RESWARA: Jurnal Riset Ilmu Teknik
2026, Vol. 4, No. 3, pp. 633-645
E-ISSN: 3025-9444

Analysis of Rainwater Harvesting's Potential For Clean Water Savings, Energy Efficiency and Carbon Emission Reduction At SDN Ragunan 08 Jakarta

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Abstract: *The increasing demand for clean water in educational facilities has led to greater groundwater exploitation, resulting in higher energy consumption for pumping and increased carbon emissions. Rainwater Harvesting (RWH) offers an alternative water source that supports sustainable development and Net Zero Carbon initiatives. This study evaluates the technical, environmental, and economic feasibility of implementing an RWH system at SDN Ragunan 08 Jakarta to meet non-potable water demands, particularly for toilet flushing. The analysis included water demand estimation, rainfall projection using Tropical Rainfall Measuring Mission (TRMM) satellite data validated through statistical methods, assessment of energy savings and carbon emission reductions, and economic evaluation using the Life Cycle Cost (LCC) approach. The results showed that the school's non-potable water demand was 9,492 liters/day (9.49 m^3/day). Validation of TRMM data using logarithmic regression produced a very strong correlation (R = 0.998), indicating high reliability for rainfall estimation. With a reservoir capacity of 60 m^3, the RWH system could reduce groundwater use by up to 56.7% during the driest month and fully meet water demand in several rainy months. Reduced groundwater pumping lowered annual carbon emissions from 2,904.55 kg CO_2 to 968.18 kg CO_2. Economically, the system requires an initial investment of IDR 74,741,413.97 and has a 10-year LCC of IDR 93,777,649.02. Although further optimization is needed to improve economic feasibility, the RWH system demonstrates strong potential as a sustainable water management strategy through groundwater conservation, energy savings, and carbon emission reduction.*

Article history:
Received: 17 June 2026
Revised: 22 July 2026
Accepted: 25 July 2026
Published: 26 July 2026

Keyword:
carbon emissions, energy efficiency, life cycle cost, rainwater harvesting, water conservation

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How to cite: Bara, H. P., Dermawan, H., & Wibowo, A. R. (2026). Analysis of Rainwater Harvesting's Potential For Clean Water Savings, Energy Efficiency and Carbon Emission Reduction At SDN Ragunan 08 Jakarta. *RESWARA: Jurnal Riset Ilmu Teknik*, *4*(3), 633–645. https://doi.org/10.70716/reswara.v4i3.622

INTRODUCTION

Water is a basic necessity that is very vital for the survival of life, but access to proper clean water services in Indonesia is not evenly distributed, especially in public facilities and educational institutions (Badan Pusat Statistik, 2024). In DKI Jakarta Province, the fulfillment of clean water needs for school buildings is still highly dependent on external water supply and groundwater exploitation through drilled wells (Badan Pusat Statistik Provinsi DKI Jakarta, 2024). The continuous use of groundwater contributes to groundwater depletion, land subsidence, and increasing electricity consumption for pumping operations, which consequently increases indirect carbon emissions associated with water supply systems. These challenges highlight the close relationship between water resources and energy consumption, commonly referred to as the Water–Energy Nexus, where improvements in water-use efficiency can directly reduce electricity demand and greenhouse gas emissions.

Jakarta receives annual rainfall ranging from approximately 1,500 to 2,000 mm, indicating considerable untapped potential for rainwater utilization as an alternative water source (Arindama,

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2024). One of the most widely implemented approaches is the Rainwater Harvesting (RWH) system, which captures, filters, stores, and redistributes rooftop runoff for non-potable purposes such as toilet flushing (Putra et al., 2023; Simanjuntak et al., 2023). Beyond increasing water availability, RWH systems reduce dependence on groundwater and centralized water distribution while enhancing urban water resilience.

