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Enhancing Model of IoT Based on Smart Water Meter and Billing System a Case Study of Busasamana Sector

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Abstract: This dissertation focuses on developing an IoT-based smart water metering and billing system designed for Rwanda, with a case study in the Busasamana Sector. The goal of this system is to improve water usage monitoring, automate billing, and enhance overall management efficiency. The system integrates several IoT technologies to ensure accurate water measurement and billing. It consists of a NodeMCU microcontroller, which processes data from a water flow sensor that measures the exact amount of water consumed. The data is then stored in a MySQL database, which calculates billing amounts based on consumption.

One of the key advantages of this system is its ability to automate the billing process, eliminating delays and ensuring that charges are accurate. This prevents inflated bills and aligns with the WASAC (Water and Sanitation Corporation) billing regulations. With real-time monitoring, users can track their water usage, making the billing system more transparent and efficient. To enhance security and accountability, the system can detect unauthorized water consumption. If the system identifies illegal usage, it notifies the relevant authorities, helping to minimize water theft. Additionally, the system includes a relay and solenoid valve that automatically cuts off the water supply if a payment delay exceeds five days.

The system is designed to be energy-efficient. A solar-powered power bank ensures that it operates continuously, even in areas with unstable electricity. An LCD screen is included to display real-time water usage, while a manual button switch allows users to fetch water when necessary, providing flexibility in case of emergencies. Furthermore, a keypad is integrated as an input device, allowing users to specify the exact level of water they need to fetch, enhancing user control and preventing wastage.

To keep users informed, the system sends monthly SMS notifications detailing the amount of water consumed and the corresponding bill. A PHP-based website has also been developed to allow users to check their water usage, view their billing history, and make payments online. By leveraging IoT and renewable energy, this smart water management system aims to improve billing accuracy, reduce operational costs, and promote sustainable water resource management in the Busasamana Sector and beyond.

Keywords: *IoT-based smart Water Meter, Billing System, Water Management, WASAC, Real-Time Data, Automated Billing, Water Flow Sensor, Keypad Input.*

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I. INTRODUCTION

Access to clean, well-managed water is essential for sustainable development, yet many regions in Rwanda, particularly rural sectors like Busasamana, continue to face challenges in water distribution, usage monitoring, and billing. The current manual systems used by the Water and Sanitation Corporation (WASAC) often lead to billing inaccuracies, delayed payments, and unauthorized consumption, resulting in operational inefficiencies and public dissatisfaction.

This study focuses on the development and implementation of an **IoT-based smart water metering and billing system** aimed at improving transparency, accuracy, and sustainability in water management. By leveraging affordable microcontroller technology, real-time monitoring, automated billing, and renewable energy solutions, the proposed system addresses critical issues in water usage tracking, revenue collection, and service delivery.

The chapter outlines the background and rationale behind the study, presents the specific problems it aims to

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solve, and defines the objectives and research questions guiding the investigation. It also highlights the significance of this research for local communities, policymakers, utility providers, and the broader academic community. By providing a clear structure of the study's scope—both geographically and thematically—this chapter lays the foundation for understanding how IoT innovation can support efficient and equitable water management in rural Rwanda and beyond.

➢ *Problem Statement*

Rwanda's water billing system, managed by the Water and Sanitation Corporation (WASAC), faces significant challenges due to its reliance on manual meter readings. This traditional approach often results in billing errors, delays, and disputes between consumers and service providers. Many users receive incorrect bills, leading to frustration and a lack of trust in the billing process.

Additionally, inefficient monitoring has led to widespread unauthorized water usage, contributing to revenue losses. Consumers may use water without proper metering, making it difficult for WASAC to track and bill accurately. Late payments are another major issue, as the absence of an automated enforcement system allows some users to delay payments without immediate consequences. These challenges are particularly severe in rural areas like Busasamana Sector, where limited infrastructure and logistical constraints further complicate meter readings and revenue collection. The lack of real-time monitoring makes it difficult to detect leaks, illegal connections, and excessive consumption in a timely manner.

As a result, WASAC experiences financial losses and operational inefficiencies, affecting its ability to maintain and expand water services. Addressing these issues requires a modern, automated system that ensures accurate billing, prevents unauthorized usage, and enhances revenue collection while providing consumers with a more transparent and efficient water management system.

II. LITERATURE REVIEW

This literature review examines key technologies and previous research related to IoT-based smart water metering and billing systems, with a particular focus on their relevance to the Rwandan context. Several concepts and tools are foundational to the development and implementation of such systems, including smart water metering, the Internet of Things (IoT), automated billing, and related hardware components such as microcontrollers and solenoid valves.

Smart water metering is defined as the use of Advanced Metering Infrastructure (AMI) to measure and monitor water usage in real time. These systems transmit data automatically to centralized servers, enabling remote access and improved billing accuracy. Compared to traditional meters, smart meters provide a more transparent and efficient approach to water resource management, offering enhanced features such as leak detection, demand forecasting, and reduced water theft (Serrano, 2018).

The Internet of Things (IoT) plays a central role in enabling communication between metering devices and back-end systems. By embedding sensors and connectivity into physical devices, IoT facilitates real-time monitoring, data analysis, and automated system control. This technology improves operational scalability and allows water utility systems to respond dynamically to changing usage patterns (Kim et al., 2019). When combined with IoT, billing systems can automatically calculate charges based on consumption data, reducing human error and improving overall service delivery. These systems often integrate with online payment platforms, giving customers flexible options to pay bills and track usage (Muriuki, 2020).

Automation features such as water cutoff mechanisms enhance revenue collection and enforce timely payments. By using IoT-connected solenoid valves, utilities can remotely suspend water supply when a bill remains unpaid after a specified grace period. This approach not only prevents revenue loss but also ensures fairness and accountability in water usage (Niyonzima, 2021). Furthermore, the inclusion of SMS gateways in smart systems provides a channel for direct communication with consumers. These gateways send real-time updates, billing reminders, and usage alerts, which increase user awareness and reduce missed payments (Mugisha, 2022).

MySQL, a robust relational database management system, is widely used for storing consumption records, customer information, and billing data. It ensures reliable data storage and quick retrieval, both of which are critical for accurate billing and reporting (Kim H. P., 2019). The database can be queried in real time to track individual usage trends, generate alerts, and produce comprehensive usage reports for both administrators and consumers.

At the hardware level, the NodeMCU (ESP8266) microcontroller is frequently used in IoT-based smart water systems due to its low cost, built-in Wi-Fi capability, and compatibility with digital sensors. It collects data from water flow sensors and transmits it to cloud servers for analysis (Zafar, 2021). Relays and solenoid valves serve as control devices, enabling or disabling water flow based on system commands. These components automate enforcement actions such as cutting off supply when payments are overdue or resuming service after a bill is settled (Kani, 2018; Ahmad, 2023). LCD screens are also utilized to display real-time data to consumers directly at the meter, reducing dependency on mobile or web platforms and promoting informed usage behavior (Khan S. Z., 2019).

Empirical studies from global, regional, and local contexts provide insight into how these technologies are applied and adapted. In developed countries like the UK and US, smart water metering has significantly reduced water consumption and improved billing accuracy. For example, a study by Gupta (2019) in the UK reported a 15% reduction in water usage and improved dispute resolution due to smart meter deployment. The integration of SMS alerts and mobile platforms also helped enhance consumer engagement and timely payments.

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In Africa, the Nairobi City Water and Sewerage Company (NCWSC) has adopted smart metering to combat water theft and improve revenue collection. Otieno (2018) found that the system provided accurate billing, reduced operational costs, and offered real-time monitoring despite infrastructural challenges. However, the rollout faced limitations due to inconsistent electricity supply and limited public awareness.

Locally, Rwanda's Water and Sanitation Corporation (WASAC) has piloted smart metering systems in urban areas like Kigali. According to Nshimiyimana (2020), these systems automated meter readings, reduced billing errors, and improved customer service. Although these initiatives have proven effective, many rural areas remain underserved, particularly in regions like Busasamana, where manual systems are still prevalent.

A comparative analysis of international and local implementations reveals differing priorities and approaches. While developed nations focus on user interaction and long-term sustainability, developing regions prioritize system automation and revenue protection. In Rwanda, the emphasis remains on enhancing operational efficiency and establishing basic infrastructure for real-time data collection and automated billing. These insights suggest that while the goals of smart metering systems—such as improving billing accuracy, reducing water losses, and enhancing customer satisfaction—are globally shared, their design and implementation must be tailored to suit the socio-economic and infrastructural context of each region (Mukhtar, 2021).

This study contributes to the existing body of knowledge by proposing a context-specific solution that integrates affordable hardware, renewable energy, and digital communication to address the unique challenges faced in the Busasamana Sector. By building on proven technologies and adapting them to local conditions, the system aims to provide a scalable and sustainable model for improving water management and billing efficiency in rural Rwanda.

➢ *Existing System*

The process for creating and distributing water usage bills under a system run by WASAC (Water and Sanitation Corporation) is shown in the diagram. A water meter placed at the user's location measures their water usage, starting the process. The water meter must be read by a billing agent, either by hand or by an automated system. A bill generation system receives this consumption data and uses the meter reading and applicable rates to determine the user's charges. The generated bill is then entered into the WASAC database server and updated in the user's account.

The user is given a billing paper, either in print or electronic format, that lists the amount owed. In addition to updating the user's account records and guaranteeing accurate billing, this workflow makes it easier to track water usage and payments.

