COMPARATIVE ANALYSIS OF EXISTING AND PROPOSED PIPELINE LEAKAGE DETECTION SYSTEM

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ABSTRACT: *This study presents a comparative analysis of the effectiveness of existing and proposed pipeline leak detection systems in selected households across three barangays in Cantilan, Surigao del Sur. The proposed system integrates sensor technology to detect pressure drops in pipelines and automatically triggers SMS alerts to users and the water district. It is supported by mobile and web-based monitoring platforms for real-time supervision. Evaluation was conducted using the ISO 25010 software quality framework, focusing on functionality, reliability, usability, efficiency, maintainability, and security. Quantitative data were analyzed through mean scores and paired-sample t-tests to determine significant performance differences between the two systems. Results revealed statistically significant improvements across all evaluated attributes in the proposed system. Reliability and efficiency showed the most notable gains, as automated detection and instant notifications minimized water loss and response time. Usability improved through intuitive interfaces, maintainability through simplified diagnostics, and security through enhanced data protection. The findings indicate that the proposed system performs better than the existing setup. It enhances user satisfaction, promotes sustainable water management at the household level, and provides a model for improving water distribution efficiency in similar communities.*

Keywords: Comparative Analysis, Leak Detection System, Sensor Technology, Water Conservation.

INTRODUCTION

Water is undeniably one of the most vital resources that sustain life, ecosystems, and human development. Despite its recognized importance, however, it remains one of the most undervalued and often overlooked resources in everyday life. The increasing global demand for potable water, combined with the accelerating effects of climate change and population growth, has made efficient water management a pressing concern. One of the persistent challenges that water utilities, communities, and households face is the problem of pipeline leaks. These leaks, whether large or small, result in the loss of significant volumes of clean water that could otherwise be allocated for essential domestic, agricultural, or industrial purposes. What makes this issue more concerning is that a substantial portion of these losses often goes unnoticed until the situation escalates into severe operational and financial consequences.

For water districts, undetected leaks do not merely translate into wasted resources. They create a chain of negative impacts that affect both service providers and consumers [12, 10]. Operational costs rise as utilities spend more on water production and distribution without recovering equivalent revenues [25]. Moreover, leaks disrupt equitable water distribution, with some areas receiving insufficient supply while others experience wastage. The problem further complicates efforts to meet conservation goals and hinders the broader agenda of sustainable resource management [24]. At the household level, the repercussions are equally troubling. Leaks, when left unattended, silently increase monthly water bills and contribute to wastefulness that undermines collective conservation efforts [23]. These household-level issues, though seemingly minor, aggregate into significant challenges when multiplied across thousands of homes within a municipality or district.

Over the past decades, researchers and practitioners have explored various strategies to mitigate water losses [14, 9]. Approaches range from traditional manual inspections to the adoption of advanced smart sensor technologies designed for large-scale pipeline systems [3]. While these innovations have yielded promising results at the utility and network levels, they often fail to address smaller-scale leaks occurring within individual households. Current leak detection practices in homes largely depend on reactive mechanisms such as periodic inspections, discrepancies noted during meter readings, or manual reporting by customers [22, 6]. Unfortunately, such methods tend to be slow, allowing leaks to persist for days or even weeks before detection. By the time action is taken, the water loss is already substantial, and repair costs have escalated unnecessarily.

To address these gaps, there is a growing need for real-time, household-centred solutions capable of promptly identifying leaks and enabling immediate intervention. This study responds to that need by comparing the effectiveness of existing leak detection approaches with a newly developed, sensor-based system. The proposed system employs continuous monitoring of water pressure, automatically detecting anomalies such as unusual drops, and immediately sending SMS alerts to both homeowners and the water district. Complemented with mobile and web-based interfaces for user-friendly monitoring and data visualization, the system represents an innovative step toward proactive household water management.

Furthermore, the evaluation of this system is grounded in the ISO 25010 quality framework, which ensures a comprehensive assessment of software and system quality. Key attributes, including functionality, reliability, usability, and efficiency, serve as benchmarks in comparing the existing methods with the proposed solution. Through performance data analysis and user feedback, this study aims to establish whether the sensor-based approach can deliver measurable improvements in water conservation, operational efficiency, and user satisfaction. The research underscores the broader societal goal of safeguarding one of the world's most critical resources, ensuring that water is managed wisely for present and future generations.

Materials and Methods

Participants

The participants were the house owners of Brgy. Magosilom, Brgy. Lininti-an and Brgy. San Pedro of Cantilan, Surigao del

Sur. They provided essential insights into its effectiveness, ease of use, and reliability in daily life.