As a form of alternative water resource utilization, the RWH system collects and stores rainwater from capture areas, such as building roofs, for reuse (Dirgawati et al., 2024; Djalle et al., 2022). To improve the quality of the water collected, the system is generally equipped with a First Flush and filtration units that serve to reduce contaminants carried from the roof surface before water is drained into the reservoir (Yushananta, 2021). In addition to providing an alternative water supply, Rainwater Harvesting supports sustainable development and contributes to Net Zero Carbon (NZC) initiatives by reducing groundwater abstraction, lowering pumping energy requirements, and decreasing greenhouse gas emissions throughout the water supply process (Teston et al., 2022). Through improved water-use efficiency and reduced groundwater pumping, RWH systems can significantly reduce electricity consumption and associated carbon emissions, thereby supporting environmentally sustainable water infrastructure (Habibi et al., 2022; Rashid et al., 2021).

The implementation of Rainwater Harvesting in educational facilities has attracted increasing attention because schools require substantial volumes of non-potable water for daily sanitation activities while providing opportunities to promote sustainable water management. Previous studies have demonstrated that appropriately designed Rainwater Harvesting systems can substantially satisfy non-potable water demand in school buildings while improving environmental performance and reducing carbon footprints (Maharaj & Friedrich, 2024; Satriawansyah et al., 2024). Furthermore, previous studies have shown that capital investment, operational expenditure, and maintenance costs remain the primary determinants of the long-term feasibility of Rainwater Harvesting implementation (Pandyaswargo et al., 2024; Rafli & Harianja, 2023).

Nevertheless, most previous studies have focused on evaluating hydrological performance, environmental benefits, or economic feasibility separately. Comprehensive studies integrating rainfall availability analysis, water-saving performance, groundwater pumping energy reduction, carbon emission mitigation, and long-term economic feasibility within a single assessment framework remain limited, particularly for elementary school buildings in tropical urban environments (Ma'rifat et al., 2024; Maharaj & Friedrich, 2024; Vaz et al., 2023).

The novelty of this study is threefold. First, this study develops an integrated assessment framework that simultaneously evaluates hydrological reliability, water-saving performance, energy efficiency, carbon emission reduction, and life-cycle economic feasibility of Rainwater Harvesting systems specifically for elementary school buildings. Second, unlike previous studies that primarily rely on conventional rainfall observations, this research utilizes validated Tropical Rainfall Measuring Mission (TRMM) satellite rainfall data as the principal hydrological input, providing an alternative approach for regions with limited ground-based rainfall observations. Third, this study explicitly integrates hydrological analysis, groundwater pumping energy reduction, carbon emission mitigation, and long-term economic evaluation using the Life Cycle Cost (LCC) method within a single assessment framework. This integrated framework provides a more comprehensive scientific basis for planning sustainable Rainwater Harvesting systems that support Net Zero Carbon implementation in educational facilities.

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Based on these research gaps and scientific contributions, this study aims to evaluate the technical, environmental, and economic performance of a Rainwater Harvesting (RWH) system implemented at SDN Ragunan 08 Jakarta. Specifically, this study assesses the potential of harvested rainwater to satisfy non-potable water demand, quantifies reductions in groundwater use, pumping energy consumption, and carbon emissions, and evaluates the long-term economic feasibility of the proposed system using the Life Cycle Cost approach. The findings are expected to provide scientific evidence and practical recommendations for implementing sustainable water resource management strategies that support Net Zero Carbon initiatives in educational facilities.

RESEARCH METHOD

Research Location

The study was conducted at SDN Ragunan 08 Jakarta which is an elementary building with a high enough water demand for sanitation activities and daily school operations. The school building consists of classrooms, toilets, teachers' rooms, and other supporting facilities that use clean water every day. The research location was chosen because the use of groundwater in school buildings is still quite high so that a more sustainable alternative water source is needed through the implementation of the Rainwater Harvesting (RWH) system.