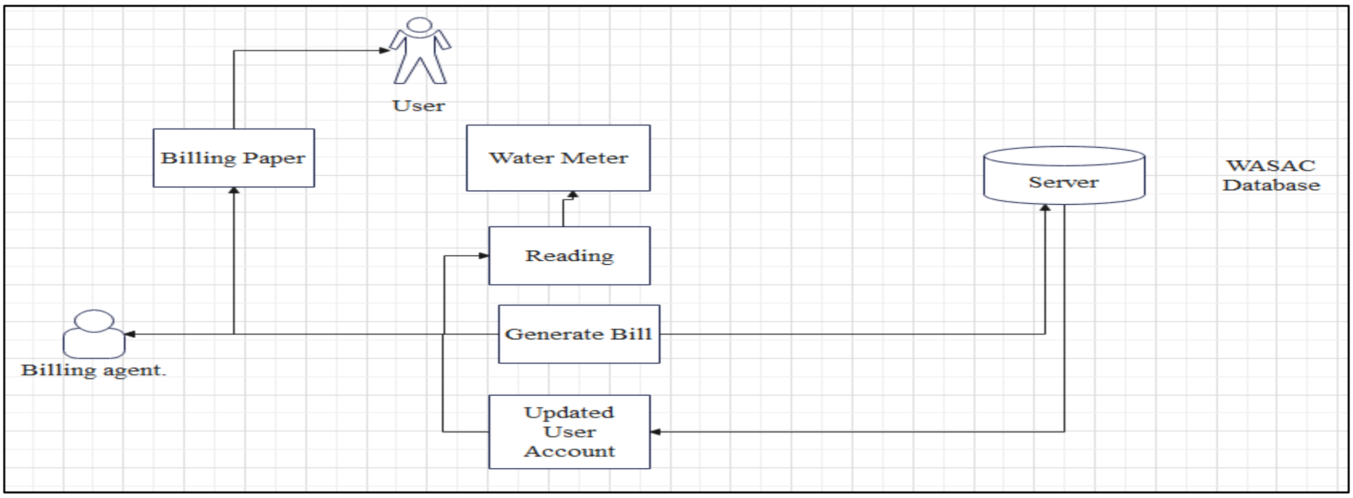

Fig 1 Existing System

➢ *Proposed Project*

The proposed Smart Meter System comprises of hardware component called the Electronic Interface Module (EIM) that resides in conjunction with the basic water-meter. The EIM is designed around a low-cost CPU board with features such as interface for meter-register and tamper-switch, Real-Time Clock and Flash memory for date-time stamped Data log, Ethernet Stack and port for interface to TCP/IP network or Wi-Fi or GSM/3G/4G Router, built-in battery and charging adaptor.

The prototype Smart Water meter constructed, is a regular water-meter but with magnet-reed switch pick-off and embedded tiny magnet on a wheel which together generates pulses corresponding to rotation of the wheel.

Fig 2 Smart-Meter Prototype with External

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The suggested system for a solar-powered smart water metering and billing system is shown in this block diagram. The system ensures sustainability and energy efficiency by using a solar PV panel that is connected to a 12V power source and a charger controller. The central processing unit of the system is a microcontroller, which regulates essential parts like a switching push button, a solenoid valve, and a water flow sensor. The solenoid valve controls the water supply in response to user inputs and payments, while the water flow sensor measures water usage. Users can access real-time water consumption and billing information via a connected LCD display.

III. CONCEPTUAL FRAMEWORK

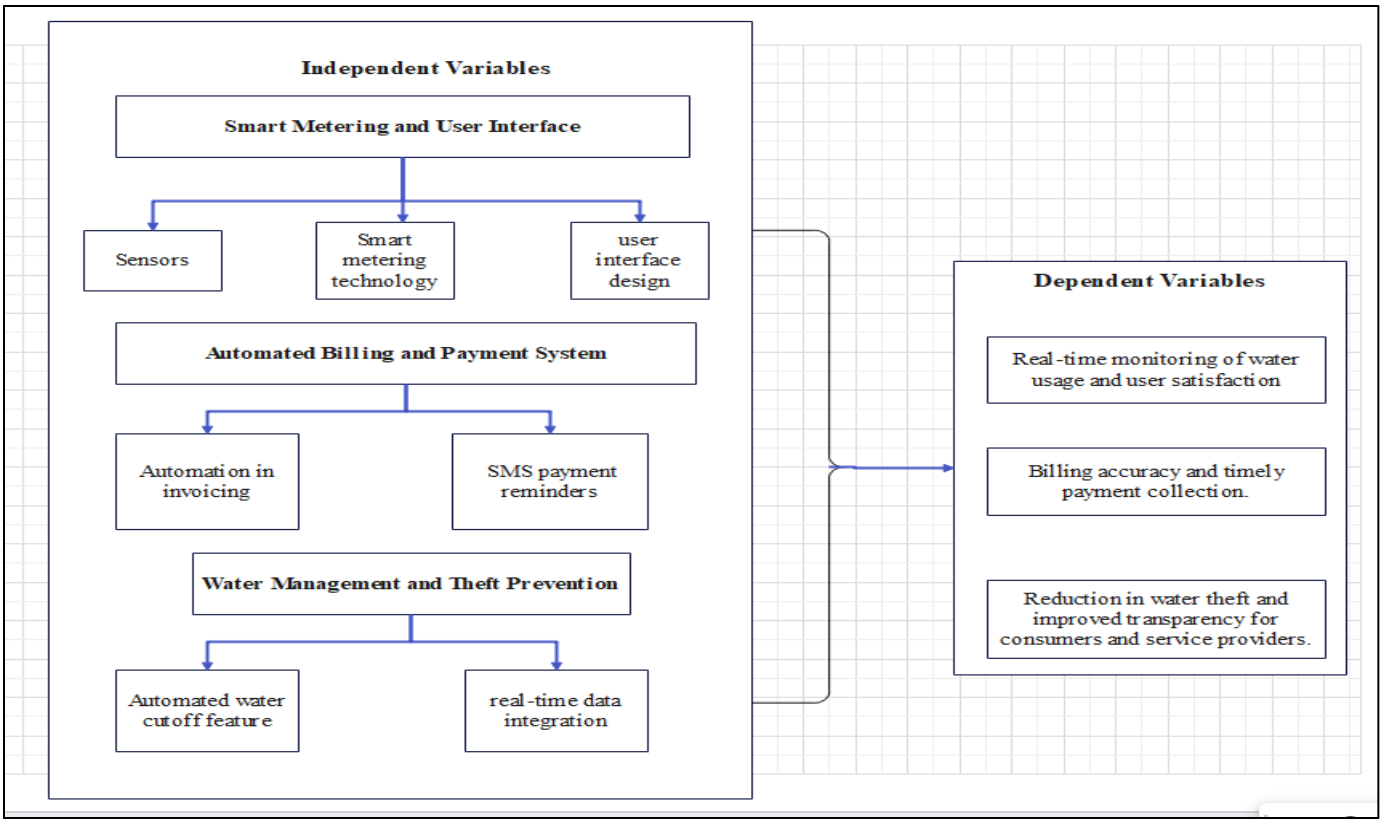

Fig 3 Conceptual Framework

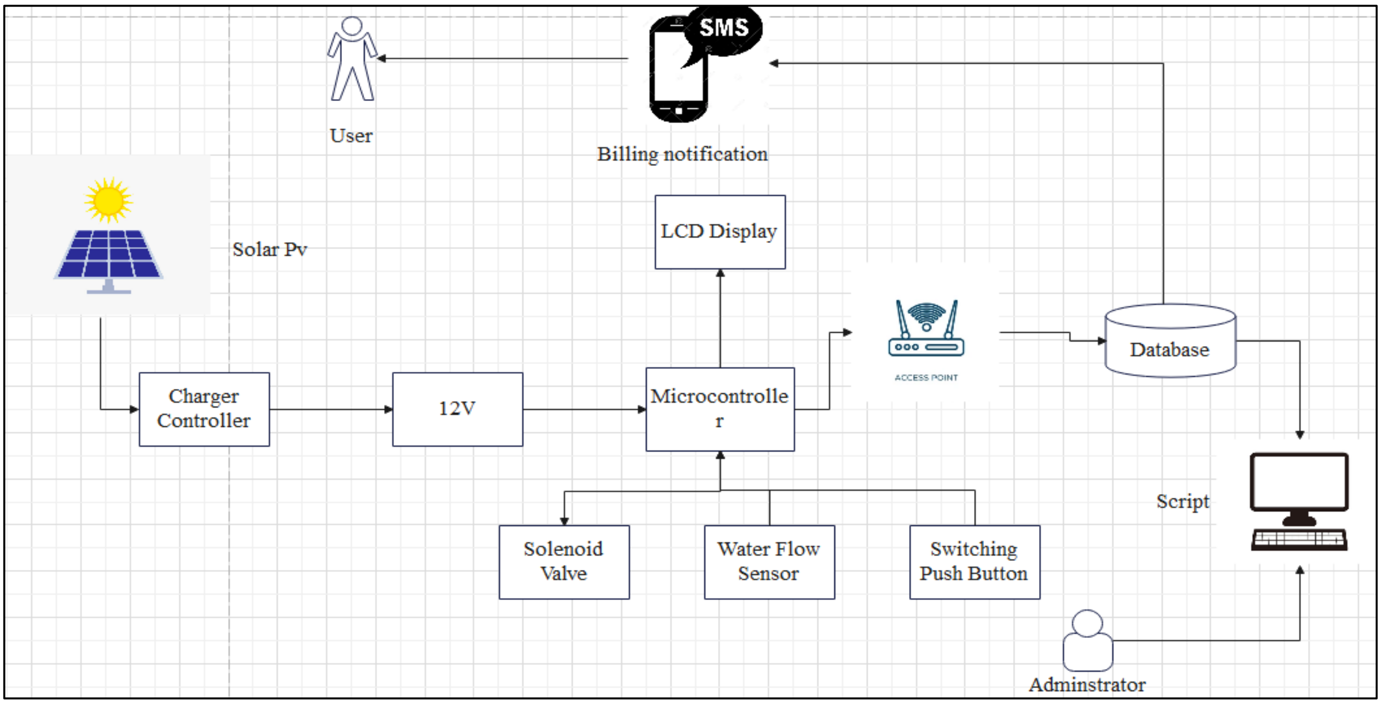

Fig 4 Proposed System

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Additionally, the system includes an SMS billing notification feature to inform users of their water usage and payments. Data storage and retrieval are made possible by the microcontroller's connection to a database via an access point. Through computer scripts, the database communicates with administrators who can remotely control the system. Through automated cutoff mechanisms, this prevents theft and non-payment while guaranteeing transparency in water usage and billing. Utilizing solar energy and real-time monitoring for efficiency, the design is scalable and appropriate for locations with limited grid power.

