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Utilizing Rainwater to Meet Clean Water Needs in Low-Cost Rusunawa Building

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Abstract: The need for non-potable water in vertical residential buildings, especially simple rental flats (rusunawa), continues to increase along with the number of occupants and variations in domestic water use. Dependence on centralized water distribution systems makes these buildings vulnerable to supply disruptions. Therefore, an Internet of Things (IoT)-based Rainwater Harvesting (RWH) system is proposed as an alternative strategy to support sustainable non-potable water supply. This study analyzes rainfall potential, estimates domestic non-potable water demand, designs storage and distribution components, and integrates IoT-based monitoring for water level, pressure, and selected water-quality indicators. The analysis used rainfall data from the nearest relevant rainfall stations for the study area, frequency analysis with the Log Pearson Type III distribution, design discharge estimation using the Rational Method, field observation, and laboratory rainwater quality testing. The results show that the 10-year return-period rainfall is 282.624 mm/day, producing a design discharge of 0.00351 m^3/s for a 1-hour rainfall duration. The daily water demand is 3.35 m^3, and the proposed system uses an existing 23 m^3 Ground Water Tank (GWT) and a 4.40 m^3 Roof Water Tank (RWT), supported by pumps, a first-flush diverter, filtration, and a web-based IoT dashboard. Because nitrate, pH, Total Coliform, and E. coli exceed the applicable quality limits, the harvested rainwater is recommended for non-potable uses such as flushing, sanitation, and environmental cleaning after appropriate treatment.

Keyword: Hydrological analysis; Internet of things; Low-cost apartments; Rainwater harvesting; Storage tanks

Introduction

Clean water availability is a fundamental indicator of sustainable development, yet rapid urbanization has increased pressure on urban water supply infrastructure and created higher risks of supply disruption. This challenge is more complex in vertical residential buildings such as low-cost rental apartments (rusunawa), where high occupancy density and daily variations in water use increase the demand for reliable alternative water sources. In this context, rainwater harvesting is a relevant strategy because it uses rainfall that is locally available on the building roof and can reduce dependence on centralized water distribution systems (He et al., 2021; Kurniawan et al., 2024; Rodrigues et al., 2023; Raimondi et al., 2023; Maryono, 2020).

Indonesia, as a tropical country, has a relatively high average rainfall, ranging from 2,000 to 4,000 mm per year in most areas (Sachoemar et al., 2021). This potential makes rainwater a very promising resource if managed appropriately. Padang City, West Sumatra, is categorized as an area with high rainfall intensity, thus offering a comparative advantage in implementing rainwater harvesting systems (Kurniadi et al., 2024). Optimally utilizing this potential in vertical residential

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buildings such as low-cost apartments (rusunawa) can significantly contribute to the efficiency of clean water consumption while supporting water resource conservation efforts at the local level (Bañas et al., 2023).

Previous studies have shown that rainwater harvesting in residential buildings has significant potential to support water resource conservation in high-density areas (Murda, 2024; Chen et al., 2025). However, conventional systems still have limitations in continuous monitoring of storage volume, pump operation, and basic water condition under varying operational conditions. The integration of Internet of Things (IoT) technology offers a more adaptive approach through sensors and digital dashboards that can monitor tank water levels, distribution pressure, and selected water-quality indicators in real time (Hui & Rahmat, 2022; Palermo et al., 2022). Accordingly, this study focuses on an IoT-based rainwater harvesting system for the Rusunawa Building as a sustainable source of non-potable domestic water (Judeh et al., 2022).

IoT technology has been proven to improve the effectiveness of building utility management through automatic monitoring and sensor-based control (Ismail et al., 2022). In rainwater harvesting systems, IoT enables building managers to obtain real-time information on tank water levels, pump performance, distribution pressure, and selected water-quality indicators, depending on the sensors installed (Jan et al., 2022). Microcontrollers such as ESP32 or Arduino can function as data-processing units that connect sensors to a digital monitoring dashboard. This approach reduces dependence on manual inspection and minimizes operational failure caused by delayed detection of system problems (Palermo et al., 2022).

The Rusunawa Building at Campus II of the Padang Institute of Technology is a vertical residential facility for students with relatively high occupancy throughout the academic year. Its large roof area and location in a tropical rainy climate make it a relevant case for implementing a building-scale rainwater harvesting system (Rodrigues et al., 2023). At present, water supply in the building depends mainly on the centralized distribution network, without an integrated alternative system that can anticipate supply disruption and support independent water-use efficiency. This condition provides a strong practical reason for conducting a technical study on IoT-based rainwater harvesting in the building (Silva et al., 2022).