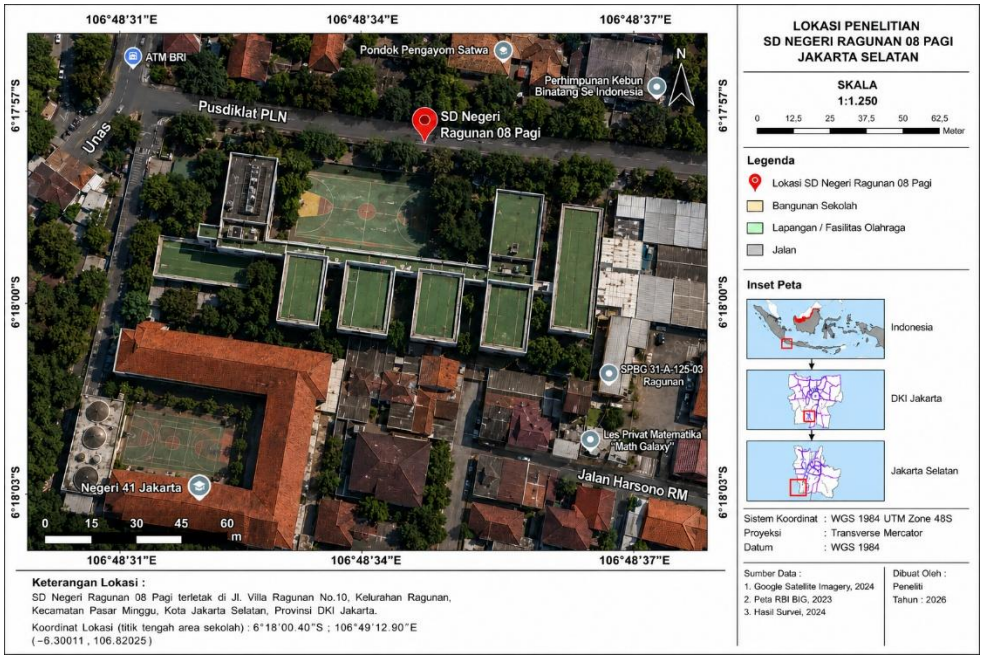

Figure 1. Satellite image of the research location of SD Negeri Ragunan 08 (Source: Google Earth Pro, processed by the author, 2026)

Data Collection

The data were used in the study consisted of primary data and secondary data. Primary data, which is data obtained through field surveys and direct observations, includes the condition of school buildings, roof area as a rainwater catchment area, existing plumbing system, toilet use, sanitation water needs, and documentation of building conditions. This data are used to identify the potential

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application of the rainwater harvesting (RWH) system. Secondary data includes BBWSCC observation rainfall data, TRMM satellite rainfall data accessed through NASA's Giovanni platform and will be validated using field data, as well as data on the number of building users, electricity tariffs, pump specifications, and unit prices of work and materials. The data are used for rainwater potential analysis as well as technical and economic planning of the RWH system.

Water Demand Analysis

The analysis of water needs is carried out to determine the total non-potable water demand in school buildings, especially for toilet flushing needs. The calculation of water needs is carried out based on the number of building users and the frequency of toilet use every day. The water requirement equation is shown as follows:

a. Non-potable water needs

$$Q_d = N \times q \times f$$

Description:
Q_d = Daily water requirement (L/day)
N = Number of users (people)
q = Water requirement per flush (L/flush)
f = Frequency of use (flush/day)

b. Regional rainfall (arithmetic method)

$$P = \frac{P_1 + P_2 + \cdots + P_n}{n}$$

Description:
P = Rainfall area (mm)
P_1 = Rainfall of the first station (mm)
n = number of rain stations

c. Correlation coefficient (R)

$$R = \frac{N\sum P_i Q_i - (\sum P_i)(\sum Q_i)}{\sqrt{[N\sum P_i^2 - (\sum P_i)^2][N\sum Q_i^2 - (\sum Q_i)^2]}}$$

Description:
P_i = Observation data
Q_i = TRMM data
N = Amount of data

d. Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - Q_i)^2}{n}}$$

Used to measure the error rate of TRMM data against observation data.

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e. Nash-Sutcliffe Efficiency (NSE)

$$NSE = 1 - \frac{\sum(P_i - Q_i)^2}{\sum(P_i - \bar{P})^2}$$

Used to evaluate the performance of TRMM data correction results.

f. Potential for rainwater to be collected

$$V = C \times I \times A$$

Description:
V = Volume of rainwater (m^3)
C = Roof runoff coefficient
I = Rainfall (m)
A = Roof area (m^2)

g. Carbon emissions

$$CO_2 = E \times FE$$

Description:
CO_2 = Carbon emissions (kg CO_2)
E = Electrical energy (kWh)
FE = Electricity emission factor (kg CO_2/kWh)

h. Life Cycle Cost (LCC)

$$LCC = C_I + C_O + C_M + C_R$$

Description:
LCC = Life Cycle Cost
C_I = Initial investment costs
C_O = Operating costs over the life of the plan
C_M = Maintenance costs over the life of the plan
C_R = Cost of component replacement over the life of the plan

