Effects of leak detection system on reducing non-revenue water losses in Tanzania: A case of Rombo water supply and sanitation authority

Christopher Venance[1]
Eugen M. Justin[2]

[1]christopher.marushwa@iaa.ac.tz
[2]massaweeeugen1@gmail.com

[1]https://orcid.org/0000-0002-7012-5592

[1,2] Institute of Accountancy Arusha, Tanzania

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ABSTRACT

For water utilities, non-revenue water (NRW) presents a serious problem that impacts both operational effectiveness and long-term financial viability. This study examines how NRW losses in ROMBOWSSA can be decreased by using wireless networks in conjunction with smart leak detection and acoustic sensors. The study employs DeLone and McLean IS Success Model to evaluate how technological performance directly mitigates water losses at ROMBOWASA. Population size was 30719 that includes customer/water users and employees (150) from ROMBOWSSA. The study used Random sampling to obtain a sample of 395 participants. The study employs cross sectional research design. Structured questionnaires were used to gather data, and multiple regression analysis and descriptive statistics were used for analysis. The results show that Smart Leak Detection is the most significant predictor of NRW reduction ($B = 0.764$, $Beta = 0.764$, $p < 0.001$), while Acoustic Sensors also contribute positively ($Beta = 0.153$, $p < 0.001$). Together, these technologies explain 76.4% of the variation in NRW reduction, highlighting their effectiveness in enhancing leak detection, timely repairs, and operational efficiency. The study concludes that adopting advanced leak detection systems is a practical strategy for minimizing water losses, optimizing resource allocation, and promoting sustainable water management in ROMBOWSSA and similar utilities. The study suggests that ROMBO-WASSA prioritize investment in leak detection systems, implement data analytics tools for predictive and real-time decision-making, and integrate smart metering with billing systems. It also suggests that staff members receive ongoing training and capacity building.

Keywords: Acoustic Sensors, DeLone and McLean IS Success Model, Non-Revenue Water, Smart Leak Detection, Sustainable Water Management, Water Loss Reduction, Water Utilities, Wireless Networks.

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I. INTRODUCTION

One of the most significant issues facing water utilities globally is Non-Revenue Water (NRW), which is the discrepancy between the volume of water supplied and the amount paid to customers (Liemberger, & Marin, 2006; Aboelnga et al., 2019). Globally, the NRW rate considered to be less than 20% that acceptable to the developing nation, but east African nations especially Tanzania face higher rate at 38% vastly exceeding the government's optimized national benchmark of 20% than other nations. On a broader scale, these persistent system inefficiencies and old, organically expanded distribution networks cost Sub-Saharan African water utilities an estimated $1.4 billion USD annually in unrecovered water revenue (Shushu et al., 2021). According to recent annual performance review reports by the Energy and Water Utilities Regulatory Authority (EWURA) in Tanzania: The Problem: The national average for NRW among regional water utilities consistently hovers between 35% and 40%. This means nearly 4 out of every 10 liters of treated water pumped into the distribution systems vanishes before reaching a paying customer. The financial toll this translates to billions of Tanzanian Shillings (TZS) lost per annum. For medium-to-large values, these financial losses strictly obstruct their ability to refund capital credits, fund network growths, or even shelter daily processes and preservation costs.

It is mostly caused by meter errors, illicit connections, distribution network leakage, and inadequate asset management (IWA, 2014; Lambert, 2003). A high NRW degrades operational effectiveness, impairs financial performance, and encourages the unsustainable use of limited resources. Physical losses from leaks make up the majority of NRW in many utilities, especially in cases where the infrastructure is outdated or not well maintained (Liemberger & Wyatt, 2019; Alharbi, 2026). The Middle Belt Water Supply and Sanitation Agency's (ROMBOWSSA) Regional Office has seen significant demand on sustainability and operating budgets due to ongoing NRW. A large portion of the water produced is not consumed, which lowers revenue collection and restricts infrastructure expenditure. In the face of population expansion and climate variability, these losses worsen the strain on scarce water supplies, jeopardize financial viability, and impair service delivery (World Bank, 2016; Kibria et al., 2022). Despite national targets restricting Non-Revenue Water (NRW) to less than 20%, public utilities in Tanzania lose an average of 38% to 40% of treated water annually (EWURA, 2024). This operational crisis is severe at the Rombo Water Supply and Sanitation Authority (ROMBOWASA), where gravity-driven pressure spikes cause frequent pipe bursts and porous volcanic soils hide leaks from visual detection.

