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An integrated smart water management system for efficient water conservation

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ABSTRACT

Water is a fundamental resource that sustains life, supports ecosystems, and plays a crucial role in various natural processes on earth. Water wastage is a major problem in the world, with a variety of causes including leaks in infrastructure and inefficient usage methods. A typical cause of water wastage is overflow from reservoirs or tanks as a result of poor maintenance or monitoring. This paper proposes a novel water resource management using internet of things (WARM-IoT) system to monitor and regulate the water level remotely by integrating IoT technology with demand side management (DSM) strategies, real-time monitoring of water levels has been achieved. The approach utilizes an ultrasonic sensor and Raspberry Pi for data acquisition and processing, fuzzy logic for decision-making, and an Android app for remote monitoring and control. The WARM-IoT assesses the system's performance, showcasing its efficacy in managing water levels and lowering electricity expenses. By analyzing consumption costs under different activation timings, significant potential for cost savings is observed, with a notable reduction of up to 6% in electricity expenses. Overall, the proposed WARM-IoT offers a comprehensive solution to water wastage and inefficient electricity usage in water management systems.

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1. INTRODUCTION

Water is a valuable natural resource that has been essential to all life on Earth since the beginning of time. It is essential to our everyday activities, including industrial processes, cleaning, bathing, and irrigation [1], [2]. From agricultural irrigation to industrial processes, from household consumption to environmental preservation, water holds a pivotal role in ensuring the well-being and prosperity of communities worldwide [3], [4]. One common source of water wastage is the overflow from tanks, reservoirs, and other storage facilities [5]. The prevention of water wastage plays a huge part for the sustainable development of a country. This has to be done in every household in a detailed level to get maximum results [6]. To manually manage water levels will prove to be a very difficult task. So, we can use the technology available to us to make the maximum impact [7], [8].

The emergence of the internet of things (IoT) [9], [10] and demand side management (DSM) technologies has revolutionized various sectors, including water management [11], [12]. Various IoT devices are connected which exchange data and enable live monitoring of water level and accordingly take control to regulate water level in the tank [13], [14]. With the integration of IoT and DSM capabilities, a new paradigm in water management systems has emerged [15], [16]. By leveraging IoT technology, which enables interconnected devices to communicate and exchange data over the internet, and DSM strategies, which focus on optimizing resource consumption based on demand patterns [17], [18].

In recent years, several studies have used smart water management to monitor the water level in tanks. Ali *et al.* [19] suggested IoT-based artificial control and monitoring systems, including fuzzy logic and traditional proportional integral derivative (PID) control systems. Supriya and Rao [20] developed an IoT-based water level indicator to prevent water waste in storage tanks using cloud computing and IoT technologies. Singh *et al.* [21] created a IoT based water tank level monitoring approach utilizing ultrasonic sensors to address water spillage issues in-home water tanks. Huque *et al.* [22] proposed a similar system to reduce water waste by utilizing sensors, communication devices, and cloud-based platforms for remote water tank level monitoring. Jayalakshmi [23] introduced automated monitoring and control capabilities to improve the effectiveness of smart water tank systems. Anugraha *et al.* [24] suggested a cost-effective IoT-based liquid tank control system to facilitate online practical courses. Additionally, Dhake *et al.* [25] created a system for smart water metering and billing to ensure accurate tracking and invoicing of water usage.

Manual management of water levels proves cumbersome and inefficient, leading to significant wastage. Despite advancements in smart water management, there remain opportunities for further innovation and improvement in efficiency and cost-effectiveness. To overcome these issues a novel water resource management using IoT (WARM-IoT) technique has been proposed to monitor the water level and control it remotely to reduce the electricity tariff that needs to be paid. The main contributions are as follows:

- An ultrasonic sensor is utilized in the water tank to collect real-time data on the water level in the tank and utilizes a Raspberry Pi board for data processing.
- Implements an intelligent water management system to activate and deactivate the motor based on predetermined water level thresholds for efficient water management and also sends this information as a notification to the user.
- Implements fuzzy logic to decide motor activation based on water level, time of day, power load, and electricity price, optimizing electricity use and sending alert messages for motor activation.
- Developed an Android app for user-friendly remote monitoring and control of the water management system, enabling users to receive alerts, view water levels, and control motor operation.