Hydrological analysis is a fundamental component in designing a reliable building-scale rainwater harvesting system (Raimondi et al., 2023). In this study, rainfall analysis was based on daily rainfall data from the nearest relevant rainfall stations, followed by frequency analysis using the Log Pearson Type III distribution and design discharge estimation using the Rational Method. These analytical steps provide design parameters for roof runoff collection, storage tank capacity, pump selection, and IoT-based monitoring configuration. The novelty of this research lies in integrating building-scale rainfall analysis, storage tank sizing, rainwater quality assessment, and IoT-based monitoring into a single design framework for a rusunawa building in a high-rainfall urban area.

Based on the above background, this study aims to analyze the potential of rainwater utilization and develop an IoT-based rainwater harvesting system design for the Rusunawa Building, Campus II, Padang Institute of Technology. The study is important because it provides a practical model for reducing dependence on centralized water supply, improving operational monitoring, and supporting sustainable non-potable water management in vertical residential buildings. The results are expected to contribute a structured technical reference for building managers and stakeholders in developing more independent, efficient, and sustainable water management systems in university residential environments.

Method

Research Characteristics

This research uses a descriptive-analytical design supported by field observation, hydrological data analysis, rainwater quality testing, and IoT system design. The study explains the concept, component structure, and operating logic of an IoT-based rainwater harvesting system in a low-cost apartment building. System performance was evaluated at the design level by comparing rainfall potential, storage capacity, water demand, and raw rainwater quality; therefore, the study does not claim long-term operational testing of the installed system.

Research flow: (1) literature review and regulatory review; (2) field observation of the Rusunawa roof catchment, existing drainage, and storage components; (3) collection and screening of rainfall data; (4) rainfall frequency and intensity analysis; (5) design discharge and storage volume calculation; (6) rainwater quality assessment; (7) selection of pumps, treatment units, sensors, and ESP32-based IoT components; and (8) formulation of the final IoT-based rainwater harvesting design.

Research Location

The research was conducted in a low-cost apartment building located on Campus II of the Padang Institute of Technology, on Jl. DPR, Aie Pacah, Padang City. This location was chosen because it features vertical residential structures with large roof areas that could potentially be used as rainwater catchment areas.

Figure 1. Location of Campus II of Padang Institute of Technology

IoT Based Rainwater Harvesting System Configuration

The rainwater harvesting system discussed in this study consists of several main elements, including a rainwater collection and storage facility that serves to channel runoff from the building's roof into a storage tank. IoT-based sensor devices are used to monitor basic system conditions, such as water level and water quality parameters. A microcontroller, such as an ESP32 or Arduino, functions as a sensor data processing unit and as a connector to the monitoring system. A dashboard-based monitoring system that presents system condition information as part of the IoT technology integration.

Water Quality Parameter Study

Rainwater quality was evaluated using laboratory test data and applicable regulatory standards. The parameters assessed included physical, chemical, and microbiological indicators, such as pH, turbidity, Total Dissolved Solids (TDS), nitrate, Total Coliform, and E. coli. The suitability assessment refers to the Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023 regarding Environmental Health.

Rainwater Potential Analysis

Hydrological analysis was conducted to describe the potential for rainwater harvesting as the basis for system design. The analysis included collecting daily rainfall data from the nearest relevant rainfall stations, screening the annual maximum rainfall series, conducting rainfall frequency analysis using the Log Pearson Type III distribution, determining rainfall intensity using the Mononobe method, and calculating design discharge using the Rational Method based on rainfall intensity, roof catchment area, and runoff coefficient. The hydrological results were then used to support the design of the storage tank, roof drainage, and IoT-based monitoring configuration.

Result and Discussion

Results

Hydrological Analysis

Based on the corrected rainfall data analysis, the annual maximum rainfall values ranged from 117.35 mm to 321.71 mm, with an average value of 179.11 mm. The 2016 Mount Nago data were corrected from 1015 mm to 101.5 mm to avoid an unreasonable outlier in the annual maximum daily rainfall series. The statistical test results indicate that the Log Pearson Type III distribution is the most suitable distribution for frequency analysis of the rainfall data.