RESULTS AND DISCUSSION

The analysis of water demand at SDN Ragunan 08 Jakarta is based on the total number of school occupants totaling 791 people with the frequency of toilet use set at 2 times per day for each user during school hours and the standard maximum toilet water output capacity of 6 liters per flush. The following is data on the number of residents at SDN Ragunan 08 Jakarta:

Table 1. Number of Occupants

Students	**752**
Teachers	29
Staff	10
Total	791

The total daily water requirement for non-consumption purposes (flushing toilet) was obtained with a constant value of 9,492 liters per day or equivalent to 9.49 m^3/day. The water needs are planned

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to be supplied using rainwater captured through a total concrete roof catchment area of 800.64 m^2 spread across Building A, Building B, Building C, and Building D. To accommodate this runoff supply, the ground reservoir capacity is designed at 60 m^3 which is considered very efficient in terms of land use in the school environment and is able to provide stored water for approximately 6 to 7 operational days.

Table 2. Catchment Area

Building Name	Area (m2)	Roof Type
Building A	221.04	Concrete Roof
Building B	193.2	Concrete Roof
Building C	193.2	Concrete Roof
Building D	193.2	Concrete Roof
Total Catch Area	800.64	

Based on the area of the catchment, a piping system is planned to drain rainwater from the roof of the building to the filtration unit and reservoir. Before being drained into the reservoir, rainwater first passes through the filtration unit to reduce suspended solids and contaminants carried away from the roof surface. The filtration unit used consists of several layers of filtering media, namely palm fiber, silica sand and gravel which are arranged in layers to improve the quality of harvested water. The design of the filtration reservoir used in the planning of the system.

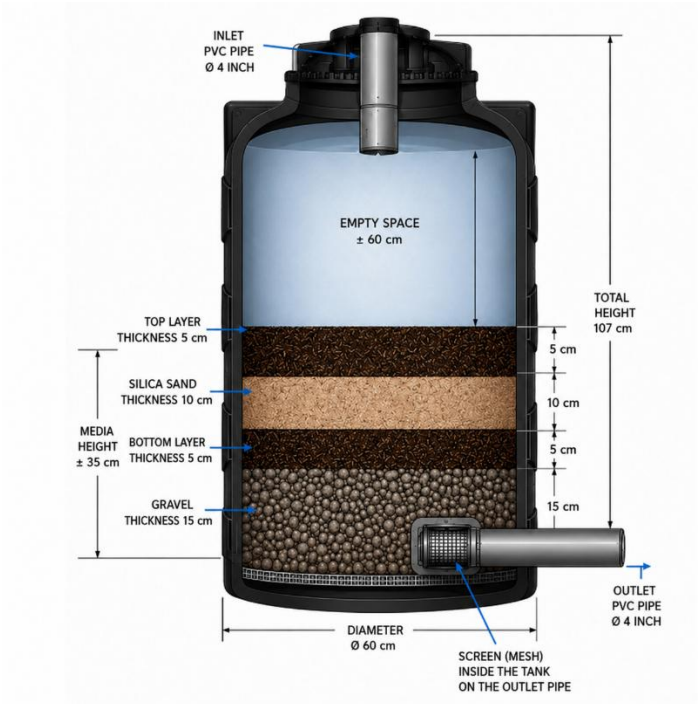

Figure 2. Filtration Reservoir Design in RWH System

After going through the filtration process in the filtration unit, the treated rainwater is then channeled to the storage and distribution system to meet the needs of flushing toilets in the school environment. System planning takes into account not only the quality of the water produced, but also the layout of the piping network, the distribution mechanism, as well as the integration between

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filtration units, reservoirs, pumps, and distribution tanks. Therefore, installation planning is needed that is able to ensure the continuity of rainwater supply from the catchment area to the point of use. Side view and details of the planned Rainwater Harvesting (RWH) system piping flow are shown in Figure 3.