While prior literature proves that digital solutions can reduce NRW (Shushu et al., 2021), a critical research gap exists: previous studies focus exclusively on mature urban networks with continuous 24/7 pressurized water supply. Consequently, there is an empirical blind spot regarding how automated leak detection technologies perform under the intermittent flow schedules and capital constraints typical of Tanzanian district authorities. This study uniquely addresses this gap by evaluating how a resource-constrained utility can implement a tailored Leak Detection System (LDS) to control hidden physical losses, stabilize revenue, and secure long-term operational sustainability.

1.1 Research Objective

The objective of this study is to assess the effects of information technology on reducing non-revenue water losses in Tanzania with a focus of ROMBOWSSA.

II. LITERATURE REVIEW

2.1 Theoretical Review

This study adapts the Updated DeLone and McLean IS Success Model (2003) to evaluate how technological performance directly mitigates water losses at ROMBOWASA. System Quality is mapped onto the operational reliability, software usability, and adaptability of the Leak Detection System (LDS) hardware such as acoustic sensors and pressure transducers—under intermittent supply schedules and gravity-driven flows. Information Quality is defined by the real-time accuracy, timeliness, and geographical precision of the leak alerts generated by the system, which directly influences NRW reduction by allowing utility technicians to locate silent, sub-surface leaks within Rombo's porous volcanic soils. Finally, Net Benefits are strictly operationalized through three concrete metrics: the volume of physical water saved in cubic meters (m^3), the financial revenue recovered in Tanzanian Shillings (TZS), and the reduction in average repair response times. By connecting these dimensions, the model demonstrates how high-quality technical inputs translate directly into proactive infrastructure management and improved financial sustainability for the utility.

2.2 Empirical Review

Leak detection systems (LDS) are vital for reducing Non-Revenue Water (NRW), but their performance depends heavily on regional infrastructure. Capital-intensive, integrated systems yield high NRW reductions, such as satellite-AI integration in the US with 30% reduction (Pan et al., 2025) and continuous pressure monitoring in Spain with 25% reduction (Santos-Ruiz et al., 2022). These rely on stable, fully mapped, and continuously pressurized networks. Fragmented infrastructure limits utilities to localized, hybrid, or manual systems, resulting in lower efficiency gains such as pressure/flow metering in India with 17% reduction (Einyu et al., 2025) and visual-acoustic coupling in Brazil with 19% reduction (Zhang et al., 2023).

Current literature frequently overlooks the physical and operational limitations of LDS technologies: Acoustic Sensors (Fares et al., 2023): Highly effective in legacy metallic networks, but fail in plastic pipes (PVC/HDPE) due to rapid sound attenuation. They are also highly prone to false positives from ambient urban noise. Pressure & Flow Monitors (Santos-Ruiz et al., 2022): These require continuous flow. In intermittent supply systems, frequent filling/draining introduces pressure transients and air pockets that distort data and damage sensors. Satellite & AI (Pan et al., 2025): These systems are cost-prohibitive for smaller utilities and suffer from coarse spatial resolution, making them unable to pinpoint small, localized underground leaks.

The DeLone and McLean IS Success Model assumes high system quality automatically yields high information quality and operational success (Boyle et al., 2022). However, this model breaks down in resource-constrained environments. As noted by Farah and Shahrour (2024) and Palermo et al. (2022), structural barriers such as unstable power, poor cellular coverage for IoT transmission, and lack of local technical expertise disrupt the data pipeline, rendering expensive LDS installations ineffective. Furthermore, empirical literature heavily focuses on Western or Asian networks. In Sub-Saharan Africa, NRW research is skewed toward commercial losses (theft and billing errors) rather than physical leak detection. There is a lack of empirical evidence showing how small-scale African utilities adapt physical LDS under capital constraints and intermittent supply regimes.

While global studies prove the utility of LDS, the methodologies are biased toward wealthy, stable environments. This study addresses these theoretical and geographical gaps by evaluating the empirical effectiveness and contextual viability of leak detection technologies at ROMBO-WASSA in Tanzania, bridging the gap between high-tech global standards and resource-constrained African realities.

III. METHODOLOGY

The impacts of smart leak detection devices and acoustic sensors on lowering Non-Revenue Water (NRW) in ROMBOWSSA are investigated in this study using a quantitative research methodology.

3.1 Research Design.

A case study research design has been used in this study by involves an in-depth, systematic investigation of a single case or a small number of cases within a specific context. This design allows researchers to explore complex phenomena within real-life settings using numerical data for analysis. Also, it used in quantitative research, focusing on the collection and analysis of numerical data to draw conclusions about a particular case or context. Case studies help to understand the specific context and environment in which the phenomenon occurs, leading to a richer interpretation of the data.