Table 1. Corrected Annual Maximum Rainfall Analysis

Year	Annual Rainfall Data (mm)					Rh Plan (mm)
	Koto Tuo (208.96)	Batu Busuk (151,294)	Gunung Nago (169,115)	Limau Manis (67,347)	Sawah Liat (97,506)	
2024	332	447	419	30	138	321.71
2023	137	207	223	51	272	183.82
2022	162	187	256	141	304	208.25
2021	174	189	261	91	107	181.00
2020	143	202	231	100	51	160.20
2019	111	140	126	91	99	117.35
2018	151	142	146	130	192	151.54
2017	140	158	241	181	122	169.98
2016	218	199	101.5	210	118	170.66
2015	145	191	231	126	76	164.44
2014	153	133	139	142	125	140.23
2013	174	169	191	167	125	169.49
2012	152	145	140	76	117	135.26
2011	155	115	170	65	118	136.01
2010	215	56	180	75	109	143.35
2009	82	87	196	71	145	118.64
2008	89	155	239	112	80	140.89
2007	325	175	98	89	75	179.00
2006	500	155	270.2	240	155	295.15
2005	500	193	270.2	240	96	295.15

Rainfall Frequency

Determining the rainfall used in calculating the planned flood discharge begins with an analysis of rainfall distribution through an evaluation of dispersion measures. Dispersion analysis is performed by calculating statistical parameters, which are then transformed into logarithmic form to test the suitability of the data distribution. The results of statistical dispersion calculations from five rainfall stations with a data span of 20 years are presented in the following table.

Table 2. Distribution Test Calculation Recapitulation

Method	Condition	Results			Information
Gumbel	Cs = 1.14	1.14	Cs	1.54	Not Fulfil
	Ck = 5.4	5.4	Tsk	4.92	Not Fulfil
Normal	Cs ≈ 0	0	Cs	1.54	Not Fulfil
	Ck ≈ 3	3	Tsk	4.92	Not Fulfil
Log Normal	$Cs = 3Cv+Cv^3 = 1.077$	1.08	Cs	1.047	Not Fulfil
	$Ck = Cv^8+6Cv^6+15Cv^4+16Cv^2+3 = 5.1313$	51.313	Tsk	4.92	Not Fulfil
Log Pearson III		In addition to the above values	Tsk	3.618	Fulfil

Based on the results in Table 3.2, the statistical parameter values are then compared with the distribution test requirements. The test results indicate that only the Log-Pearson Type III distribution meets the criteria, so the daily rainfall calculation is carried out using the Log-Pearson Type III method, as presented in Table 3.

Table 3. Pearson Log III Distribution

Period Repeat T (Year)	Log X	Sd. Log X	Cs	K	Y	CH daily Mom (mm/day)
2	2.25	0.1480	1.047	-0.164	22.286	169.268
5	2.25	0.1480	1.047	0.758	23.651	231.770
10	2.25	0.1480	1.047	1.34	24.512	282.624
25	2.25	0.1480	1.047	2.043	25.553	359.147
50	2.25	0.1480	1.047	2.542	26.291	425.734
100	2.25	0.1480	1.047	3.023	27.003	501.579
200	2.25	0.1480	1.047	3.489	27.693	587.923

Based on Table 3, the calculation results for the Log Pearson Type III distribution for a 10-year return period are 282.624 mm per day. This value is then used as the basis for determining rainfall intensity in the next analysis stage.

Rainfall Intensity

Rainfall intensity analysis was conducted to represent the characteristics of rainfall distribution across various rainfall durations (Fajriyah & Wardhani, 2020). Rainfall intensity varies depending on the duration and frequency of rainfall events. The determination of rainfall intensity values for each duration in this study was conducted using the Mononobe method, with the calculation results presented in Table 4.