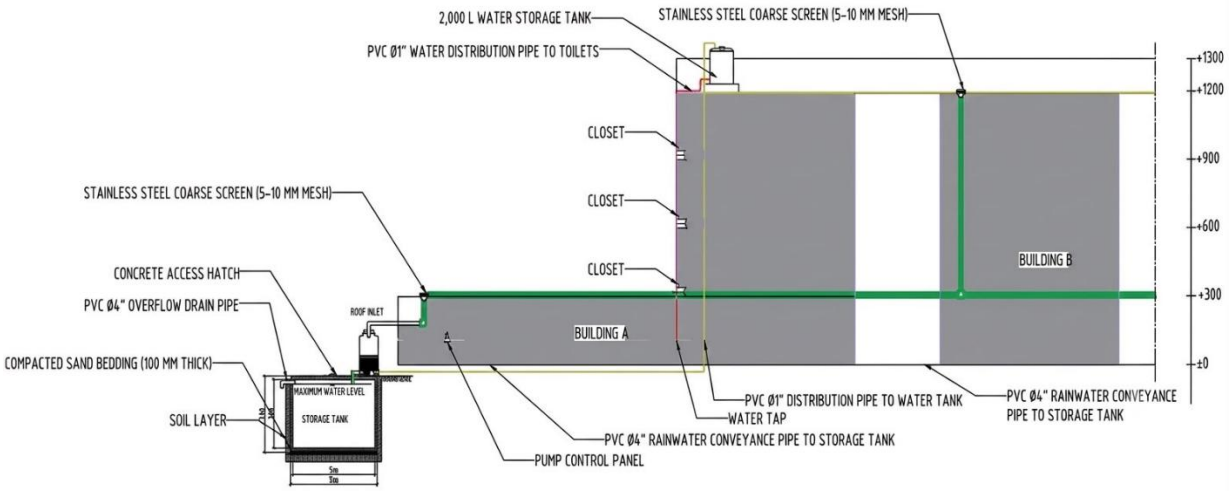

Figure 3. Schematic Layout of the Rainwater Harvesting System

Figure 3 shows that the system is designed by utilizing gravitational flow and pump distribution in an integrated manner. The filtration unit is placed before the reservoir to improve the quality of the water entering the system, while the distribution tank serves to maintain the continuity of water supply to the school's sanitation facilities. This configuration was chosen to improve operational efficiency while ensuring the availability of rainwater that has been treated before being used for non-consumption needs.

In determining the potential availability of rainwater supply, this study utilizes satellite data Tropical Rainfall Measuring Mission (TRMM) which is evaluated for its suitability to field station observation data. Based on the results of the validation carried out, the bias-corrected TRMM rainfall data demonstrated superior performance than the TRMM data without correction. This is indicated by the NSE value and correlation coefficient (R) approaching 1, as well as lower RMSE values and relative errors. These results indicate that the correction process is able to increase the level of conformity of TRMM data to field observation data (Jarwanti et al., 2021). Therefore, the corrected TRMM data can be used as an alternative source of hydrological data, especially in areas that have limited rainfall data observations. The results of the initial validation of the TRMM data before correction showed that the entire test period (either 10 days, 15 days, or monthly) provided an interpretation of "Does Not Meet" the statistical validation standard due to the high level of deviation. As an illustration, the data validation test was not corrected in a 10-day period with a span of 2 years resulting in a value Root Mean Square Error (RMSE) of 75.20, value Nash-Sutcliffe Efficiency (NSE) of -1.896, relative error (KR) of 0.243, and correlation coefficient (R) of 0.743 which are in the strong category. In the accumulated monthly period for the same time span (2 years), the RMSE value was recorded at 83.59, the NSE value was -1.336, the KR value was 0.344, and the correlation value (R) was 0.776.

Similar results were also shown in the 7-year observation period, where the uncorrected TRMM data still showed considerable deviations from the field observation data. The relatively high RMSE

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value and the NSE value that does not meet the criteria indicate that satellite data has not been able to adequately represent actual rainfall conditions without a correction process. This condition confirms that the TRMM data that has not been calibrated has not been able to represent the field observation data optimally.