The remaining portion of this research is explained as follows: The suggested system is explained in great length in section 2. Section 3 is the outcome and discussion. Whereas section 4 is the conclusion.

2. WATER RESOURCE MANAGEMENT USING IOT (WARM-IOT)

In this paper, a novel WARM-IoT has been proposed to monitor the water level and control it remotely. A water tank system utilizes an ultrasonic sensor and Raspberry Pi for real-time water level monitoring. It features an intelligent management system that controls the motor based on set water levels for efficiency. Notifications are sent to users for motor actions. Fuzzy logic is employed to optimize electricity usage considering various factors like water level, time, power load, and electricity price. An Android app allows remote monitoring, alert reception, and motor control with a user-friendly interface. The WARM-IoT approach is given in Figure 1.

2.1. Data acquisition

Data acquisition involves collecting, measuring, and recording information from various sources. In this study, a Raspberry Pi board and ultra-sonic sensor are used to gather real-time data on the tank’s water level. The ultrasonic sensor detects the distance to the water's top, while the Raspberry Pi processes these readings. This setup ensures accurate and continuous monitoring of water levels. The collected data is then recorded and analyzed for effective water resource management. This real-time data acquisition system enhances the automation and efficiency of the water management process, enabling timely decisions and interventions.

2.1.1. Ultrasonic sensor

An ultrasonic sensor is an electronic device that uses high-frequency sound waves to calculate the distance to an object. It then converts the reflected sound waves into an electrical signal. For measuring the water level, the sensor is mounted at the top of the tank. Using ultrasonic sensors to identify non-opaque things is an excellent option. Ultrasonic sensors can identify the existence of items irrespective of their color, surface, or ultrasound may be used indoors or outdoors and is dependable in all illumination conditions.

2.1.2. Raspberry Pi

The Raspberry Pi board is a tiny computer that unifies and combines all the parts. Using the most recent Broadcom 2837 ARMv8 64-bit CPU, the Raspberry Pi 3 models B+ include a built-in 1.4 GHz quadcore 64-bit processor with low-power onboard Wi-Fi, Bluetooth, and USB ports. Ethernet, Bluetooth, Wi-Fi, and USB are just a few of the communication choices that the Raspberry Pi provides. Tank water levels may be remotely monitored and controlled thanks to this link. The real-time data processing capabilities of the Raspberry Pi enable quick reactions to variations in water levels.

2.1.3. Energy-meter

It permits the systematic pricing of energy consumed by individual users since it measures the amount of electrical energy spent by a house, business, or electrically powered object. This computerized energy meter, which calculates total energy used and examines the load curve, helps with DSM. Energy meters give instantaneous power by multiplying the rapid voltage and current measurements. By integrating this power over a certain time, the energy utilized at that particular moment is found.