Ethics and Data Gathering Procedure

The study adhered to strict ethical standards to ensure the protection of participants' rights and well-being. Informed consent was obtained from all homeowners participating in the study, ensuring they fully understood the purpose of the research, the process, and how their feedback would be used. Participants were made aware that their involvement was voluntary, and they had the right to withdraw from the study at any time without facing any negative consequences. Confidentiality was maintained throughout the study, and personal information will not be disclosed in any reports or publications. All collected data were securely stored, accessible only to authorized researchers, and were used solely for this study. The researcher was committed to transparency, ensuring that participants were informed of the study's goals, methods, and findings. Additionally, the study ensured that no harm was caused to participants, and all procedures were carried out in a way that is non-disruptive to their daily lives.

The data gathering procedure involved homeowners from Brgy. San Pedro, Brgy. Magosilom and Brgy. Linintian. Once consent was obtained, the pipeline leak detection system was installed in the participants' homes. The installation process was non-invasive, and homeowners received clear instructions on how to use the system. After installation, feedback was collected through surveys or interviews, allowing participants to share their experiences regarding the system's usability, reliability, and effectiveness in leak detection. Simultaneously, the system monitored data such as pressure levels and alert logs, which were used to assess the system's performance. The GSM module also generated logs of SMS notifications sent to the participants, which were reviewed to evaluate the timeliness and accuracy of alerts. Finally, the feedback and system data collected were analyzed, and the findings were compiled into a report.

Device Components

The leak detection system was carefully designed using several interconnected components that worked seamlessly to monitor water flow, identify irregularities, and respond automatically in case of leaks. At the heart of the system was the NodeMCU V3 Type C microcontroller, which functioned as the central processing unit or the "brain" of the setup. This microcontroller managed all incoming data from the sensors and coordinated the actions of the connected modules. It was mounted on a NodeMCU base board that provided both physical stability and organized wiring connections, making the system easier to assemble and maintain.

To ensure stable power delivery, a 12V/24V to 5V step-down power supply module was included. This component converted the voltage from the primary 12V 2A adapter into a safe 5V output suitable for the microcontroller and other modules. For monitoring purposes, the system utilized an analogue water pressure sensor that continuously measured the water pressure in the pipes. When this sensor detected an unusual pressure drop—often a strong indication of a leak—the NodeMCU immediately activated a 5V relay module. The relay served as a switching device that controlled a 220V solenoid valve connected to the water line. Once triggered, the solenoid valve automatically shuts off the water supply, thereby minimizing potential water loss and property damage. In addition to the automatic shutoff feature, the system was equipped with a SIM800L V2 GSM module. This module sent SMS notifications to users, ensuring they were instantly informed of any detected leak. All components were interconnected with DuPont wires, allowing efficient transmission of both power and signals. Collectively, these elements formed an intelligent, responsive, and reliable leak detection system designed to safeguard households and promote responsible water use.

Figure 1. Device Components

Data Analysis

The data analysis for this study was conducted through a structured evaluation of both the existing and the proposed household pipeline leak detection systems. The process involved not only measuring technical performance but also incorporating user feedback to capture how the system functions in practical settings. The ISO 25010 quality framework served as the guiding standard for the evaluation. This framework, developed under ISO/IEC 25010:2011, provides a comprehensive model for assessing software and system quality. It was applied to examine the proposed system in terms of functional suitability, performance efficiency, usability, reliability, maintainability, and security. By doing so, the analysis offered a balanced view that considered both system capability and user experience.

Qualitative insights were obtained through survey questionnaires administered to homeowners and IT experts. The surveys were designed to capture perceptions about the system's usefulness, ease of operation, consistency in performance, and responsiveness in sending leak alerts. These perspectives were essential in determining how well the system addresses real-world needs and whether it provides improvements over the current leak detection methods.

To ensure accuracy in comparing the two systems, statistical tools were employed. The mean was calculated to summarize the quality characteristics of both the existing and the proposed systems. This provided a clear measure of overall performance across the key attributes. Furthermore, a t-test for paired samples was utilized to statistically determine whether there were significant differences between the two systems in terms of functionality, reliability, usability, efficiency, maintainability, and security. This approach allowed the researcher to validate improvements with empirical evidence, ensuring that conclusions drawn were both systematic and reliable.

RESULTS AND DISCUSSION

This study discussed the results of the system's effectiveness, evaluated across six quality attributes: functionality, reliability, usability, efficiency, maintainability, and security. These aspects were based on well-established international standards, the ISO/IEC 25010, which provide a clear and reliable way to measure how well a system performs and how good its overall quality. The information gathered from user feedback, system tests, and expert reviews was carefully examined to see how well the system delivers on its goals and meets what users expect from it.