Table 3. Analysis of TRMM Data Validation Not Corrected

Period		RMSE	NSE		KR	R	
			Value	Interpretation		Value)	Interpretation
10 Daily	5 Years	-	-	-	-	-	-
10 Daily	2 Years	75.20	-1.896	Not Compliant	0.243	0.743	Strong
10 Daily	1 Year	84.84	-1.950	Not Compliant	0.167	0.715	Strong
15 Daily	5 Years	-	0.080	-	-	-	-
15 Daily	2 Years	97.76	-0.765	Not Compliant	0.104	0.661	Strong
15 Daily	1 Year	110.22	-1.950	Not Compliant	0.326	0.742	Strong
Monthly	5 Years	142.92	-1.178	Not Compliant	0.296	0.544	Medium
Monthly	2 Years	83.59	-1.336	Not Compliant	0.344	0.776	Strong
Monthly	1 Year	98.19	-0.671	Not Compliant	0.136	0.834	Very Strong

In order to overcome these deviations, the data calibration process was carried out using several forms of simple regression equations. The logarithmic equation was chosen as the best correction model because it produced the best performance at the 5-year data calibration stage, which was indicated by a correlation coefficient (R) value of 0.998, an RMSE value of 0.600 which met the accuracy criteria, an NSE value of 0.799 which indicated a good model conformity, and a reliability coefficient (KR) of 97.14% which was included in the strong category. After the TRMM data was corrected using this logarithmic model, the validated results of the corrected data showed a very significant improvement in the quality of accuracy. In the 10-day period with a validation period of 2 years, the RMSE value was successfully suppressed to 52.86, the NSE value increased sharply to 0.709 with the status of "Fulfilling", the KR value to 0.828, and the correlation coefficient (R) jumped to 0.974 with a very strong interpretation. A commensurate improvement in performance was also shown in the monthly period of the 2-year validation period, where the RMSE value was 100.02, the NSE value was 0.594 with the status of "Fulfilling", the KR value was 0.816, and the correlation coefficient (R) was 0.783 with the very strong category. The results of this final test prove that the calibrated TRMM satellite data has high reliability to project the actual rainwater potential in the field.

Table 4. Recapitulation of Corrected Data Validation Calculation Results

Period		RMSE	NSE		KR	R	
			Value	Interpretation		Value	Interpretation
10 Daily	5 Years	-	-	-	-	-	-
10 Daily	2 Years	52.86	0.709	Acceptable	0.828	0.974	Very Strong
10 Daily	1 Year	29.352	0.653	Acceptable	0.823	0.929	Very Strong
15 Daily	5 Years	-	-	-	-	-	-
15 Daily	2 Years	51.215	0.515	Acceptable	0.989	0.930	Very Strong
15 Daily	1 Year	47.355	0.455	Acceptable	0.865	0.810	Very Strong
Monthly	5 Years	97.14	0.600	Acceptable	0.799	0.998	Strong

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Monthly	2 Years	100.02	0.594	Acceptable	0.816	0.783	Very Strong
Monthly	1 Year	92.194	0.670	Acceptable	0.788	0.988	Very Strong

The results of the rainfall analysis provide an overview of the potential availability of rainwater that can be utilized through the RWH system. The validated and calibrated rainfall data were subsequently used to estimate the volume of rainwater that can be harvested and stored throughout the year. This harvested rainwater can serve as an alternative water source to meet part of the building's non-potable water demand. By comparing the available rainwater volume with the water demand, the potential reduction in the use of conventional water sources can be determined.

Table 5. Potential Reduction in Conventional Water Use through the Implementation of the Rainwater Harvesting (RWH) System

Month	RWH *Supply* (m^3)	Water Demand (m^3)	Difference	Percentage (%)
Jan	191.179	189.84	1.339	100.7
Feb	172.862	189.84	-16.978	91.1
Mar	167.255	208.824	-41.569	80.1
Apr	154.395	161.364	-6.969	95.7
May	133.553	199.332	-65.779	67.0
Jun	121.388	170.856	-49.468	71.0
Jul	109.863	170.856	-60.993	64.3
Aug	118.362	208.824	-90.462	56.7
Sep	124.324	199.332	-75.008	62.4
Oct	161.485	218.316	-56.831	74.0
Nov	176.395	199.332	-22.937	88.5
Dec	177.851	170.856	6.995	104.1

Based on Table 5, the implementation of the RWH system demonstrates a considerable potential to reduce the use of conventional water sources throughout the year. The percentage of water savings varies from month to month, reflecting fluctuations in rainfall availability and harvested rainwater volume. The highest water-saving percentage was observed in December (104.1%), followed by January (100.7%), indicating that the harvested rainwater was sufficient to fully meet the water demand during these months. In contrast, the lowest savings percentage occurred in August (56.7%) due to reduced rainfall during the dry season. Overall, the results indicate that the RWH system can significantly contribute to meeting non-potable water demand while reducing dependence on groundwater resources.