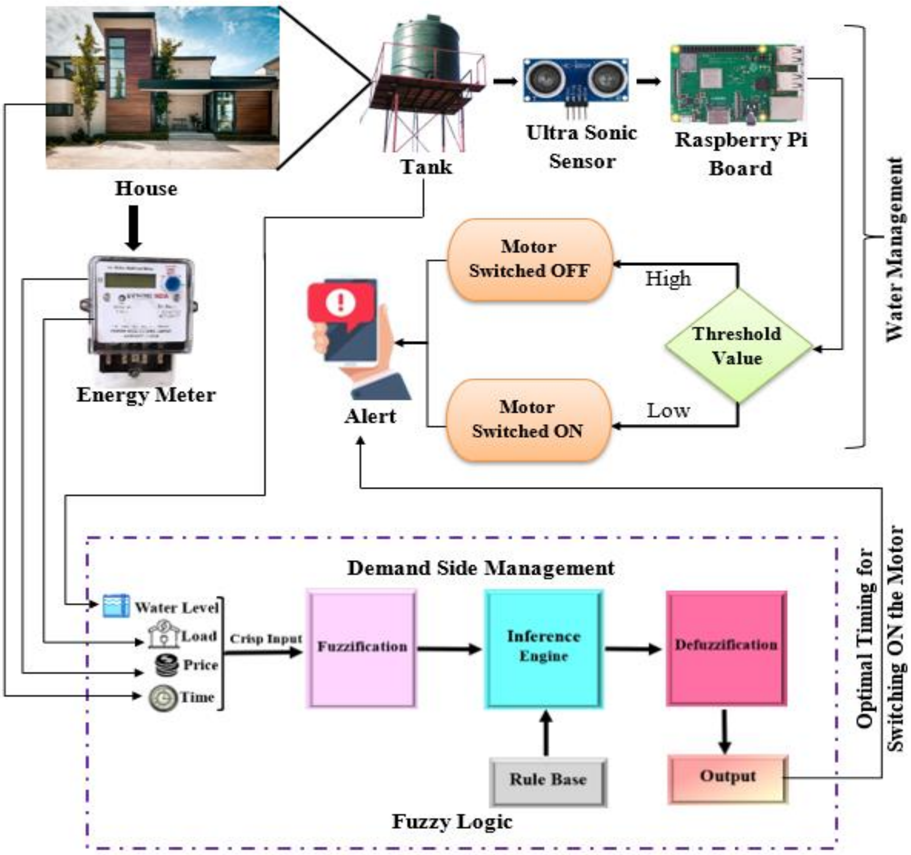


Figure 1. Overall workflow for the proposed WARM-IoT framework

2.2. Motor operation based on threshold value

Motor operation based on a threshold value relies on an intelligent system that ensures efficient water management in a tank. Moreover, another critical aspect of this system is the automatic shutdown of the motor once the water level reaches its maximum capacity to prevent water wastage and potential overflow. These alerts can be in the form of notifications sent to developed connected devices. These notifications serve as reminders for users to take appropriate actions, such as refilling the tank or addressing any potential issues with the water supply system promptly.

2.3. Demand side management

The concept of DSM comes into play in this position. The power consumption by a water pump/motor is significantly high. When it is switched on during peak load, the cost is higher and hence the tariff that needs to be paid is also higher. To avoid this, DSM is brought into the picture. Based on the day ahead prices of electricity per hour, when the cost is the lowest, a timing is suggested to the user's app when water level is below a certain level, so then he can switch on the motor remotely.

2.3.1. Fuzzification

Fuzzification, a critical phase in fuzzy logic, transforms precise or crisp inputs into fuzzy representations, enabling the modelling and analysis of systems characterized by uncertainty, imprecision, and vagueness. This process is essential when dealing with variables affected by imprecision, ambiguity, or vagueness, which can be represented using membership functions within a fuzzy set framework. Membership functions define the degree of membership or truth of each input value within a specified range, allowing fuzzy logic systems to effectively interpret and process uncertain data.

2.3.2. Inference engine

The inference engine comprises a rule base and several techniques for inferring the rules to process the fuzzified values. Every input variable has three linguistic states for the four factors involved. It, therefore, suggests that there are a total of 81 fuzzy inference rules that might be used. There are three categories for electricity load: Ll, Ml and Hl. Levels of water level are classified as high (H), medium (M), and low (L), while levels of electricity price are classified as low price (Lp), moderate price (Mp) and high price (Hp). Time is classified as morning (FN), afternoon (AN) and night. Alert for switch-on motors based on levels of chances on various input variables can be found in Table 1. The 27 rules of 81 rules are listed in Table 1 regarding the three variables. During low morning water levels and low power load, activating the motor optimizes water management. In the afternoon, if water levels stay low with moderate or high-power load, the system activates the motor for efficient water distribution. Table 2 describes the range value of the input parameter.