Table 4. Rainfall Intensity

T (O'clock)	R24						
	R_2	R_5	R_{10}	R_{25}	R_{50}	R_{100}	R_{200}
	169.27	231.77	282.62	359.15	425.73	501.58	587.92
1	58.74	80.44	98.08	124.64	147.75	174.07	204.04
2	37.00	50.66	61.77	78.50	93.06	109.63	128.51
3	28.23	38.66	47.14	59.90	71.00	83.65	98.06
4	23.30	31.91	38.91	49.44	58.61	69.05	80.93
5	20.08	27.49	33.53	42.60	50.50	59.50	69.74
6	17.78	24.35	29.69	37.73	44.72	52.69	61.76
7	16.04	21.97	26.79	34.04	40.35	47.54	55.72
8	14.68	20.09	24.50	31.14	36.91	43.49	50.97
9	13.57	18.58	22.65	28.79	34.12	40.20	47.12
10	12.65	17.32	21.12	26.83	31.81	37.47	43.92
11	11.87	16.25	19.81	25.18	29.85	35.17	41.22

T (O'clock)	R24						
	R_2	R_5	R_{10}	R_{25}	R_{50}	R_{100}	R_{200}
	169.27	231.77	282.62	359.15	425.73	501.58	587.92
12	11.20	15.33	18.70	23.76	28.17	33.18	38.90
13	10.62	14.54	17.73	22.52	26.70	31.46	36.87
14	10.10	13.83	16.87	21.44	25.41	29.94	35.09
15	9.65	13.21	16.11	20.47	24.27	28.59	33.52
16	9.24	12.66	15.43	19.61	23.25	27.39	32.10
17	8.88	12.15	14.82	18.83	22.33	26.30	30.83
18	8.54	11.70	14.27	18.13	21.49	25.32	29.68
19	8.24	11.29	13.76	17.49	20.73	24.42	28.63
20	7.96	10.91	13.30	16.90	20.03	23.60	27.66
21	7.71	10.56	12.87	16.36	19.39	22.85	26.78
22	7.47	10.23	12.48	15.86	18.80	22.15	25.96
23	7.26	9.94	12.12	15.40	18.25	21.50	25.20
24	7.05	9.66	11.78	14.96	17.74	20.90	24.50

Design Discharge

The design discharge analysis was carried out using the Rational Method, which is appropriate for estimating peak discharge in small-scale catchment areas such as building roofs. The calculation is expressed as follows: $Q = 0.278 \times C \times I \times A$, where $C = 0.90$, $I = 98.08$ mm/hour, and $A = 0.0001432$ km². Thus, $Q = 0.278 \times 0.90 \times 98.08 \times 0.0001432 = 0.00351$ m³/s.

Storage Volume

The storage volume was calculated using $V = Q \times t$. Because rainfall intensity decreases as rainfall duration increases, Q was recalculated for each rainfall duration using the corresponding intensity value from Table 4. The corrected rainwater storage volume calculation is presented in Table 5.

Table 5. Rainwater Storage Volume

Rain Duration (hour)	Time (Seconds)	Corrected Q (m³/s)	Storage Volume (m³)
1	3600	0.003514	12.65
2	7200	0.002213	15.93
3	10800	0.001689	18.24
4	14400	0.001394	20.07
5	18000	0.001201	21.62
6	21600	0.001064	22.98

Raw Water Requirements

The analysis results show that the average non-potable water requirement in the building is 0.73 m³/hour. Assuming an operating time of 8 hours/day, the total daily non-potable water requirement is estimated at 3.35 m³.

Table 6. Daily Raw Water Requirements for Rusunawa Buildings

Floor	Length X Width	Number of Rooms	Flat/Room	Used	Empty	Amount
Floor 1	5.40 X 4.25	13	4	13	-	52
2nd Floor	5.40 X 4.26	15	4	15	-	60
3rd floor	5.40 X 4.27	15	4	15	-	60
Total						172

Rainwater Quality

The results of initial laboratory testing conducted by the West Sumatra Provincial Health Office on physical, chemical, and microbiological parameters, which include a total of 19 parameters, are presented as follows.

Table 7. Rainwater Quality Test Results

No	Parameter	Test Results Rainwater	Quality Standard (Maximum Level)	Unit	Method Specification
A. Physics					
1	Smell	Odorless	Odorless	-	SNI 3554:2015
2	Solid Dissolved	3.04	<300	mg/L	WI.MK11.LK.SB
3	Turbidity	1.13	<3	-	SNI 06.6989(1).25 2005
4	Temperature	24.7	Air Temperature ±3	°C	SNI 06.6989(1).23 2005
5	Color	10.3	10	TCU Scale	SNI 06.6989.80.2011
B. Chemistry					
6	Arsenic (As)	<0.010	0.01	mg/L	APHA 21st ed
7	Iron (Fe)	<0.0306	0.2	mg/L	SNI 6989.84.2019
8	Fluoride (F)	0.285	1.5	mg/L	IKM.12.LK.SB

