Coef. Runoff	Type of Roof
Karang Jinawi	7	Office	50	87.30	0.80	Zinc Roofing Sheets and Concrete Slab
Bukit Raya	8	Office	50	90.28	0.80	Clay and Zinc Roofing Sheets
Argo Mulyo	22	Office	50	92.95	0.75	Zinc Roofing Sheets and Concrete Slab
Suko Mulyo	50	Mosque	5	89.75	0.70	Zinc Roofing Sheets and Concrete Slab
Semoi Dua	19	Multipurpose Building	25	63.50	0.80	Zinc Roofing Sheets
Wonosari	18	Office	50	61.88	0.80	Zinc Roofing Sheets
Tengin Baru	8	Office	50	52.06	0.80	Zinc Roofing Sheets

Table 2. Input for Perumdam Supply

Village/District	Perumdam Piping Network	Flow rate (L/s)
Karang Jinawi	Unserved	-
Bukit Raya	Served	30
Argo Mulyo	Unserved	-
Suko Mulyo	Served	30
Semoi Dua	Unserved	-
Wonosari	Unserved	-
Tengin Baru	Served	30

This 20-year dynamic simulation framework provides a more thorough and accurate evaluation of water distribution and use patterns in public facilities. Therefore, in order to assess the long-term efficacy of rainwater harvesting systems as a sustainable way to improve clean water resilience in places with limited supply, like Sepaku District, this study presents a novel methodological approach.

3. Results and Discussion

The modeling of clean water demand fulfillment was developed by considering two primary sources: rainwater through the Rainwater Harvesting (RWH) system and water supply by Perumdam. This simulation focused on seven villages in Sepaku District, where public facilities served as the primary objects of the analysis. Each location of public facility was analyzed based on rainfall potential, catchment (roof) area, tank capacity, and the availability of Perumdam services. This modeling aims to examine the effectiveness of RWH system in meeting the non-domestic clean water demand for public facilities in each location in 7 villages, both independently and in combination with Perumdam services.

After the dynamic system was simulated over the period of 20 years, the results regarding the fulfillment of clean water needs in seven public facilities in Sepaku District were obtained. These results were found through graphical analysis of the fulfillment of clean water needs related to scenarios of water storage capacity used in the model. The graphs represent the system performance in fulfilling clean water needs based on the variations of storage capacity and demonstrate the effectiveness of rainwater harvesting as an alternative source in supporting the sustainable availability of clean water.

The validation or verification process involved comparing the data computed using the Stochastic Thomas-Fiering formula with the monthly rainfall output graph. The resulting graphs are presented in Figures 3 and 4.

From Figures 3 and 4, it can be observed that the generated rainfall exhibits relatively similar variations. This comparison refers solely to the values produced from data generation using the stochastic Thomas-Fiering formula. The comparison results between the two software indicate that July, August, and September represent dry months or the dry season. Based on these findings, it can be concluded that the rainfall data generated by PowerSim can be used as the initial baseline for calculating rainwater potential in the seven village locations within Sepaku District.

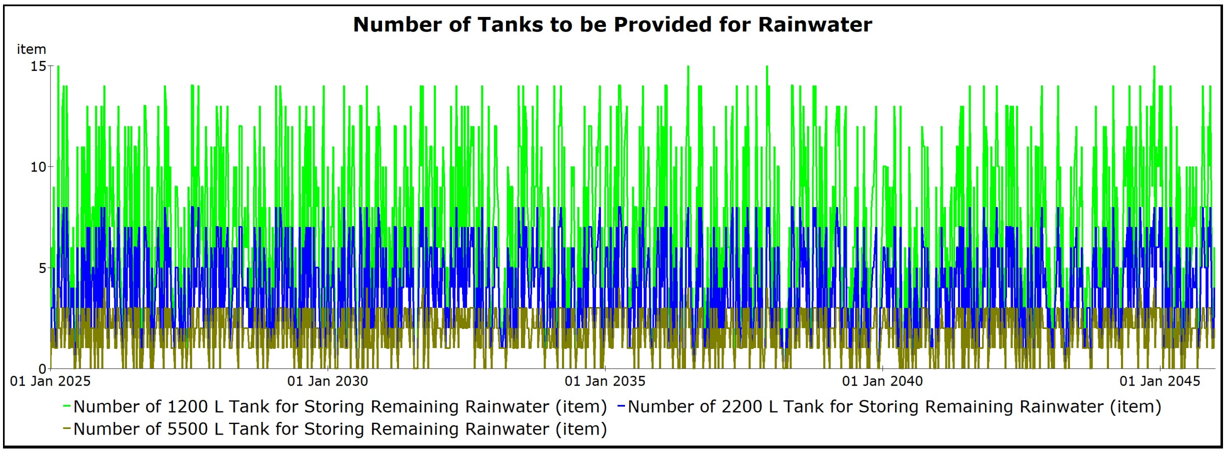
Visualization of the outputs generated by the modeling of the fulfillment of clean water needs in seven public facilities in each village was displayed in graphical forms, illustrating the relative contributions of the two main sources, i.e. rainwater and water supply by Perumdam in meeting non-domestic needs for clean water (Figure 3).