The implementation of this rainwater harvesting system also has a significant impact on the aspect of reducing carbon emissions when compared to the initial conditions before the RWH system. In conventional conditions without RWH, all school clean water needs are met with a groundwater well with a two-stage pumping system Cost Budget Plan (RAB) (a total of 4 pump units with a combined power of 1,500 Watts) that consumes 3.417.12 kWh/year of electrical energy. This intensive groundwater pump operation produces indirect carbon emissions of 8.0682 kg CO2/day, which accumulates to 242.046 kg CO2/month, and reaches 2.904.55 kg CO2/year. On the other hand, in the conditions after the implementation of RWH, the use of groundwater pumps can be reduced because part of the water needs are diverted to rainwater reservoirs that only require one stage of

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distribution pumping (2 units of 500 Watt power pumps), thus cutting annual electricity consumption to only 1,139.04 kWh/year. This decrease in electrical energy consumption has a direct impact on significantly reducing carbon emissions to 2.6894 kg CO2/day, 80.682 kg CO2/month, and only 968.184 kg CO2/year. The success in cutting annual emissions from 2.904.55 kg of CO2 to 968.184 kg of CO2 proves the real contribution of the RWH system as part of mitigating the environmental impact of school operations (Ward et al., 2012).

Table 6. Carbon Emissions Comparison

Conditions	Emissions (kg CO_2/day)	Emissions (kg CO_2/month)	Emissions (kg CO_2/year)
No RWH	8.0682	242.046	2904.55
With RWH	2.6894	80.682	968.184

The table shows that the use of the RWH system is able to reduce energy consumption and make a positive contribution to reducing carbon emissions. Although it has a positive ecological impact, the aspect of financial feasibility analysis shows its own characteristics in the long run. Based on the preparation of the Bill of Quantities (BoQ) and Cost Estimate which includes excavated earthworks, reservoir concrete structures, pipeline network installations, and the procurement of pump and toren components, the total initial investment (Capital Expenditure) needed to build this RWH system is IDR 74.741.413.97 after adding 11% VAT.

Table 7. Economic Analysis Results of Rainwater Harvesting System

Yes	Job Type	Total Price (Rp.)
1	Excavation Work	IDR 9.935.500.00
2	Practical Column Work 15 cm x 15 cm	IDR 1.696.596.90
3	Beam Work 15 cm x 20 cm	IDR 4.391.719.14
4	Reservoir Floor Plate Work	IDR 2.724.633.84
5	Reservoir Cover Plate Work	IDR 2.508.235.50
6	Pipe work	IDR 8.672.740.00
7	Wall Work	IDR 28.245.619.80
8	Filtration reservoir work	IDR 1.369.562.00
9	Installation Work Accessories (pumps and tanks)	IDR 7.790.000.00
	TOTAL	IDR 67.334.607.18
	11% VAT + Total Cost	IDR 74.741.413.97
10	Pump Operating Costs	IDR 1.798.059.59/Year
11	Maintenance Costs	IDR 500.000.00/Year
12	Component Replacement Cost	IDR 800.000.00/Year
13	Project Plan Lifespan	10 Years
14	*Life Cycle Cost* (LCC)	IDR 93.777.649.02
15	*Payback Period* (PP)	52 Years
16	*Net Present Value* (NPV) (I = 10%)	– IDR 63.692.534.73

Based on Table 7, from economic analysis, the construction of the RWH system requires an initial investment cost of IDR 74.741.413.9 with a projected Life Cycle Cost (LCC) over the 10-year

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plan life of IDR 93.777.649.02. The results of the analysis show that the economic benefits obtained have not been fully able to offset the investment costs in the analysis period used. However, the implementation of this system still provides significant benefits from technical and environmental aspects, especially in reducing groundwater use, reducing electrical energy consumption, and supporting efforts to reduce carbon emissions (Vieira et al., 2014). Therefore, the RWH system implementation in this case study is more appropriately positioned as an investment in environmental sustainability in educational facilities, not solely as an investment with short-term financial benefits.