No	Parameter	Test Results Rainwater	Quality Standard (Maximum Level)	Unit	Method Specification
9	Cadmium (Cd)	<0.00093	0.003	mg/L	SNI 6989.38.2005
10	Chromium Valence VI (Cr)	<0.0030	0.01	mg/L	APHA 24th ED. 3500. Cr. B
11	Manganese (Mn)	<0.0169	0.1	mg/L	SNI 6989.84.2019
12	Nitrate (NO3)-N	82.0	20	mg/L	SNI 06.6989.2004
13	Nitrite (NO2)-N	<0.009	3	mg/L	SNI 3554:2015
14	pH	6.01	6.5 - 8.5	-	SNI 6989.11.2019
15	Lead (Pb)	<0.0037	0.01	mg/L	SNI 6989.84.2019
16	Aluminum	0.112	0.2	mg/L	IKM.4.LK.SB
17	Residual Chlorine	0.09	0.2-0.5 with contact time 30 minute	mg/L	IKM.2.LK.SB
C. Microbiology					
18	Total Coliform	179	0	CFU/100ml	APHA.9221-B
19	E. coli	27	0	CFU/100ml	SNI 3554:2015

Rainwater Catchment Building Design

Initial Cross-section Building

Rainwater is collected from the roof runoff of the Rusunawa Building, Campus II, Padang Institute of Technology, and channeled through a gutter system and horizontal pipes to the initial reservoir. The reservoir is designed as a rectangular storage unit with dimensions of 4 m wide, 2 m high, and 2 m long, functioning as temporary storage before the water is directed to the main ground tank. To maintain water quality for non-potable use, the system is equipped with a first-flush diverter to divert the initial rain flow that may carry pollutants from the roof surface.

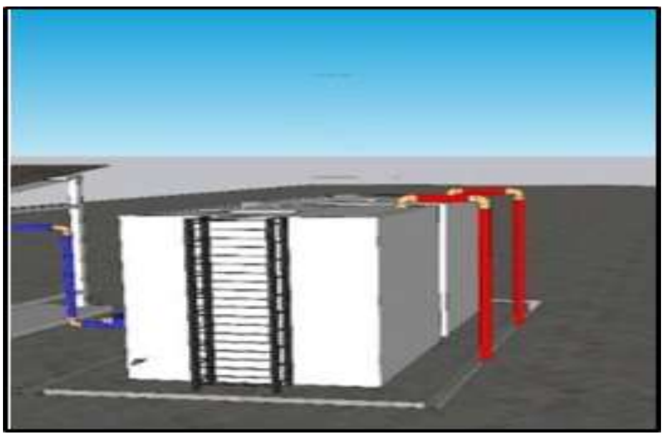

Figure 2. Initial shelter building

Ground Water Tank

Based on the calculation results, the average usage discharge is obtained at Qs = 0.49 m³/hour. Assuming a usage time of 8 hours/day in the Flat Building Campus II Padang Institute of Technology, the capacity of the lower storage tank required to meet water needs can be calculated as follows.

Ground tank volume is calculated using Eq. (1):

$$V\_GT = [Q\_d - (Q\_s \times t)] \times T \quad (1)$$

$$V\_r = [26.83 - (0.49 \times 8)] \times 1$$

$$V\_r = [26.83 - 3.92] \times 1$$

$$V\_r = 22.92 \text{ m}^3$$

Effective water level T = 2 m

$$A = V\_r / T \quad (2)$$

$$A = 22.92 / 2 = 11.46 \text{ m}^2$$

If the width L = 2.5 m, then:

$$P = A / L \quad (3)$$

$$P = 11.46 / 2.5 = 4.58 \text{ m}$$

Based on the volume calculation and existing tank capacity, the lower storage tank is proposed with an effective volume of 23 m³.

Roof Water Tank

The capacity of the roof water tank is calculated using Eqs. (4)-(7).

$$Q\_p = Q\_m\text{-}max = 0.29 \text{ m}^3/\text{hour} \quad (4)$$

$$Q\_h\text{-}max = 5.87 / 60 = 0.097 \text{ m}^3/\text{minute} \quad (5)$$

$$Q\_pu = Q\_h\text{-}max = 0.097 \text{ m}^3/\text{minute} \quad (6)$$

Assumptions: T_p = 30 minutes and T_pu = 15 minutes.