IV. RESEARCH METHODOLOGY

➢ *Research Design*

The study employed a mixed-methods research design, integrating both quantitative and qualitative approaches. Quantitative data was gathered on aspects such as water consumption, billing trends, and payment behaviors. In contrast, qualitative data from surveys and interviews provided insights into user perceptions, system usability, and implementation challenges. This dual-method approach ensured a comprehensive analysis that combined measurable outcomes with human perspectives, aligning with the research objectives of enhancing billing accuracy, reducing theft, and improving water management efficiency.

➢ *Study Population*

The research targeted water users and administrators in the Busasamana sector of Rwanda. The consumer population included households, small businesses, and commercial establishments, all of which regularly use water services. On the administrative side, participants included WASAC employees, responsible for billing and maintenance, and technical personnel involved in the installation and upkeep of smart water meters. The selected population size ranged between 100 and 150 respondents to ensure comprehensive data collection across diverse user categories.

➢ *Sampling*

A stratified random sampling technique was applied to ensure fair representation across different consumer groups. Yamane's formula was used to determine the sample size, based on a total population of 2,000 and a 5% margin of error, resulting in a final sample of 333 respondents.

Table 1 The Sample Distribution Included

Category	Total Population	Sample Size
Households	1,192	198
Small Businesses	500	83
Commercial Establishments	300	50
Water Utility Staff	8	2
Total	2,000	333

➢ *Data Collection Methods and Instruments*

The study utilized surveys, interviews, and document reviews to collect both primary and secondary data. Structured questionnaires were used with consumers to collect quantitative data on consumption patterns and billing behavior. Interviews were conducted with WASAC staff and technical experts to understand system implementation challenges and user feedback. Additionally, document reviews of usage logs and billing reports provided context and historical data. Instruments were pre-tested to ensure reliability and validity.

- *Data Processing*

Post-collection, data was processed using Excel and SPSS. Quantitative responses were coded, entered into structured databases, and cleaned for errors or missing values. Qualitative interview data was transcribed and thematically coded, allowing researchers to identify recurring patterns and insights. This methodical approach ensured accuracy, consistency, and readiness for analysis.

- *Data Analysis*

The analysis involved both descriptive and inferential statistics. Descriptive tools like mean, standard deviation, and frequency distributions were used to summarize trends in usage, billing, and payment. Inferential methods, including regression analysis and chi-square tests, explored relationships between variables—such as the link between smart metering and billing accuracy. Qualitative data was analyzed using thematic analysis, uncovering user experiences, challenges, and satisfaction levels. This combination of statistical and thematic approaches provided a holistic interpretation of findings.

- *Limitations*

The study acknowledged several limitations. First, its focus on the Busasamana sector limits the generalizability of findings to other regions. Second, data accuracy might be affected by respondent sensitivity to topics like water theft. Third, technical constraints, such as poor connectivity or sensor inaccuracies, could influence implementation outcomes. Lastly, resource limitations might restrict the scalability and broader application of the smart meter system across Rwanda.

- *Ethical Considerations*

Strict ethical standards guided the research. Informed consent was obtained, and participants were made aware of their rights and the study's purpose. Confidentiality and data protection were ensured, with all personal information securely stored and anonymized. The study was conducted in alignment with local laws and cultural norms, ensuring respect and ethical compliance throughout. Academic integrity was maintained by presenting honest and accurate findings, free from data fabrication or manipulation.

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V. PRESENTATION AND ANALYSIS OF RESEARCH FINDINGS

This chapter presents the findings of the study based on the research objectives outlined in Chapter One. The study aimed to design, develop, and implement an IoT-based smart water metering and billing system that enhances real-time monitoring, improves billing accuracy, and prevents unauthorized water usage. The analysis focuses on the system's functionality, performance, and impact on water management in Busasamana Sector. The findings are structured as follows:

- Design of the smart water metering and billing system with a user interface.
- Development of water billing accuracy and payment collection automation.
- Implementation of a water management system that prevents theft.

- *Design of the Smart Water Metering and Billing System*

- *System design*

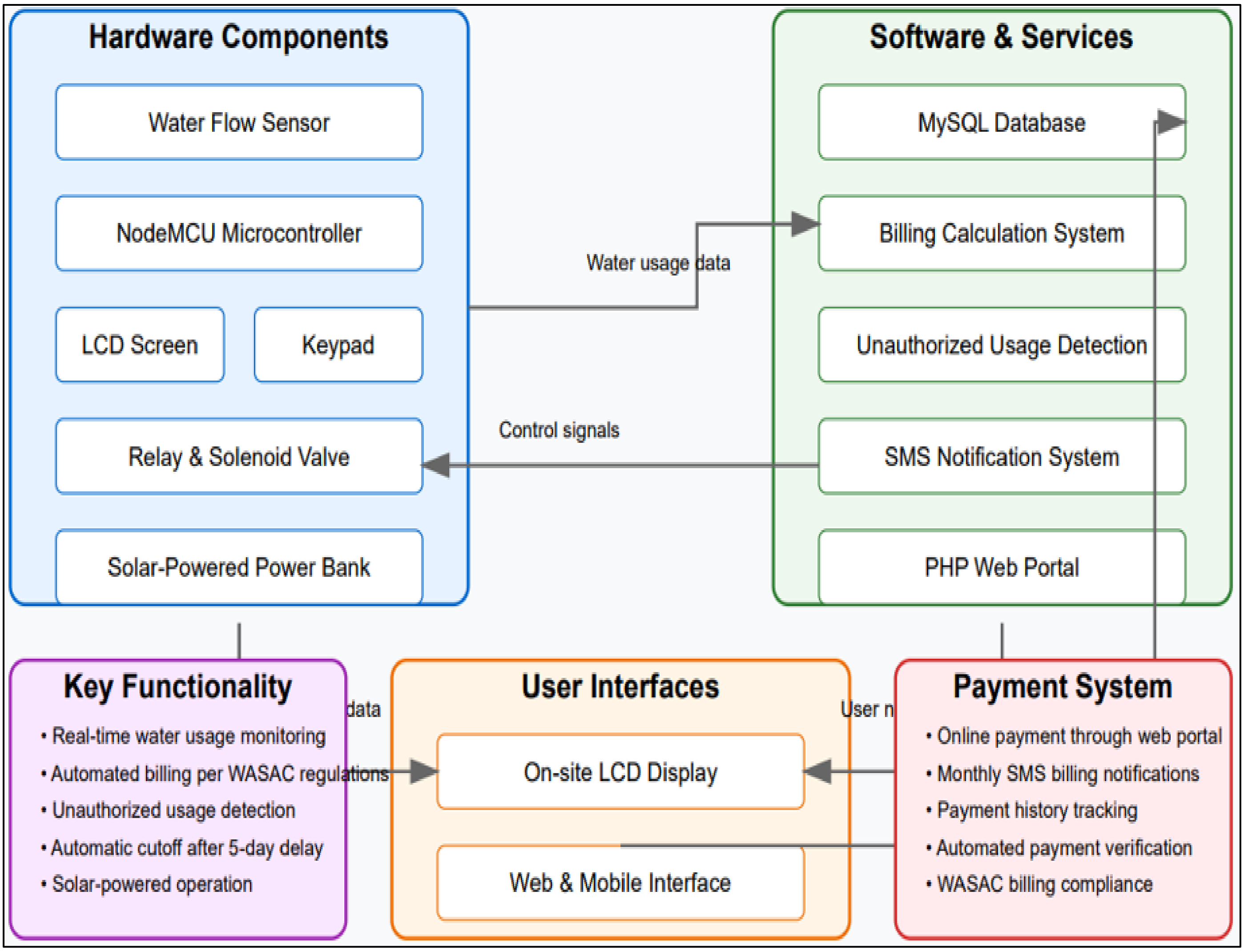

Fig 5 System Architecture

This architecture represents an IoT-based smart water metering and billing system that integrates hardware components, software services, user interfaces, and a payment system for efficient water management. The hardware includes a water flow sensor for real-time consumption monitoring, a NodeMCU microcontroller for processing, an LCD screen for display, a keypad for user input, and a relay & solenoid valve for water flow control, all powered by a solar-powered power bank. Software services include a MySQL database for data storage, a billing calculation system, an unauthorized usage detection module, an SMS notification system for alerts, and a PHP-based web portal for user access. Key functionalities include automated billing as per WASAC regulations, real-time monitoring, unauthorized usage detection, and automatic water cutoff after a 5-day payment delay. Users interact via an on-site LCD display and a web & mobile interface for remote access. The payment system enables online payments, automated billing notifications, payment history tracking, and compliance with WASAC billing standards. This system enhances water management through automation, security, and remote accessibility while ensuring transparency and efficiency in usage and billing.