Table 1. Fuzzy rules

Rule	Water level	Time of day	Power load	Electricity price	Output
1	L	FN	Ll	Lp	Switch on motor (Alert)
2	L	FN	Ml	Hp	No alert
3	L	AN	Hl	Mp	No alert
5	L	Night	Ll	Lp	Switch on motor (Alert)
6	L	Night	Ml	Hp	No alert
7	L	FN	Ml	Lp	Switch on motor (Alert)
8	M	AN	Ll	Mp	No alert
9	M	Night	Hl	Mp	No alert
10	M	Night	Hl	Hp	No alert
14	H	AN	Hl	Hp	No alert
15	H	Night	Ll	Lp	Switch on motor (Alert)
16	H	Night	Ml	Hp	No alert

Table 2. Parameters with range

Fuzzy input parameter	Range		
Water level	0-30%	40%-70%	80%-100%
	Low (L),	Medium (M),	High (H)
Time of day	6 AM-12 PM	12 PM-6 PM	6 PM-7 AM
	Morning	Afternoon	Night
Power load	0-500 W	500-1000 W	1000-1500 W
	Light load (Ll),	Medium load (Ml)	High load (Hl)
Electricity price	\$0.10-\$0.15	\$0.16-\$0.20	\$0.21-\$0.25
	Low price (Lp)	Moderate price (Mp)	High price (Hp)

2.3.3. Defuzzification

The defuzzifier executes defuzzification on the fuzzy solution space. The objective is to produce an exact number from a fuzzy set, like a vector or function. An axiomatic or empirical justification can be used to support the choice of an appropriate defuzzification strategy. The center of gravity, the center of singleton, and maximum methods are the three most widely used defuzzifers. Here, defuzzification is accomplished by using the center of gravity (COG) as a defuzzifer which is given in (1).

$$COG = (\sum \mu_b(z) * z)/(\sum \mu_b(z)) \tag{1}$$

Here, z represents the range of possible input values and $\mu_b(z)$ membership function of value z. Based on the defuzzified output, the switch ON the motor alert notification passes to the developed user's app so that he can switch on the motor remotely through the app designed.

3. RESULTS AND DISCUSSION

In this section, WARM-IoT is developed to automatically control the motor based on the water level present in the tank. Sensors like ultrasonic sensor is equipped in the water tank to monitor the water level. In this section, the practical implementation of the suggested approach is examined to determine the performance of the system. The experiments are conducted using Python as the programming language. NumPy, pandan, sklearn, and Matplotlib are among the various Python packages that can be accessed through multiple packages.

3.1. Outcome of demand side management

Fuzzy logic has become an important technique in the DSM space. To produce customized solutions that maximize the utility of water pumps. Through the use of a variable cost parameter, the optimization results are converted into precise dispatch times for every load. The hourly noted load shown in Table 3 is calculated for a residential area. In this paper, the study is done only for a single household. So, accordingly, the calculation needs to be adjusted. The Table 3 has been modified and shown below in Table 4.

Table 3. Price and hourly noted load for each hour of the day for a residential area

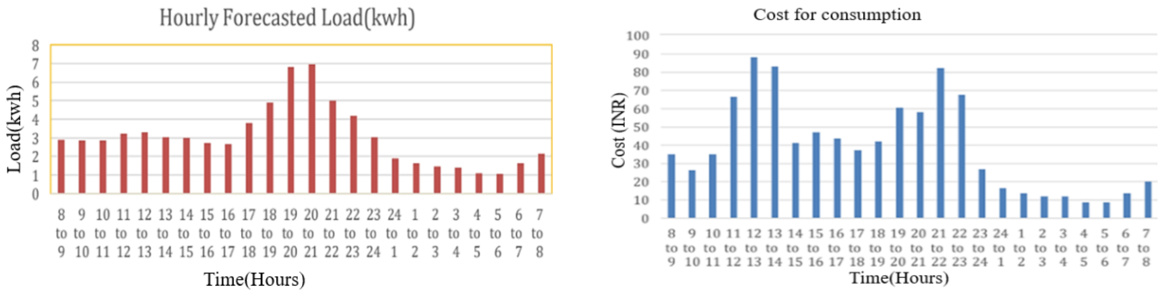
Time (Hours)	Price	Hourly noted load (kWh)
8-9	12	729.4
9-10	9.19	713.5
11-12	20.61	808.2
15-16	17.31	68.18
18-19	8.63	1220.9
20-21	8.35	1363.6
22-23	16.19	1046.6
24-1	8.69	475.1
1-2	8.13	412.8
5-6	8.13	269.6
7-8	9.35	539.1

The hourly forecast data in Table 3 was initially computed for a residential area, encompassing various households. However, this study focuses solely on a single household, necessitating adjustments in the calculations. Table 4 presents the modified hourly noted load specifically for this household across different time intervals.