T_p is the peak demand period, and T_pu is the pump operating time for filling the roof tank.

$$V\_E = [(Q\_p - Q\_h\text{-}max) \times T\_p] - (Q\_pu \times T\_pu) \quad (7)$$

$$V\_E = [(0.29 - 0.097) \times 30] - (0.097 \times 15)$$

$$V\_E = 6.0 - 1.5 = 4.40 \text{ m}^3$$

Based on the calculation, the effective capacity of the roof water tank is 4.40 m³.

IoT-Based Rainwater Harvesting

Existing Rainwater Pipes

The Rusunawa building uses a conventional roof drainage system in the form of gutters installed on the front and rear sides of the building to collect rainwater runoff from the entire roof area. Rainwater is then channeled through vertical PVC pipes with a diameter of 4 inches (100 mm) to the surface drainage system. The use of gutters in multi-story buildings with large roof areas aims to channel rainwater effectively, distribute the flow load evenly, and reduce the risk of uncontrolled runoff at the roof edge.

Figure 3. Horizontal gutters and water pipes in the rusunawa building

Management Unit

Based on the rainwater quality test results (Table 7), several parameters exceeded the quality standards stipulated in the Regulation of the Minister of Health of the Republic of Indonesia No. 2 of 2023. Therefore, harvested rainwater should not be used directly as drinking water. The proposed treatment unit is intended to improve water quality for non-potable applications, such as flushing, sanitation, and environmental cleaning. If potable use is targeted in future development, additional advanced treatment such as disinfection, UV treatment, ozonation, or reverse osmosis must be incorporated and verified through laboratory testing.

Figure 4. Rainwater treatment filter unit

Distribution Pumps and Control Systems

Transfer Pump System (Ground Tank –Roof Tank)

Horizontal end-suction centrifugal pumps are used to pump water from ground tanks to roof tanks, with a capacity range of 2–3 L/s, a lifting height of 20–30 m, and a motor power of 1–2 HP, adjusted to the operational needs of the building.

Figure 5. Horizontal end suction centrifugal pump 2-3 l/d

Distribution Pump System (Roof Tank – Building Unit)

Water distribution from the roof tank to the building's piping network is carried out using a similar type of pump, with capacity and working pressure settings so that the flow is stable and even at all points of use.

Figure 6. Horizontal end suction centrifugal pump 2-3 l/d

Automatic Control System (Transfer and Booster Pump Controller)

Pump performance is automatically controlled using a Transfer Pump Controller and Booster Pump Controller based on level and pressure sensors, and is integrated with an IoT system to enable real-time monitoring of operating conditions through a digital interface.

Figure 7. Transfer pump controller and booster pump controller

Implementation Internet of Things (IoT) Technology in Rainwater Harvesting Systems

Ultrasonic Sensor

Ultrasonic sensors are used to measure the water level in ground tanks and roof tanks non-contactly as a basis for automatic control of transfer pumps.

Figure 8. Ultrasonic sensor

Water Pressure Sensor

Water quality sensors are used to monitor selected parameters such as turbidity and electrical conductivity (EC) as supporting indicators of harvested rainwater condition. These sensor readings should be interpreted as operational monitoring data and must be verified by laboratory testing when regulatory compliance is required.

Figure 9. Water pressure sensor

Water Quality Sensor

Figure 10. Water quality sensor

Water quality sensors are used to measure turbidity and electrical conductivity (EC) parameters as indicators of the quality of harvested water to ensure it meets the established standards.

Microcontroller and IoT Communication Module

The ESP32 microcontroller acts as the main control unit of the IoT system, processing all sensor data and sending it to a web-based dashboard for real-time monitoring and remote control.