Figure 5 shows the relative contribution of the two main sources (rainwater and Perumdam) in fulfilling non-domestic needs for clean water. Every bar represents one village in Sepaku District, with color segmentation indicating whether the needs for clean water were met by rainwater alone, or a combination of rainwater and Perumdam, or remain unmet.

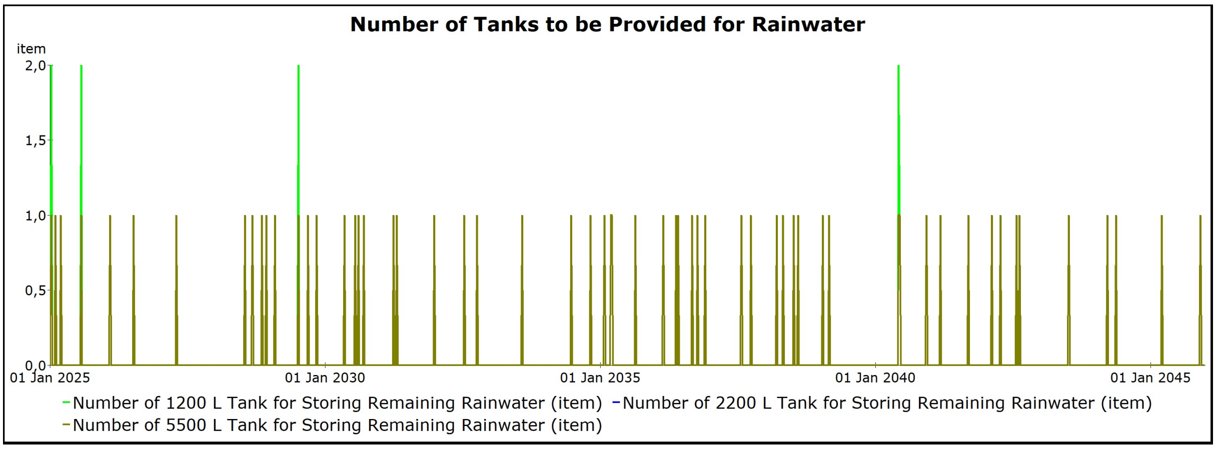
It is also shown in Figure 5 that most villages indicate positive potential in applying a rainwater harvesting system. Several villages, such as Bukit Raya, Suko Mulyo, and Tengin Baru, indicate that their needs for clean water are met by the combination of the two sources, while Karang Jinawi and Semoi Dua are able to meet their needs only by relying on rainwater. However, the villages such as Argo Mulyo and Wonosari are not able to optimally satisfy their needs for clean water, indicating that it is necessary to increase the system capacity and integrate alternative sources of clean water. These graphs also provide a comprehensive illustration of the distribution of the system effectiveness in providing clean water in each village and serve as the basis for analysis to determine required technical interventions that match the local conditions.

Figure 6 presents graphs illustrating the cumulative fulfillment of clean water needs from rainwater in seven villages within Sepaku District over a projected period of 20 years. Each panel represents one village and depicts the cumulative distribution of clean water fulfillment based on the monthly simulation results of the Rainwater Harvesting (RWH) system. The graphs show that the variable of cumulative clean water demand in several villages can be met by the cumulative rainwater storage variable and the cumulative municipal water supply (Perumdam) storage variable. This condition occurs because, under existing circumstances, those villages are already served by the municipal water supply system (Perumdam) as their primary clean water source. The results of modeling input for the seven public facilities in each village regarding the fulfillment of clean water based on water sources: rainwater and Perumdam, are presented in Table 3.