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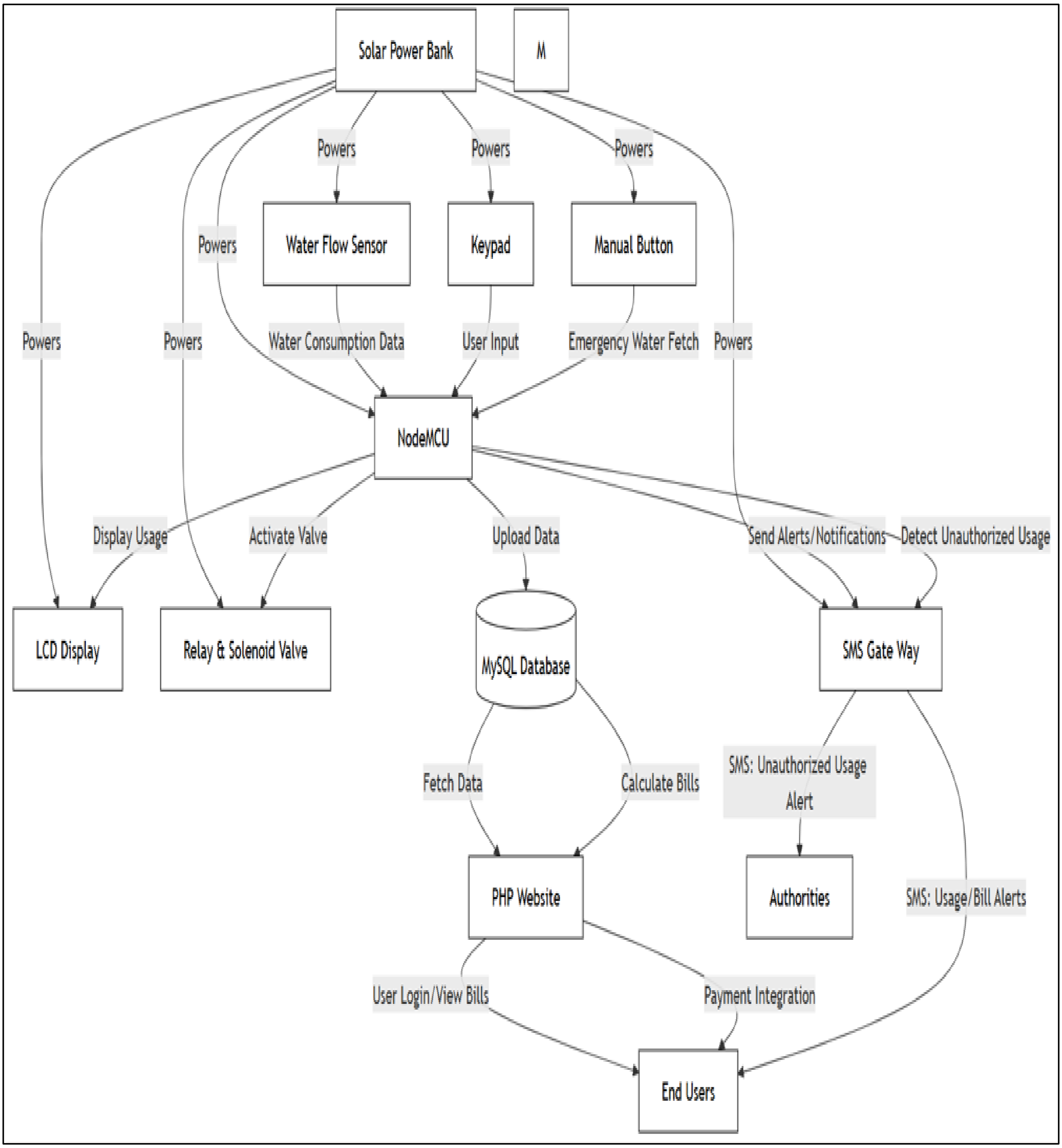

Fig 6 Block Diagram

The block diagram illustrates the smart water metering and billing system. A solar power bank supplies energy to all components, including the NodeMCU, which serves as the central controller. The water flow sensor measures water consumption, while the keypad allows users to input the required amount of water, and a manual button enables emergency water fetching. The NodeMCU processes this data, displaying real-time consumption on an LCD screen and controlling the relay and solenoid valve to manage water flow. The MySQL database stores consumption data and calculates billing amounts, which are accessible via a PHP-based website, enabling users to view bills and make payments. The GSM module sends SMS notifications about billing and unauthorized usage, alerting both end users and authorities. This system enhances transparency, prevents water theft, and automates billing for efficient water management.

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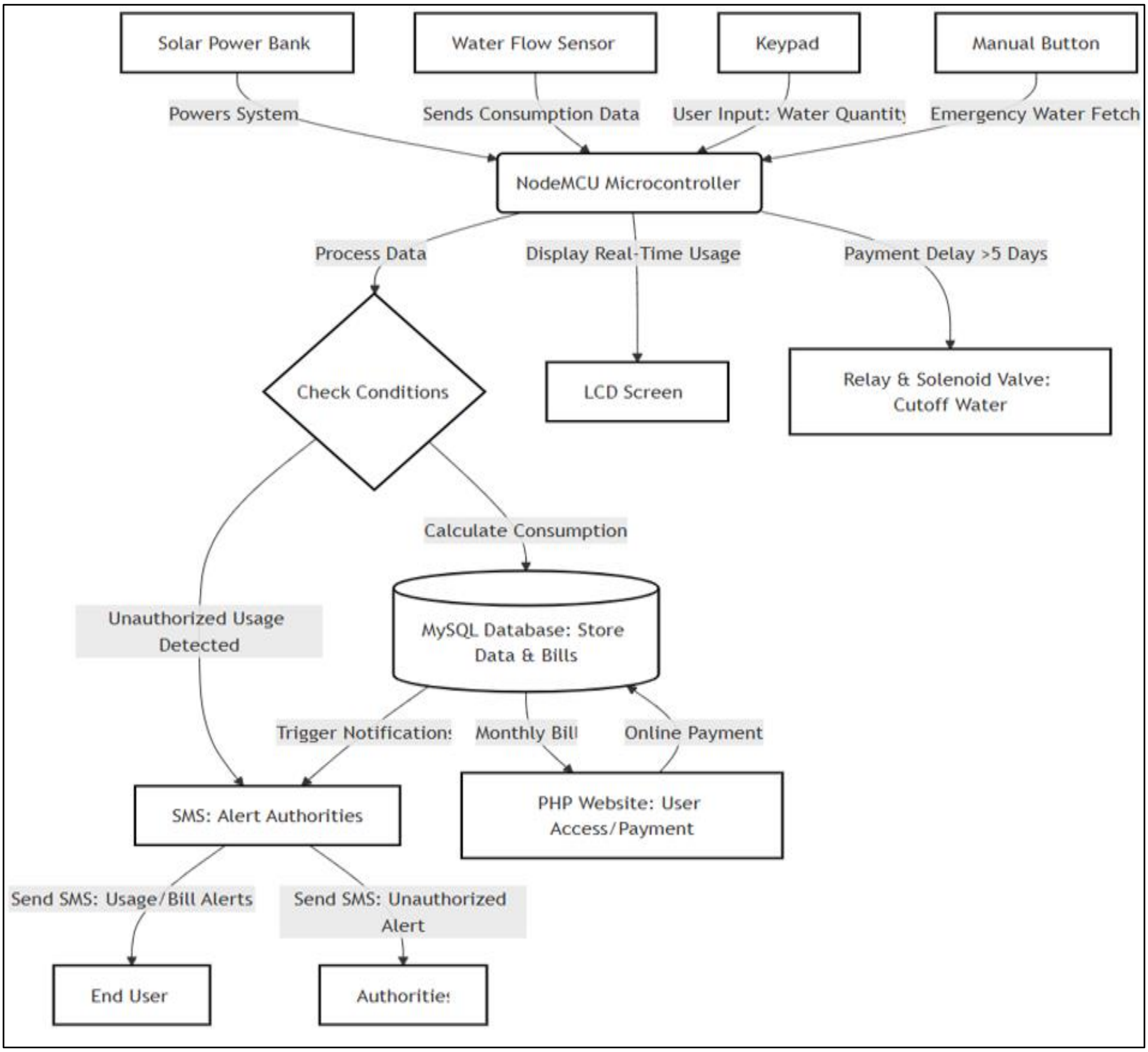

Fig 7 Flowchart of the System

This flowchart represents system that monitors consumption, detects unauthorized usage, and automates billing and control. The NodeMCU microcontroller receives data from a water flow sensor, keypad, and manual button to process water usage inputs. If unauthorized usage is detected, the system sends an SMS alert to authorities. Consumption data is stored in a MySQL database, generating monthly bills accessible via a PHP web portal, where users can make online payments. The system also sends SMS notifications for bills and unauthorized usage. If a payment delay exceeds five days, the relay and solenoid valve cut off the water supply. Additionally, an LCD screen provides real-time consumption updates.

➢ *System Components and Setup*

The Smart Water Metering and Billing System was developed using various components to ensure efficient water monitoring and automated billing.

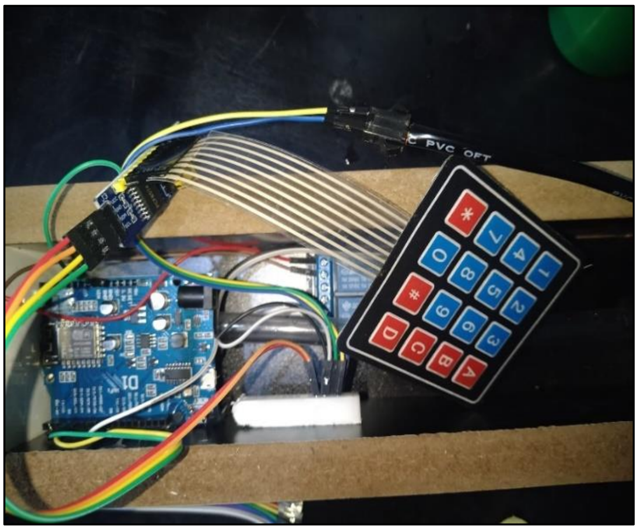
Fig 8 Component Connection

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The NodeMCU Microcontroller plays a central role in processing sensor data and managing system operations. It collects real-time data from the Water Flow Sensor, which accurately measures the amount of water consumed. This data is then displayed on an LCD Display (LiquidCrystal_I2C), allowing users to monitor their water usage and billing details.