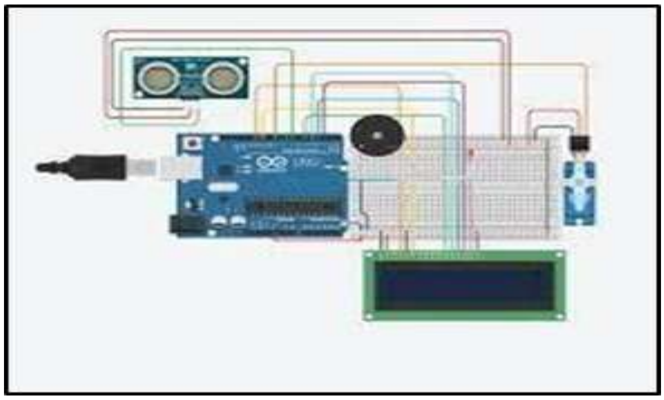

Figure 11. Microcontroller and IoT communication module

Discussion

The corrected hydrological analysis based on 20 years of rainfall data showed that the annual maximum rainfall ranged from 117.35 mm to 321.71 mm, with an average of 179.11 mm. The Log Pearson Type III distribution was selected as the distribution that met the statistical criteria, resulting in a design rainfall of 282.624 mm/day for a 10-year return period. Rainfall intensity calculated using the Mononobe method produced the highest value of 98.08 mm/hour for a 1-hour duration. Using the Rational Method, the 1-hour design discharge was 0.00351 m^3/s, which served as the basis for roof runoff and storage design.

The daily non-potable water requirement for the low-cost apartment building is estimated at 3.35 m^3 to serve 172 residents on three floors, with an average usage rate of 0.73 m^3/hour for 8 hours of operation. The system utilizes an existing ground tank capacity of 23 m^3 (4.6 m × 2.5 m × 2.0 m) and a roof tank of 4.40 m^3. This configuration provides sufficient operational storage, but future optimization should compare tank capacity with rainfall variability, demand patterns, and cost efficiency to avoid oversizing.

Laboratory test results showed that several physical and chemical parameters of rainwater, such as turbidity (1.13) and TDS (3.04 mg/L), were below the applicable limits. However, nitrate, pH, Total Coliform, and E. coli exceeded the required standards, indicating that the harvested rainwater cannot be directly claimed as clean or drinking water. These findings are consistent with

Mazurkiewicz et al. (2022), who reported that microbiological contamination is a major problem in collected rainwater. Therefore, a first-flush diverter and treatment unit are necessary, and the harvested water should be limited to non-potable uses such as flushing, sanitation, and environmental cleaning unless advanced treatment is added and verified.

The integration of IoT technology, including ultrasonic sensors, pressure sensors, selected water-quality sensors, and an ESP32 microcontroller, makes the rainwater harvesting system more adaptive and easier to monitor. Ultrasonic sensors monitor the water level in the ground tank and roof tank, while pressure sensors support automatic pump control to maintain stable distribution. The ESP32 microcontroller processes sensor data and sends it to a web-based dashboard for real-time monitoring. This supports the findings of Hui et al. (2022) and Pratama et al. (2023), which emphasize the role of IoT in improving water-system monitoring and reducing delayed response to operational problems.

Overall, the IoT-based rainwater harvesting system in the Rusunawa Building, Campus II ITP, is a relevant technical solution for supporting sustainable non-potable water management. The proposed model combines rainfall analysis, corrected storage calculation, water quality assessment, first-flush and filtration components, pump control, and IoT-based monitoring. This integrated framework can serve as a reference for other university residential buildings in high-rainfall areas, provided that future studies validate the system through long-term operational monitoring and water quality performance testing.

Conclusion

This study designed an Internet of Things (IoT)-based rainwater harvesting system for the Rusunawa Building, Campus II, Padang Institute of Technology. The hydrological analysis produced a 10-year return-period rainfall of 282.624 mm/day and a 1-hour design discharge of 0.00351 m^3/s. The estimated daily non-potable water requirement is 3.35 m^3 for 172 residents, while the system utilizes an existing 23 m^3 ground tank and a 4.40 m^3 roof tank as the main storage components. Rainwater quality testing showed that nitrate, pH, Total Coliform, and E. coli exceeded the applicable standards; therefore, the harvested water is recommended for non-potable uses such as flushing, sanitation, and environmental cleaning after appropriate treatment. The IoT system, consisting of ultrasonic sensors, pressure sensors, selected water-quality sensors, and an ESP32-based dashboard, enables real-time monitoring and supports more efficient operation. Future research should conduct long-term field testing, evaluate seasonal water-quality variations, optimize tank capacity based on cost and reliability, and validate the effectiveness of the treatment and IoT control system under actual operating conditions.

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Author Contribution

A, A, A: preparation of original draft, results, discussion, methodology, conclusion; N. S, H, N. C and J. M: analysis, review, proofreading and editing.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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