CONCLUSION

Based on the results of the technical, environmental, and economic analyses, the implementation of the Rainwater Harvesting (RWH) system at SDN Ragunan 08 Jakarta demonstrates significant potential to support sustainable water management in educational facilities. Overall, the findings confirm that the proposed RWH system is technically effective, environmentally beneficial, and environmentally justified despite limited economic feasibility for supporting sustainable water management in elementary school buildings. The system effectively supplies non-potable water for toilet flushing, with a daily demand of 9.492 m^3/day, while a 60 m^3 ground reservoir reduces groundwater use by 56.7%–100% each month. The calibrated Tropical Rainfall Measuring Mission (TRMM) satellite data showed excellent reliability (R = 0.998), and the use of harvested rainwater reduced annual carbon emissions from 2.904.55 kg CO_2/year to 968.18 kg CO_2/year through lower groundwater pumping. Economically, although the system requires an initial investment of IDR 74.741.413.90 and produces a negative Net Present Value (NPV), its long-term environmental benefits justify its implementation in supporting Net Zero Carbon (NZC) initiatives. The integrated assessment framework developed in this study provides a practical decision-support tool for evaluating the technical, environmental, and economic feasibility of Rainwater Harvesting systems in educational facilities. This study is limited to a single school case study and a 10-year economic evaluation period. Future research should validate the proposed framework in schools with different climatic and operational characteristics while incorporating climate change scenarios and broader environmental assessments. Nevertheless, the proposed framework has strong potential for wider implementation in schools with similar conditions to improve water security, reduce groundwater dependence, enhance energy efficiency, and support sustainable educational infrastructure and Net Zero Carbon initiatives.

This study has several limitations. First, the analysis was conducted on a single case study, namely SDN Ragunan 08 Jakarta. Therefore, the findings cannot be directly generalized to other schools with different building characteristics, roof catchment areas, occupancy levels, and water demand patterns. Second, the economic evaluation was performed based on a 10-year design life using the economic parameters available at the time of the study. Consequently, potential changes in water tariffs, electricity tariffs, inflation rates, component replacement costs, and other external factors that may influence the long-term economic performance of the Rainwater Harvesting (RWH) system were not considered.

Based on these limitations, future studies are recommended to expand the analysis to multiple schools with diverse characteristics in order to improve the representativeness of the findings. In addition, further research should incorporate sensitivity analyses of key economic parameters, including water tariffs, electricity tariffs, inflation rates, component service life, and different system

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operation scenarios. Future studies are also encouraged to evaluate the implementation of Rainwater Harvesting systems in various types of educational buildings with different storage capacities and water demand profiles to determine the most efficient and cost-effective system design for each site.

In terms of practical implementation, the findings of this study indicate that the Rainwater Harvesting system has strong potential to be adopted in other schools, particularly those with sufficient roof catchment areas and high non-potable water demand. The implementation of this system can reduce dependence on groundwater and municipal water supplies, improve energy efficiency by reducing groundwater pumping requirements, and contribute to carbon emission reduction. Therefore, the adoption of Rainwater Harvesting systems can support sustainable water resource management and contribute to the development of environmentally friendly educational facilities in line with the Net Zero Carbon initiative.

ACKNOWLEDGMENT

The author would like to express his sincere gratitude to Mrs. Elly Kusumawati, S.T., M.T. from PT. Wahana Duta Jaya Rucika for the support, constructive input, and expertise provided in the process of methodological validation, data analysis, and interpretation of research results. The author also expresses his appreciation to SDN Ragunan 08 South Jakarta for the support and granting of research permits so that the data collection process could be carried out properly. In addition, the author would like to thank the Ciliwung Cisadane River Area Center (BBWS) for the support and access to the data needed in the implementation of this research. The contributions, support, and cooperation provided by all parties are very meaningful in supporting the smoothness, validity, and success of this research.

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