Table 4. Hourly noted load for a single house during each hour of the day

Time (Hour)	Hourly noted load (kWh)
8-9	2.91
11-12	3.23
14-15	2.98
16-17	2.66
19-20	5.32
20-21	5.45
23-24	3.04
24-1	1.9
3-4	1.39
5-6	1.07
7-8	2.15

Figure 2 illustrates the variations in electrical load throughout the day. Figure 2(a) demonstrates the variation in electrical load measured in kilowatt-hours (kWh) throughout the day, recorded hourly. The graph indicates that the load peaks at 7 kWh between 5-6 PM, which is significantly higher compared to other times of the day. The lowest recorded load is at 1 kWh during 8-9 AM. The graph shows a noticeable decrease in load after 6 PM, with some fluctuations occurring in the subsequent hours. Figure 2(b) demonstrates that during Case 1 at 12 PM, consumption costs peak at around 120 units, indicating a significant increase compared to other times of the day. The x-axis depicts time in two-hour intervals from 8 AM to 7 AM the following day, while the y-axis shows consumption cost. This peak at 12 PM represents one of the highest costs observed on the graph. This increase is further explained by the data in Table 5, where the water pump is switched on at 12 PM. This figure highlights the impact of specific appliance usage on overall consumption costs, emphasizing the importance of understanding and managing peak usage times to optimize expenses.



(a) (b)

Figure 2. Electrical cost and load throughout the day (a) load throughout the day in one-hour intervals and (b) cost of consumption for Case 1: 12 PM

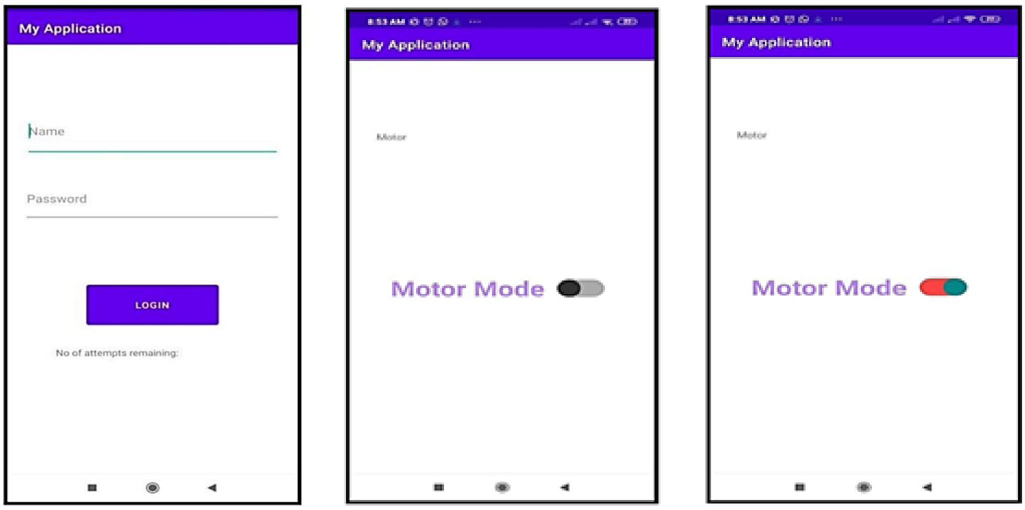
3.2. Android app studio

The official IDE for developing Android apps, Android studio is centered around IntelliJ IDEA. Java is the programming language used to create apps. With the help of Android studio's apply change tool, you may update code and resources in your running application without having to restart it or, in some situations, the current activity. This flexibility allows you to maintain the current state of your device while deploying and testing minor, incremental updates. It also helps you regulate how much of the app is resumed.