Fig 9 Initializing Network

To enable user interaction, an I2C Keypad is incorporated into the system. This allows users to input the amount of water they intend to fetch. Additionally, EEPROM Storage is used to store total water consumption data, ensuring that records are maintained even in the event of power loss.

For system automation and user notifications, a Buzzer and Relay System is included. The buzzer alerts users in case of unusual water usage or low balance, while the relay system automates the cut-off of the water supply when necessary.

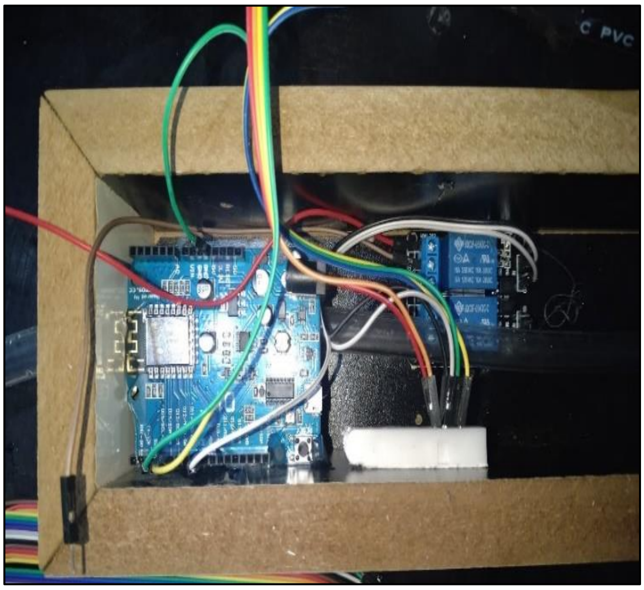


Fig 10 Relay Connection

To enhance accessibility, a PHP-based Web Interface is integrated into the system. This interface enables remote monitoring of water usage and facilitates payment processing, allowing users to conveniently manage their water consumption and billing from anywhere.

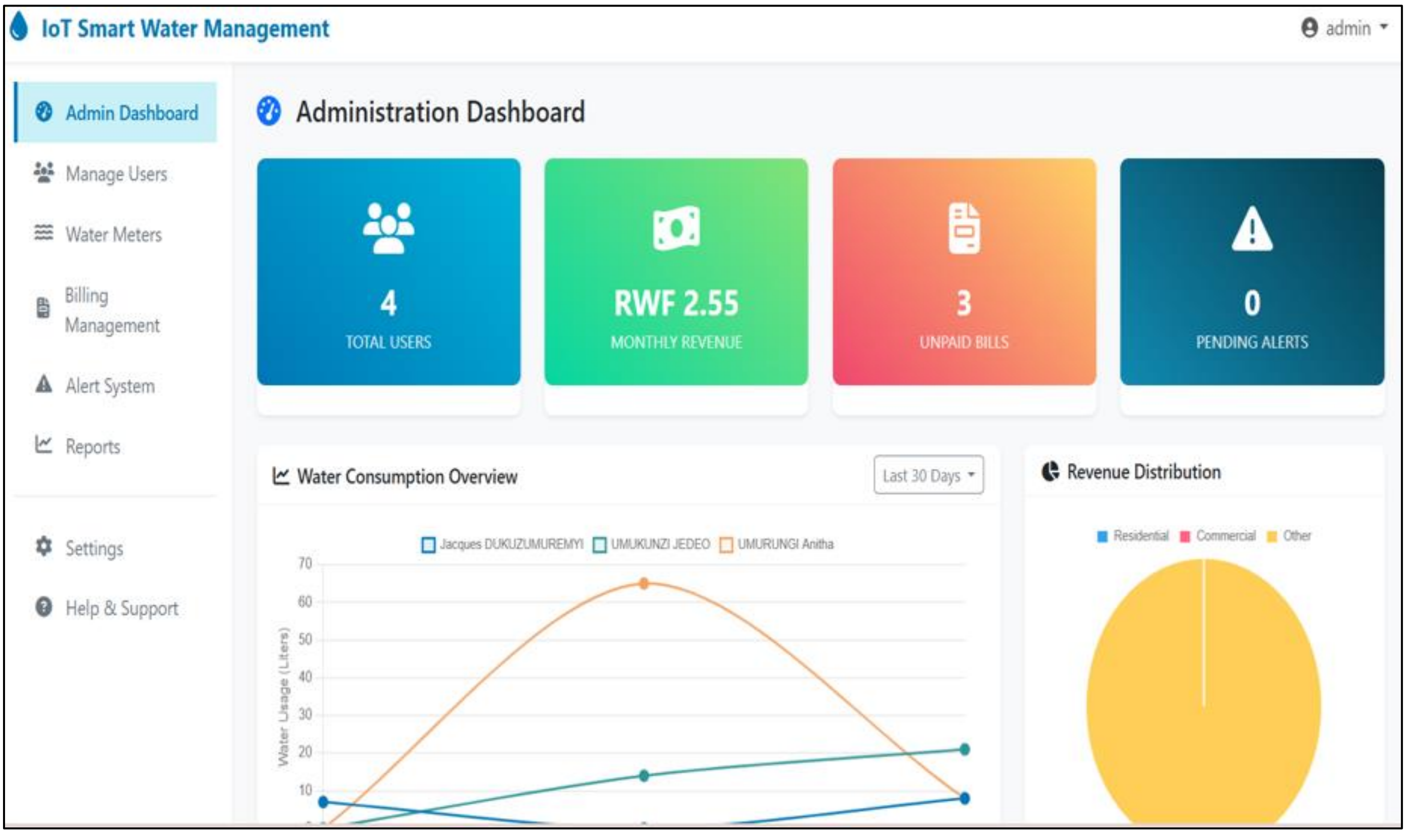


Fig 11 Home Page

➢ *System Functionality and Performance*

The system was thoroughly tested to evaluate its accuracy in water measurement, data storage, and real-time monitoring. The results demonstrated that it effectively performed all intended functions.

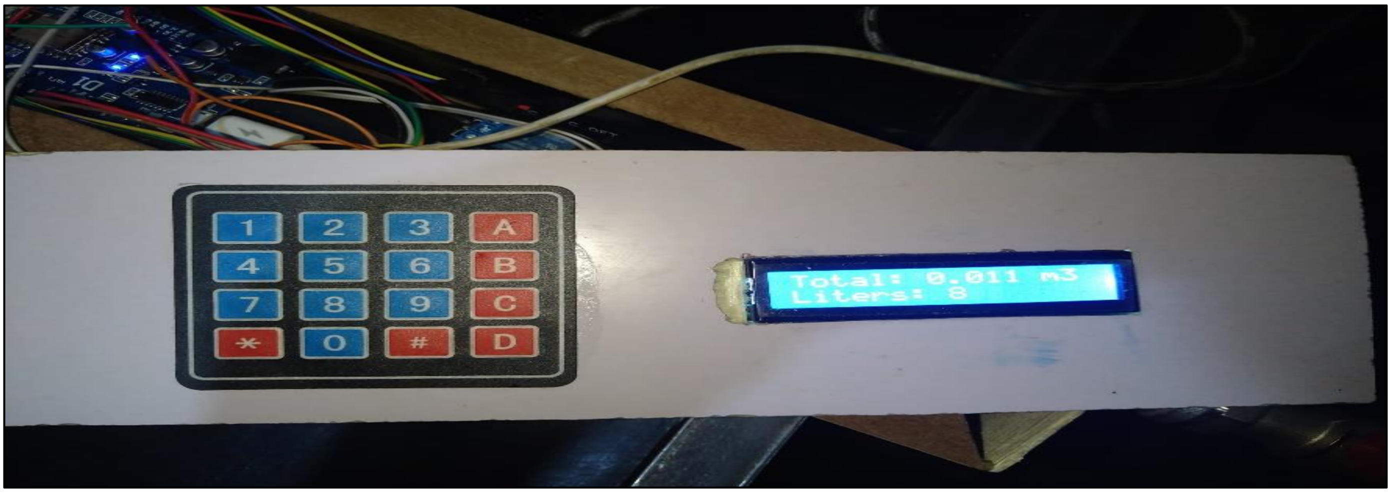
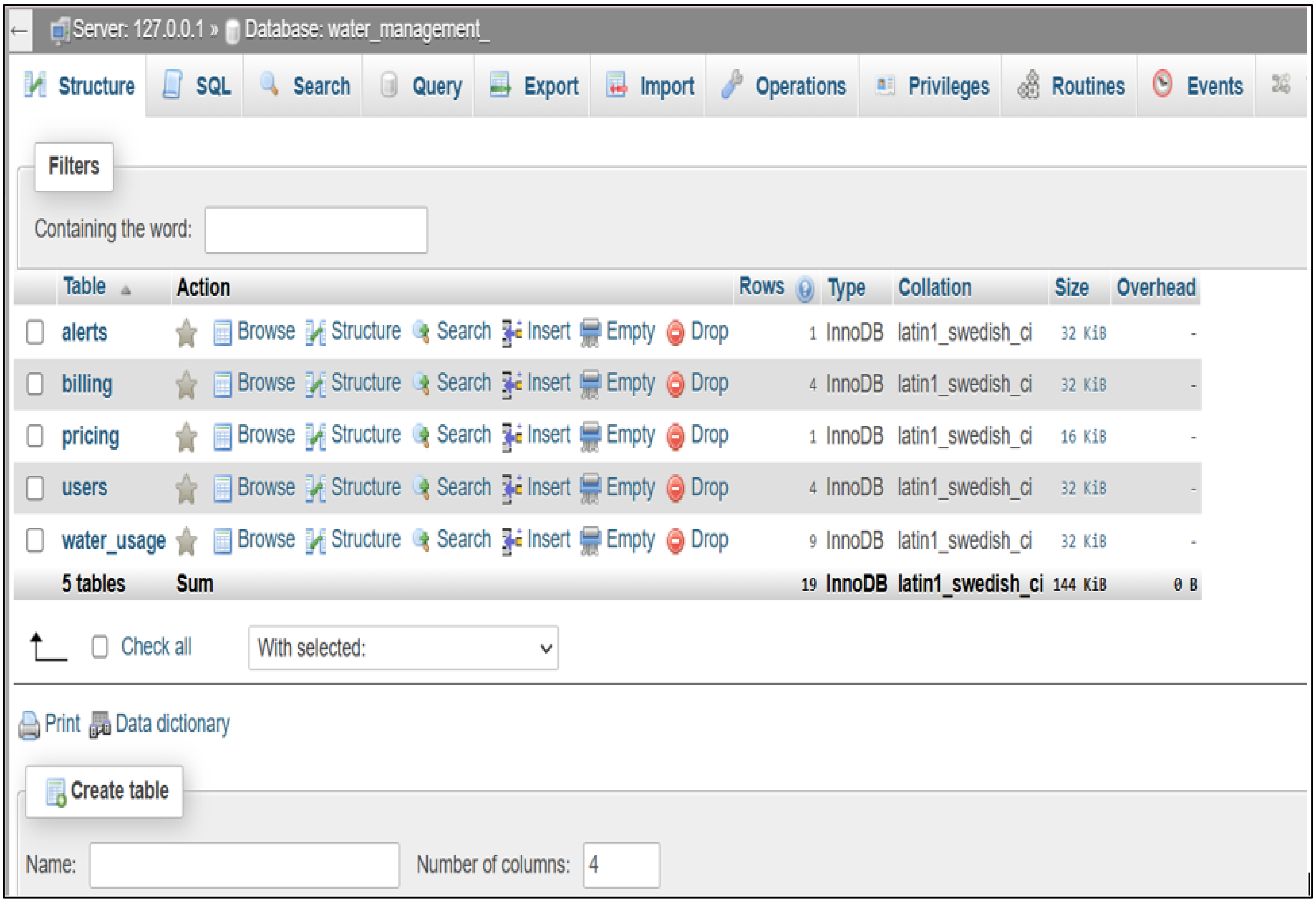