SEMOI DUA



WONOSARI



TENGIN BARU

BUKIT RAYA

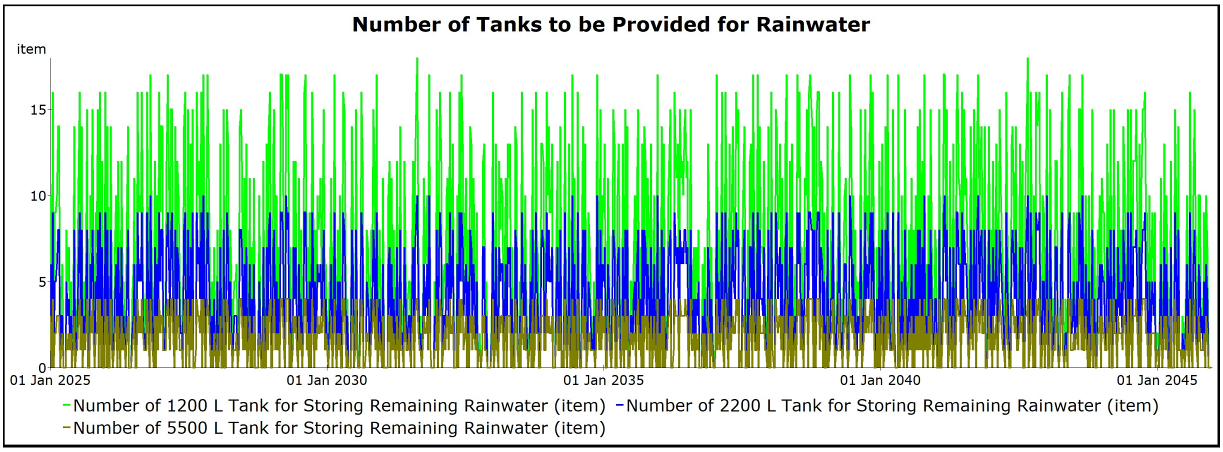


Figure 7. The Number of Storage Tanks Needed for Rainwater Runoff in 7 Villages

Table 4. Scenario Modeling Analysis Results

Village/District	Water Demand (L/month)	Duration for Remaining Rainwater Utilization (month)	Number of Storage Tanks Required per Month (units)		
			1200 L	2200 L	5500 L
Karang Jinawi	7000	± 1	6 – 8	3 – 5	1 – 2
Bukit Raya	8000	± 1	7 – 9	4 – 5	2 – 3
Argo Mulyo	22000	± 0,08	2	2	1
Suko Mulyo	7500	± 1	7 – 8	4	2
Semoi Dua	3325	± 3	10	6	3
Wonosari	18000	± 0,01	1	1	1
Tengin Baru	8000	± 0,3	3	2	1

These data serve as a crucial basis for evaluating the sustainability of RWH system application in the region, as well as for designing adaptive and local potential-based clean water management policies.

4. Conclusions

Based on the modeling results, it can be concluded that most villages in Sepaku District have considerable potential to meet public facility water needs through rainwater harvesting systems. Among the seven villages analyzed, five villages (Karang Jinawi, Bukit Raya, Suko Mulyo, Semoi Dua and Tengin Baru) exhibited adequate rainwater storage capacity to satisfy their estimated monthly water demand, with the required number of storage tanks varying in accordance with their respective volumetric capacities. The duration of runoff utilization in these villages ranges from approximately 0.3 to 3 months, with a relatively reasonable number of tanks required, particularly for a 5,500-liter capacity, which only needs one to three tanks per month. This indicates that the rainwater harvesting systems in these villages are optimally designed in terms of both storage volume and distribution duration.

However, two villages (Argo Mulyo and Wonosari) were unable to meet their water demands through rainwater harvesting. Although the number of required tanks in these villages is relatively small, the very short runoff duration (approximately 0.08 months in Argo Mulyo and 0.01 months in Wonosari) indicates a low rainwater storage potential. This may be attributed to high water demand or suboptimal catchment capacity, such as limited roof area available for rainwater collection. These findings demonstrate that rainwater harvesting systems have the potential to be a feasible solution for improving access to clean water, particularly in areas not fully served by piped water infrastructure. However, to achieve comprehensive water security, an integrative strategy that combines rainwater harvesting with the water supply from Perumdam should be considered, especially in regions with limited seasonal rainfall or insufficient storage capacity.

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