Table 1. Functionality

	Statements	Existing System		Proposed System	
		M	D	M	D
1	The required task is performed by the system satisfactorily	2.63	ME	4.9	VE
2	The output generated by the system is correct.	2.6	ME	4.78	VE
3	The system helps the user overcome any problem encountered.	2.43	SE	4.85	VE
4	The system regulates user access to data.	2.48	SE	4.83	VE
	Average	**2.53**	**ME**	**4.84**	**VE**

Legend: M - Mean, D - Description
SE - Slightly Effective, ME - Moderately Effective, E - Effective, VE - Very Effective

Table 1 presents the effectiveness of the proposed system compared to the existing system in terms of its functionality. The existing system received low satisfaction ratings from users, averaging a mean score of 2.53 and was categorized as Moderately Effective. It performed poorly, particularly in providing user support and regulating data access, both of which were rated as Not Effective. In contrast, the proposed system gained consistently high ratings across all areas, with an impressive average of 4.84, and was classified as Very Effective. The most notable improvements were seen in user assistance and the system's ability to perform required tasks efficiently.

The existing system received a low average rating of 2.51, shown in Table 2, indicating it was only Moderately Effective, particularly in handling system errors and restoring data. Notably, it was rated as not effective in maintaining performance during errors and in data recovery after failure. On the other hand, the proposed system demonstrated significant improvements across all aspects, achieving a high average rating of 4.82 and being classified as Very Effective. It especially excelled in real-time monitoring and restoring lost data, indicating stronger reliability and resilience. Overall, the results highlighted a clear advantage in transitioning to the proposed system for better performance and system stability.

Table 2. Reliability

	Statement	Existing System		Proposed System	
		M	D	M	D
1	Most errors have been corrected over time.	2.6	ME	4.68	VE
2	The system can maintain its performance despite the presence of errors during operation.	2.48	SE	4.78	VE
3	The system restores the operation of lost data after failure.	2.48	SE	4.85	VE
4	The system provides real-time monitoring to ensure availability.	2.48	ME	4.98	VE
	Average	**2.51**	**ME**	**4.82**	**VE**

Legend: M - Mean, D – Description
SE - Slightly Effective, ME - Moderately Effective, E-Effective, VE - Very Effective

Table 3. Usability

	Statements	Existing System		Proposed System	
		M	D	M	D
1	The system is intuitive and receptive to learning	2.4	SE	4.85	VE
2	The information generated by the system is easy to understand and act upon.	2.5	ME	4.85	VE
3	The documentation is very informative.	2.55	ME	4.9	VE
4	The system straightforwardly performs tasks.	2.48	SE	4.85	VE
	Average	**2.48**	**SE**	**4.86**	**VE**

Legend: M - Mean, D – Description
SE - Slightly Effective, ME - Moderately Effective, E - Effective, VE - Very Effective

Table 3 illustrates the effectiveness of the proposed system compared to the existing system in terms of usability. The existing system was generally seen as Slightly Effective, with an average score of 2.48. Users reported difficulty with how the system handled tasks, its ease of use, and how clearly it presented information. On the other hand, the proposed system earned a much higher average of 4.86, with users finding it very effective in all areas evaluated. They found it intuitive, easy to learn, informative, and straightforward in performing tasks. This highlighted a major improvement in

Table 4. Efficiency

	Statements	Existing System		Proposed System	
		M	D	M	D
1	The system responds immediately to sensor inputs.	2.45	SE	4.85	VE
2	The system maximizes the efficient utilization of available resources (i.e., people, data, machines, and materials).	2.55	ME	4.95	VE
3	The system performs efficiently on intended tasks with ease and scalability.	2.58	ME	4.73	VE
4	The system meets established efficiency benchmarks for industry standards	2.43	SE	4.88	VE
	Average	**2.5**	**ME**	**4.85**	**VE**

Legend: M - Mean, D - Description

SE - Slightly Effective, ME - Moderately Effective, E - Effective, VE - Very Effective

User experience and usability of the proposed system was designated a Mean of 4.86, described as Very Effective.

The evaluation in Table 4 shows that the existing system was only Moderately Effective, with an average score of 2.5, particularly lacking in responsiveness and meeting industry efficiency standards. Users found it ineffective in responding to sensor inputs and underperforming in terms of resource utilization

Table 5. Maintainability

	Statements	Existing System		Proposed System	
		M	D	M	D
1	Deficiencies can be easily diagnosed and modified in the system.	2.58	ME	4.9	VE
2	The system can be easily customized and modified.	2.53	ME	4.78	VE
3	The system continues functioning if changes are made.	2.48	SE	4.83	VE
4	The system can easily be tested.	2.55	SE	4.83	VE
	Average	**2.53**	**ME**	**4.83**	**VE**

Legend: M - Mean, D – Description

SE - Slightly Effective, ME - Moderately Effective, E - Effective, VE - Very Effective

. In contrast, the proposed system was rated Very Effective across all aspects, scoring a high average of 4.85. It impressed users with its quick response time, efficient resource use, and ability to meet performance benchmarks. This indicated that the proposed system was a major upgrade in terms of speed, efficiency, and reliability.