3.2.1 Creation of Android app

To create an app, create a new project and then choose a blank activity. The first page of the app is coded in the MainActivity.java file. This page will allow the user to log in successfully by providing the correct details. Subsequently, the other pages are created and linked to the Raspberry Pi. Following are the screenshots from the android phone of the app. The first one is the login page while the second and third are the next page when motor is switched on and off respectively.

Figure 3 illustrates the Android app interface for the motor control and login page. Figure 3(a) demonstrates the login page of the app where the user has to provide the username and password. In case the user provides incorrect login details, the app restricts the user to three attempts maximum. After that, the login button gets disabled. Hence, it ensures user authorization. After every attempt, the user can view the number of attempts left to try. Figures 3(b) and 3(c) demonstrate the user interface that facilitates the control of the motor's operation based on recommendations. Users are presented with options to either activate or deactivate the motor according to the system's suggestion. The consumption of a water pump is taken to be 1.5 kW for one hour. The calculation is done for two cases where the motor is switched on at two different timings, and the difference in the prices is calculated.



(a) (b) (c)

Figure 3. Android app interface for motor control and login (a) login page, (b) motor OFF, and (c) motor ON

Case 1: The water pump is switched on at 12 PM

Table 5 illustrates the calculation of consumption costs when the motor is activated at 12 PM. It factors in various parameters such as time, hourly noted load, cost per hour. This comprehensive analysis provides insights into the financial implications of operating the motor during this specific time.

Table 5. Calculation of cost of consumption when motor is switched ON at 12 PM

Time (Hours)	Hourly noted load (kWh)	Cost per hour	Cost for consumption
8-9	2.91	12	34.92
9-10	2.85	9.19	26.19
13-14	4.54	27.35	124.169
14-15	2.98	13.81	41.153
17-18	3.8	9.83	37.354
18-19	4.88	8.63	42.114
22-23	4.18	16.19	67.674
23-24	3.04	8.87	26.964
24-1	1.9	8.69	16.577
1-2	1.65	8.13	13.414
2-3	1.45	8.25	11.962
6-7	1.64	8.34	13.677
7-8	2.15	9.35	20.102
		TOTAL=	1001.207

Case 2: Water pump is switched on at 7 PM

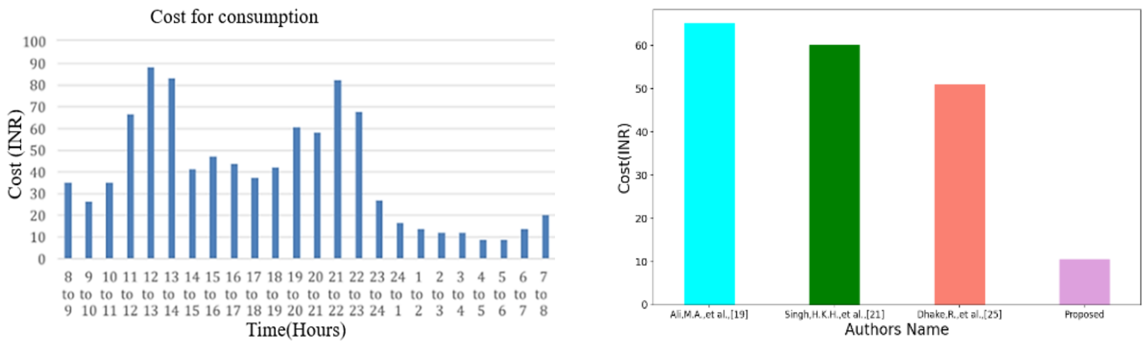
The computation of consumption costs when the motor is turned on at 7 PM is shown in Table 6. It takes into account several variables, including time, hourly noted load and hourly expense. Based on the bar graph in Figure 4, for Case 2 at 7 PM, the cost of consumption is around 70 units. There’s a noticeable decrease in costs during the early morning (1 AM to 6 AM) and late evening (after 7 PM). The cost varying throughout the day, with the highest costs occurring between 3 PM to 4 PM and 8 PM to 9 PM, reaching close to or just above 80. Figure 4 demonstrates the cost comparison of consumption with existing approaches. Figure 4(a) demonstrates that in this case, the water pump is switched on at 7 PM, and the water pump is switched on at 7 PM. Hence, 1.5 kW is added to the time slot at 7 PM. The total the user has to pay then comes out to be Rs.945.78. The percentage change can be calculated as:

$$(1001.20 - 945.78)/945.78 * 100 = 5.85\ \%$$

It is shown that when only the water pump is scheduled to a timing, the cost reduction is almost as much as 6%. Figure 4(b) illustrates a comprehensive cost comparison between existing Ali *et al.* [19], Singh *et al.* [21], Dhake *et al.* [25] methods and the proposed WARM-IoT. The analysis considers factors such as initial setup and maintenance expenses. The proposed WARM-IoT cost is decreased by 16.5%, 17.5% and 20.63% to the existing Ali *et al.* [19], Singh *et al.* [21], Dhake *et al.* [25] method respectively.

Table 6. Calculation of cost of consumption when a motor is switched on at 7 PM

Time (Hours)	Hourly noted load (kWh)	Cost per hour	Cost for consumption
8-9	2.91	12	34.92
9-10	2.85	9.19	26.19
10-11	2.85	12.23	34.855
11-12	3.23	20.61	66.570
14-15	2.98	13.81	41.153
16-17	2.66	16.42	43.677
17-18	3.8	9.83	37.354
19-20	6.82	8.87	60.493
20-21	6.95	8.35	58.032
23-24	3.04	8.87	26.964
24-1	1.9	8.69	16.577
1-2	1.65	8.13	13.414
2-3	1.45	8.25	11.962
6-7	1.64	8.34	13.677
7-8	2.15	9.35	20.102
		TOTAL =	945.782



(a) (b)

Figure 4. Cost comparison of consumption for different scenarios (a) cost of consumption for Case 2: 7 PM and (b) comparison in terms of cost

3.3. Discussion

The implementation of the WARM-IoT system demonstrates significant advancements in managing water resources and optimizing electricity consumption. The system's performance was assessed based on various scenarios, indicating that activating the water pump during off-peak hours significantly reduces electricity costs, with a reduction of approximately 6% when activated at 7 PM, as demonstrated in Figure 2(b). This optimization avoids peak electricity price periods, presenting tangible economic benefits for both residential and commercial applications. The cost analysis reveals that electricity costs vary throughout the day, with the highest costs between 3 PM to 4 PM and 8 PM to 9 PM, and scheduling pump activation during lower-cost periods minimizes overall expenditure, as shown in Figure 4(a).

The development of an Android app for remote monitoring and control adds convenience, allowing users to receive real-time alerts, monitor water levels, and control pump operation remotely, ensuring continuous and efficient operation, as illustrated in Figure 3. In conclusion, the WARM-IoT system successfully integrates IoT and fuzzy logic for efficient water and energy management, offering significant cost savings, environmental benefits, and a user-friendly interface, making it a valuable solution for modern water resource management challenges.

4. CONCLUSION

In this paper, a novel WARM-IoT framework has been proposed to monitor the water level and control it remotely and also give an alert message to switch on the water pump to reduce the electricity tariff that needs to be paid. By integrating IoT and DSM strategies, this research proposes a comprehensive solution to address water wastage and inefficient electricity usage in water management systems. Additionally, the development of an Android app provides users with a user-friendly interface for remote monitoring and control of the water management system. The practical implementation of the WARM-IoT demonstrates its effectiveness in controlling water levels and reducing electricity costs. By analyzing consumption costs under different activation timings, the system showcases significant potential for cost savings, with a notable reduction of up to 6% in electricity expenses. Future work can focus on further improving the system's capabilities by integrating additional sensors for comprehensive monitoring and refining the fuzzy logic algorithms for improved decision-making.

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