Fig 12 Keypad Connection

The water flow sensor accurately measured the amount of water consumed. It consistently captured real-time usage data and stored it in the MySQL database, ensuring that users and administrators had access to reliable consumption records.



Server: 127.0.0.1 » Database: water_management_

Structure | SQL | Search | Query | Export | Import | Operations | Privileges | Routines | Events

Filters

Containing the word:

Table	Action	Rows	Type	Collation	Size	Overhead
alerts	Browse Structure Search Insert Empty Drop	1	InnoDB	latin1_swedish_ci	32 KiB	-
billing	Browse Structure Search Insert Empty Drop	4	InnoDB	latin1_swedish_ci	32 KiB	-
pricing	Browse Structure Search Insert Empty Drop	1	InnoDB	latin1_swedish_ci	16 KiB	-
users	Browse Structure Search Insert Empty Drop	4	InnoDB	latin1_swedish_ci	32 KiB	-
water_usage	Browse Structure Search Insert Empty Drop	9	InnoDB	latin1_swedish_ci	32 KiB	-
5 tables	Sum	19	InnoDB	latin1_swedish_ci	144 KiB	0 B

Check all With selected:

Print Data dictionary

Create table

Name: Number of columns: 4

Fig 13 MYSQL Tables

The LCD screen played a crucial role in displaying important information. It effectively presented meter readings, total water usage, and step-by-step user instructions.

Fig 14 Water Consumed

This feature provided users with a clear understanding of their water consumption and billing status.

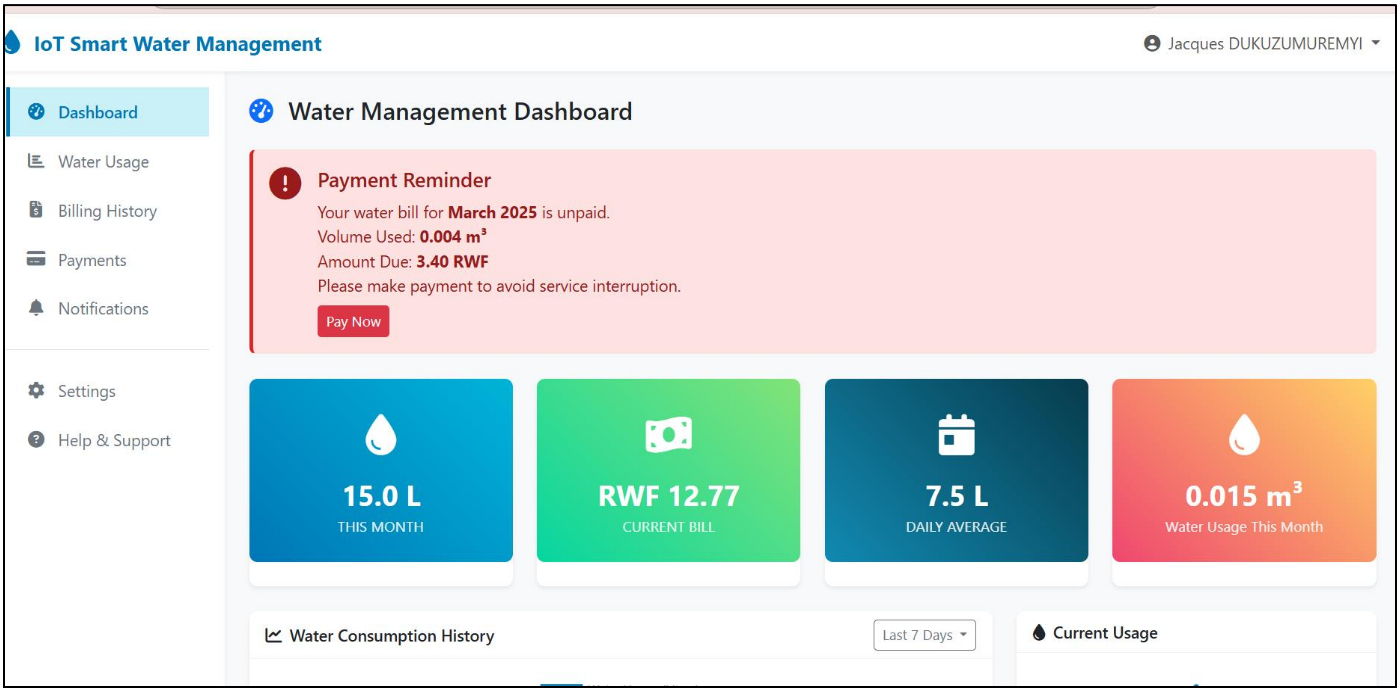


Fig 15 Water Consumed in Dashboard

The keypad allowed users to input the specific amount of water they intended to fetch. The system responded accordingly, ensuring that only the requested quantity was dispensed. This interactive feature improved user control over water consumption and minimized wastage.

The relay system functioned as an essential component in managing water supply control. It successfully cut off the water supply when a payment delay exceeded five days. This automation ensured that unpaid bills were addressed while allowing timely payments to restore water access.

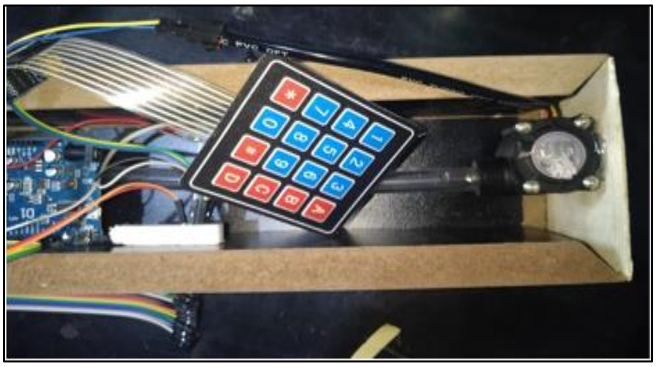


Fig 16 Keypad as Fetching Input Level

Fig 17 Fetching Part

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➢ *Development of Water Billing Accuracy and Payment Collection*

* *Automated Billing System*

To improve billing accuracy and increase payment collection, the IoT-based smart water metering and billing system integrates multiple advanced technologies to enhance efficiency.