The data in Table 5 shows that the existing system was considered only Moderately Effective, with an average rating of 2.53. Users found it difficult to modify or test, and it performed poorly when changes were applied. In contrast, the proposed system received a much higher average of 4.83, earning a Very Effective rating in all areas. It stands out for its ease of customization, smooth operation during changes, and the ability to quickly diagnose and resolve issues. These results highlighted the proposed system's strong adaptability, stability, and overall efficiency.

Table 6. Security

	Statements	Existing System		Proposed System	
		M	D	M	D
1	The system has its security level access with pre-determined action.	2.45	SE	4.85	VE
2	The data and its associated records are secured.	2.48	SE	4.7	VE
3	Access to top-level management data is topped with necessary security credentials.	2.5	ME	4.65	VE
4	Logs are maintained to detect unauthorized changes to system data	2.48	SE	4.68	VE
	Average	**2.48**	**SE**	**4.72**	**VE**

Legend: M - Mean, D – Description

SE - Slightly Effective, ME - Moderately Effective, E - Effective, VE - Very Effective

Table 6 illustrates the effectiveness of the proposed system compared to the existing system in terms of security. The results in Table 6 revealed that the existing system was rated as having low effectiveness in terms of security, with an average score of 2.48. Users felt that data protection, access control, and activity monitoring were insufficient, particularly for sensitive or top-level information. In contrast, the proposed system was rated very effective, with a strong average of 4.72, showing major improvements in all areas of system security. It was especially noted for its secure access levels, protection of records, and ability to detect unauthorized changes. These findings emphasized that the proposed system provided a much safer and more reliable data environment.

Table 7. Comparisons of the Quality of Existing and Household Water Leak Detection Systems using Sensor Technology

Characteristic	System	Mean	t-value	p value	Decision on Ho	Interpretation
Functionality	Existing Proposed	2.53 4.84	34.59	<0.001	Rejected	Significant
Reliability	Existing Proposed	2.51 4.82	32.10	<0.001	Rejected	Significant
Usability	Existing Proposed	2.48 4.86	33.26	<0.001	Rejected	Significant
Efficiency	Existing Proposed	2.50 4.85	33.39	<0.001	Rejected	Significant
Maintainability	Existing Proposed	2.53 4.83	33.12	<0.001	Rejected	Significant
Security	Existing Proposed	2.48 4.72	26.21	<0.001	Rejected	Significant

Table 7 illustrates the comparison between the existing and proposed household water leak detection systems across various software quality characteristics. In each category: functionality, reliability, usability, efficiency, maintainability, and security—the p-values were all less than 0.001. These p-values indicated a statistically significant difference between the two systems for every characteristic assessed. As a result, the null hypothesis, which posited that there was no significant difference in quality between the existing and proposed systems, was rejected in all cases.

Upon examining the mean scores, the proposed household water leak detection system using sensor technology consistently obtained higher mean values than the existing system. In terms of functionality, the proposed system achieved a mean score of 4.84, higher than the 2.53 mean of the existing system. The reliability values also increased from 2.51 in the existing system to 4.82 in the proposed one. Similar improvements were seen in usability (from 2.48 to 4.86), efficiency (from 2.50 to 4.85), maintainability (from 2.53 to 4.83), and security (from 2.48 to 4.72). These results strongly indicated that the integration of sensor technology in the proposed system significantly enhances its overall performance and user experience, establishing it as a superior alternative to the existing water leak detection system.

CONCLUSION

It was concluded that the effectiveness of the proposed household pipeline leak detection system was successfully validated through both actual deployment and systematic user evaluation. Guided by the ISO 25010 software quality standards, the system was assessed across critical dimensions of quality, including functionality, reliability, usability, efficiency, maintainability, and security. In all these categories, the system consistently obtained a “Very Effective” rating, which highlights its strong performance and significant improvements compared to existing approaches that rely mainly on manual detection methods. These findings confirm that the proposed system is not only technically sound and highly functional but also easy to use, dependable, and responsive in addressing real-life challenges associated with water loss. Moreover, its positive evaluation demonstrates that it is sustainable and adaptable, making it suitable for practical deployment in residential settings where early leak detection is crucial for conservation and cost savings.

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