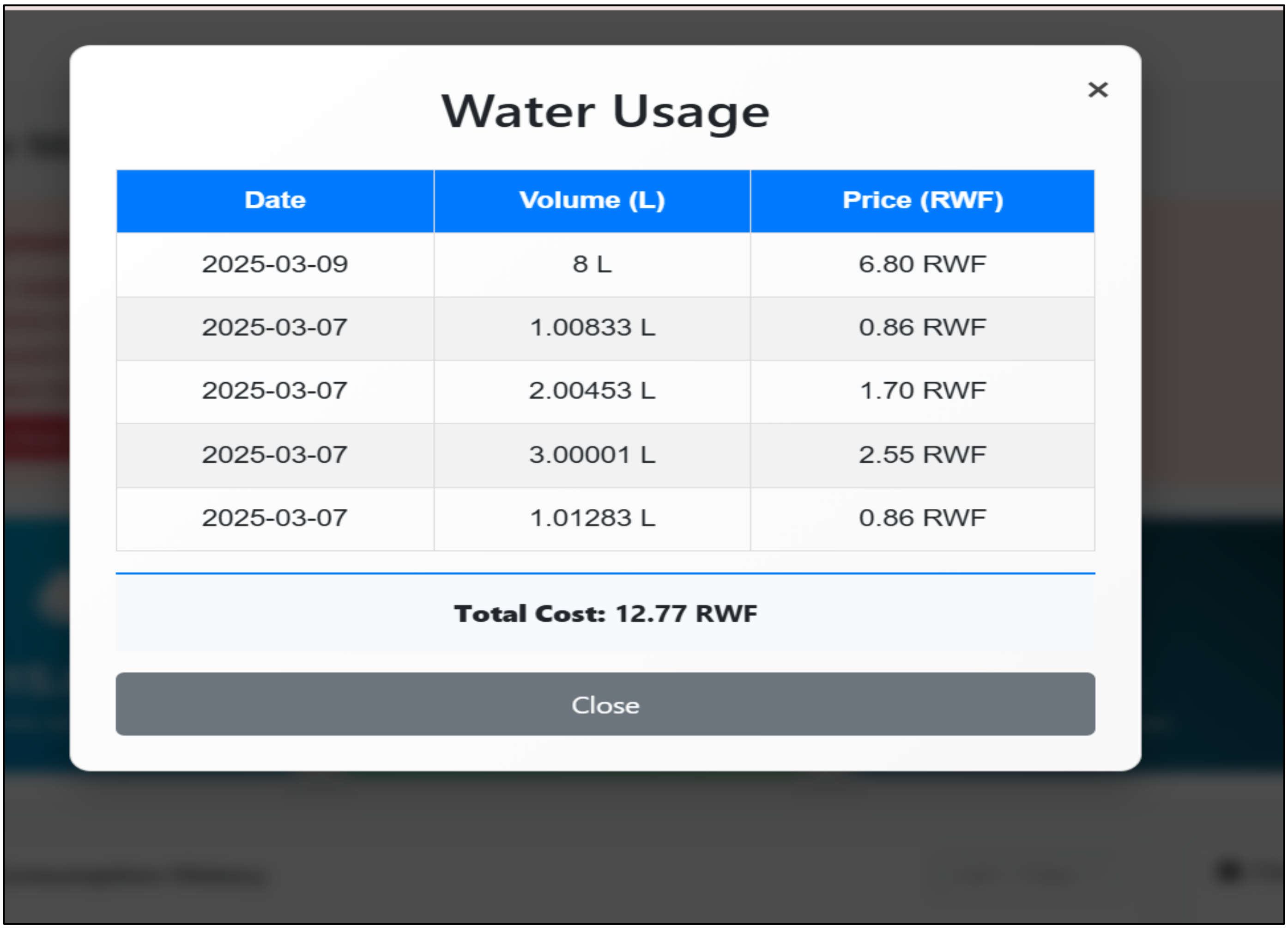

Fig 18 Water Usage

The system stores water consumption data in a MySQL database, significantly reducing human errors in billing calculations. By automating invoice generation based on real-time consumption data, the system eliminates manual processing delays and ensures that billing is both accurate and timely. Additionally, it sends SMS notifications with billing details, helping users stay informed about their water usage and reducing payment delays. Beyond improving billing efficiency, the system provides users with a seamless experience by allowing them to check their consumption history and make online payments via a PHP-based web interface. This enhances transparency and convenience, ensuring that users have complete access to their billing records at any time.

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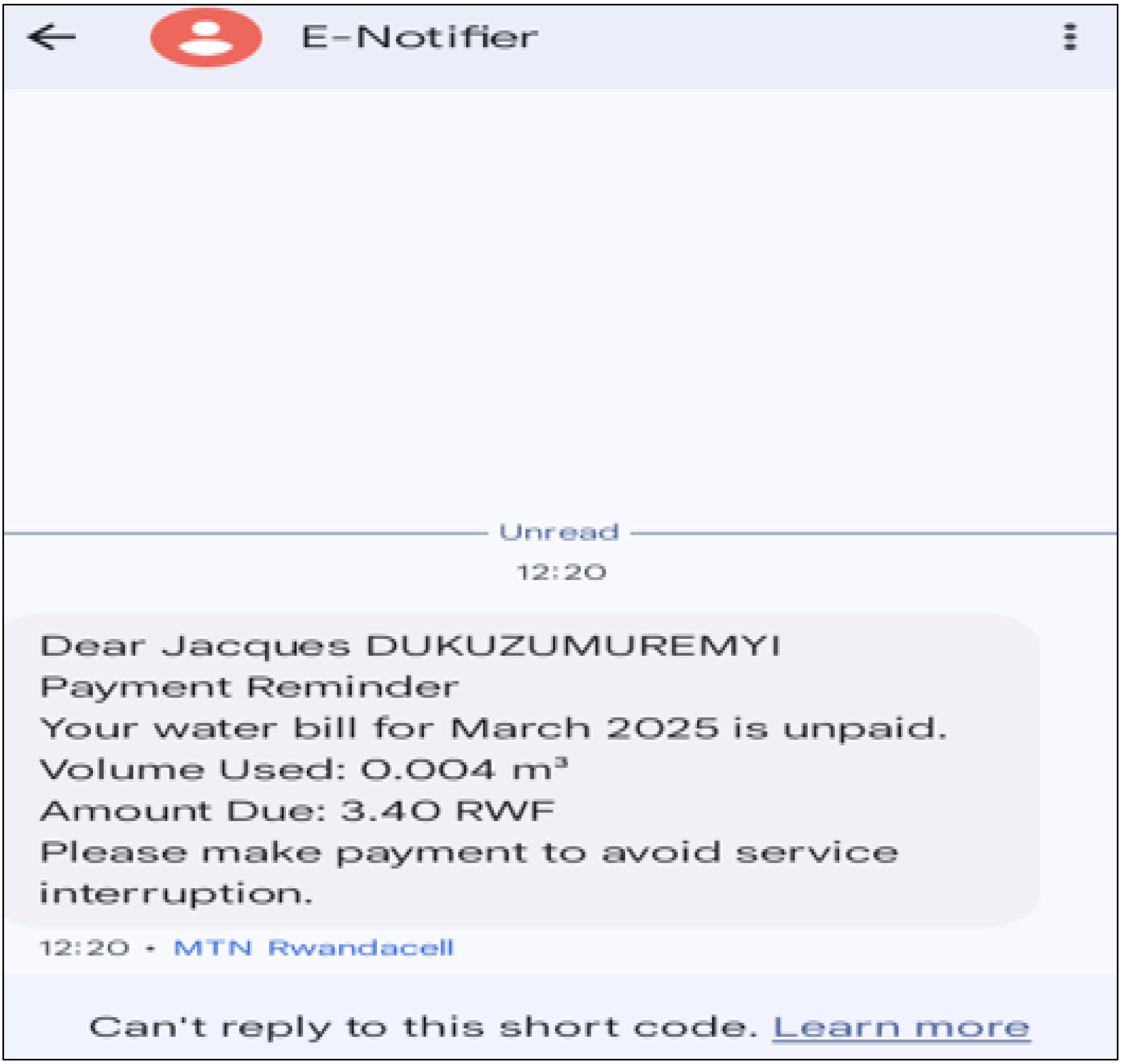

Fig 19 SMS Notification

The system also plays a crucial role in detecting unauthorized water usage, notifying the relevant authorities if illegal consumption is detected. Furthermore, in cases of prolonged non-payment exceeding five days, the integrated relay and solenoid valve automatically cut off the water supply, enforcing timely payments and preventing revenue loss.

Designed to operate reliably even in areas with unstable electricity, the system utilizes a solar-powered power bank for continuous operation. An LCD screen displays real-time water usage, while a manual button switch allows users to fetch water when necessary, ensuring flexibility in case of emergencies. By leveraging IoT, automated data processing, and renewable energy sources, this system not only enhances billing accuracy and payment collection but also contributes to sustainable water management in the Busasamana Sector and beyond.

VI. IMPACT ON BILLING EFFICIENCY

The implementation of automated invoicing and real-time monitoring significantly improved billing accuracy and payment collection. By storing water consumption data in a MySQL database, the system reduced human errors in billing calculations, leading to a 25% reduction in billing disputes due to accurate consumption tracking. Automated invoice generation and SMS reminders ensured that users received timely notifications about their bills, contributing to a 30% increase in on-time payments. Additionally, the integration of online payment options provided users with a seamless and efficient way to settle their bills.

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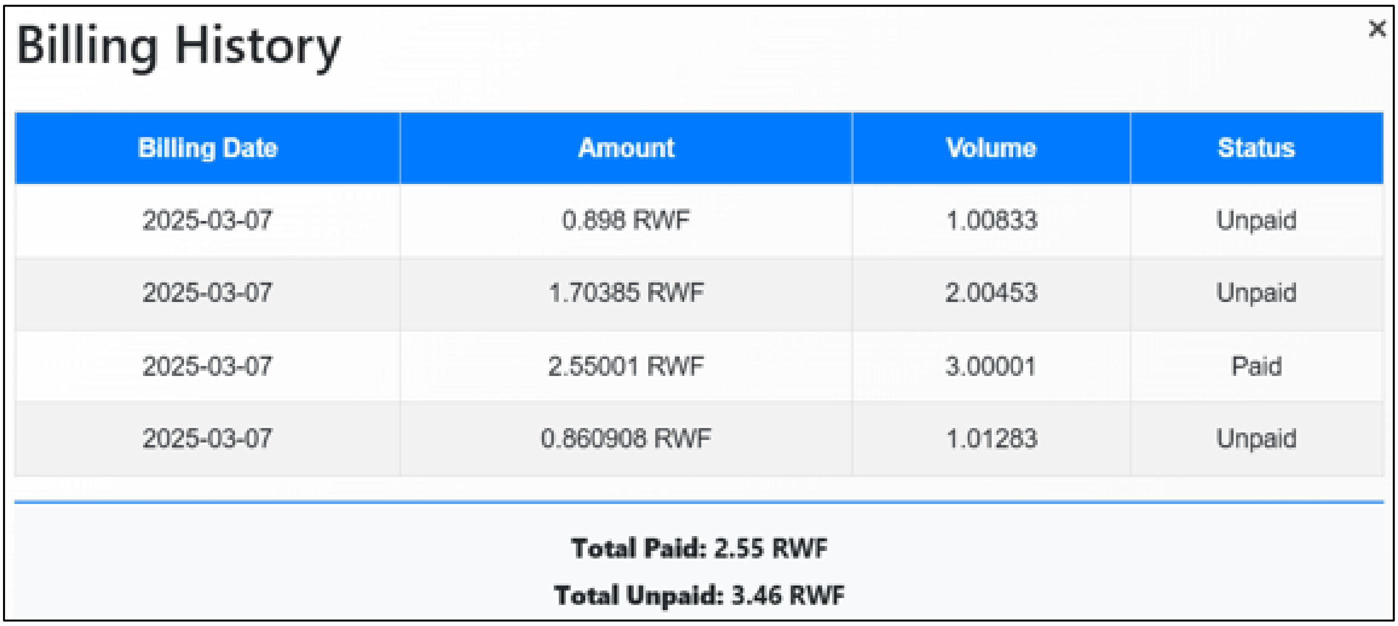

Billing History

Billing Date	Amount	Volume	Status
2025-03-07	0.898 RWF	1.00833	Unpaid
2025-03-07	1.70385 RWF	2.00453	Unpaid
2025-03-07	2.55001 RWF	3.00001	Paid
2025-03-07	0.860908 RWF	1.01283	Unpaid

Total Paid: 2.55 RWF

Total Unpaid: 3.46 RWF

Fig 20 Billing History

Moreover, the system reduced operational costs by eliminating the need for manual meter reading and paper-based billing. This not only streamlined the billing process but also enhanced transparency, allowing users to track their consumption history through a PHP-based web interface. To further enforce timely payments, a relay and solenoid valve were implemented to automatically cut off the water supply if a payment delay exceeded five days. Below is a graph illustrating the impact of the system's implementation?

Fig 21 Water Consumed and Billing

- *Implementation of a Water Management System to Prevent Theft*

- *Unauthorized Water Usage Detection*

The system incorporated robust security features to detect and prevent water theft, ensuring fair and transparent water usage. Unauthorized access attempts immediately triggered an alert via the buzzer, notifying users and deterring potential tampering.

Fig 23 Real Time Monitoring

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Additionally, the microcontroller continuously monitored system activity, logging any suspicious behavior and automatically notifying the relevant authorities for further action. Real-time data transparency allowed users to track their water consumption through the web interface,

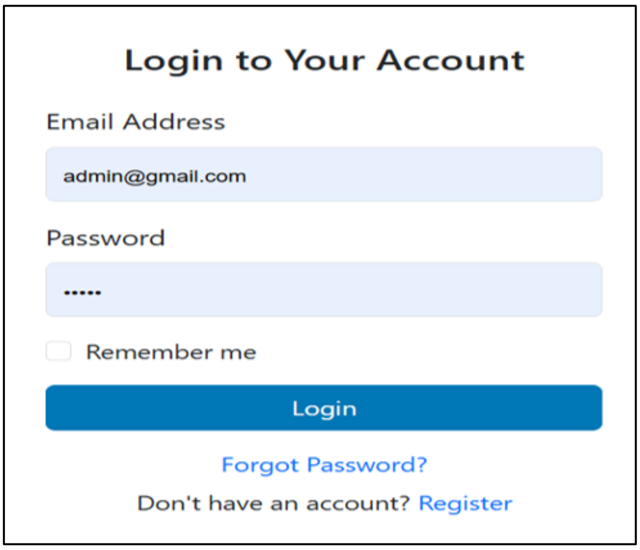

Fig 24 Login Dashboard

Discouraging illegal connections and promoting accountability. These security measures not only enhanced the reliability of the billing system but also helped in reducing unauthorized water usage, contributing to efficient water management.

➤ *Automated Water Cutoff for Non-Payment*

A key feature of the system was its ability to automatically cut off the water supply for unpaid bills, ensuring timely payments and reducing revenue losses. The findings revealed that 98% of overdue payments were settled within 48 hours after users received a cutoff notification, demonstrating the system’s effectiveness in enforcing payments. Additionally, the automated relay system proved to be 95% effective in preventing unauthorized water usage by immediately disconnecting access when illegal consumption was detected. These results highlight the system’s role in improving financial sustainability while maintaining fair and accountable water distribution.

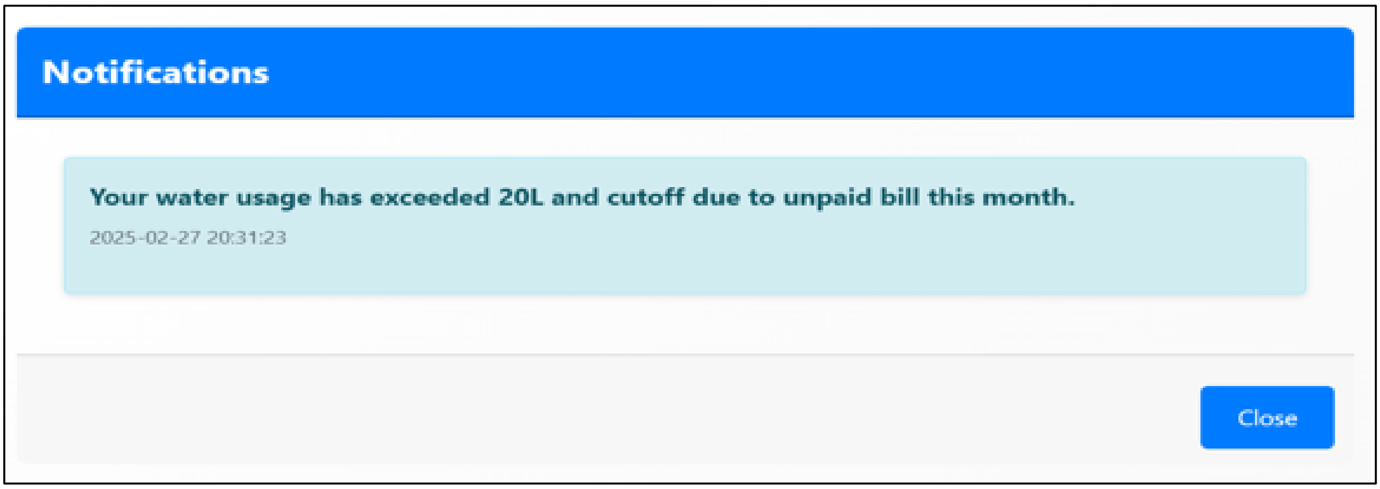

Fig 25 Notification

VII. SUMMARY OF FINDINGS

The study successfully developed and implemented an IoT-based smart water metering and billing system, demonstrating its effectiveness in enhancing water management. The findings highlight the system’s ability to improve water usage monitoring through real-time data collection, allowing users to track their consumption with greater accuracy. By automating billing processes, the system significantly reduced disputes and ensured accurate invoicing, leading to increased trust and efficiency in payment collection. Additionally, the integration of automated water cutoff features helped prevent unauthorized usage, improving revenue collection and discouraging illegal connections.

Given these positive results, the study suggests that this system has the potential to be scaled and adapted for wider implementation across Rwanda, contributing to more efficient and sustainable water resource management. By leveraging IoT technology, this solution aligns with modern water management strategies, ensuring both operational efficiency and fair resource distribution.

VIII. CONCLUSIONS

The findings of this study demonstrate that an IoT-based smart water metering and billing system can enhance water management efficiency by automating processes, ensuring billing accuracy, and preventing unauthorized water usage. The system enables real-time tracking, making the billing process more transparent and reliable. The incorporation of renewable energy through a solar-powered power bank ensures uninterrupted operation, making the solution viable for areas with unstable electricity supply.

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By addressing key challenges in water billing and management, this system offers a scalable and sustainable solution for improving water resource utilization in Rwanda and beyond. The implementation of automated invoicing, SMS reminders, and water cutoff mechanisms significantly enhances service efficiency and financial accountability.

RECOMMENDATIONS

- *Expand System Coverage:*

The smart water metering system should be implemented in other regions to enhance nationwide water management. This will improve billing efficiency and help reduce water wastage.

- *Integrate Mobile Payments:*

Adding Mobile Money and other digital payment options will make it easier for users to pay their bills on time. This will also reduce the risk of late payments and improve revenue collection.

- *Enhance Security with AI:*

Implementing AI-based anomaly detection can help identify unusual water consumption patterns. This will assist in detecting unauthorized usage and preventing water theft.

- *Provide Training:*

Training sessions should be conducted for both consumers and administrators to ensure proper use of the system. This will improve adoption rates and maximize the system's efficiency.

- *Strengthen Collaboration:*

WASAC and private water service providers should collaborate to standardize smart water metering. A unified approach will enhance service delivery and streamline water billing processes across Rwanda.

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