3.2 Research Approach

This study utilizes a quantitative approach, which facilitates the easy analysis and presentation of data through numerical information, such as percentages and fractions. Graphical representations of various phenomena were also be included. The quantitative approach is selected because it aims to test the effects of information technology (such as smart metering, data analytics tools, and leak detection systems) based on the data gathered and analyzed from ROMBOWSSA. Ultimately, the findings will determine whether the empirical results align with the framework. Additionally, quantitative research questions are deductive, focusing on how the variables being studied relate to each other, impact different groups, or can be defined. A deductive approach is particularly useful in quantitative research as it seeks to prove, disprove, or validate existing theories (Leavy, 2017).

3.3 Study area

This study was conducted in the Kilimanjaro region, specifically focusing on ROMBOWSSA, the government agency responsible for providing water and sanitation services in Rombo district. The operational area consists of 28 wards, with an estimated population of around 314,698 people as of June 2023, based on projections from the 2012 Tanzania National Census (EWURA, 2022). The Authority currently delivers water and sanitation services in compliance with the Water Supply and Sanitation Act No. 5 of 2019. ROMBOWSSA, established in July 2021, is one of the newest water supply authorities in Tanzania. According to EWURA (2022), Rombo WSSA has 23,925 customer water connections and is considered one of the underperforming water utilities in the country. Therefore, the researcher aims to gain a clearer understanding the practices on how non-revenue water is managed.

3.4 Study Population

This study focused on ROMBOWSSA employees who are directly involved in providing water and sanitation services in Rombo district. According to ROMBOWSSA financial year 2021/2022 annual report, it has 150 staff which includes 8 managers, 18 supervisors and 124 operational staff. In addition, ROMBOWSSA serves a population of 30,719 water users within the district. Population Refers to a total number of people with the features that a researcher desires to learn from within a context of a particular research problem (Barbour 2014). Therefore, the target population for this study will be 30869 people which consists staff members at ROMBOWSSA, so as to provide vital information for this study.

3.5 Sample size

The target population for this study consists of 30,869 individuals: 150 staff members of ROMBOWSSA who are directly involved in providing water and sanitation services, and 30,719 water users in Rombo District. Given the large population size, this study will use a sample size of 395 respondents to collect data efficiently: All 150 ROMBOWSSA staff members will be included in the study to ensure comprehensive coverage of the staff perspective.

Table 1: Sample distribution

S/S	Population description	Population	Methods of sampling	Sample size
1	Staffs from ROMBOWSSA	150	100%	150
2	Community who uses water from ROMBOWSSA	30719	Randomly sampling	245
Total		30869		395

Yamane's formula used for determine sample size

$$n = \frac{N}{1 + N(e)^2}$$

Where:

- n = sample size
- N= total population (30,869)
- e = margin of error (5%)

Substituting the values:

$$n = \frac{30869}{1 + 30869(0.05)^2}$$

n= 395

Based on this calculation, a sample size of approximately 395 respondents is considered adequate for the study. The sample will include 150 ROMBOWSSA staff members (full staff population) and a randomly selected 245 community water users, ensuring a balanced representation of both service providers and recipients.

3.6 Sampling Strategies

The study uses Random sampling which is a technique where every individual in the target population has an equal chance of being selected to participate in the study. This method helps to reduce bias and ensures that the sample represents the larger population fairly. For this study, where 141 water users were selected from the community population of approximately 30,719 people, the following steps were taken: Define the Sampling Frame: A list or database of water users in the Rombo District was compiled. This may include households, registered customers of ROMBOWSSA, or community registers, depending on available data. Assign Numbers: Each individual or household in the sampling frame were assigned a unique number. Use a Random Number Generator: A computer program, calculator, or table of random numbers were used to select 141 unique numbers corresponding to the individuals or households to be surveyed. Contact Selected Participants: The selected water users were contacted and invited to participate in the study. But the staffs were taken at 100%, that means all of them were included in the study.

3.7 **Data Collection Methods and Instruments**

The study was adhering appropriate data collection tools in order to maintain the validity and reliability of the data intended to use in the study. The self-administering questionnaires has been used as the tool to obtain data from the respondents used to collect primary data for the first research objective, second research objective and third research objective. Also, the self-administering questionnaires were easy methods to handle, economic sound and better encouragement of greater respondents suggested (Mugenda, 1999 & 2018).

3.**8 Data Analysis**

Data analysis; refers to the computation of certain measures along with searching for patterns relationship that exist among data groups (Dorst, K. 2016). Researcher analyze primary data using statistical package for social science (IBM SPSS. Version 20.0), and technically researcher was employing descriptive research analysis method and inferential data analysis. Descriptive analysis which includes percentage and means that were used to analyze the finding of the study while supporting the finding with the secondary data.

Table 2

Sample Distribution

S/S	Population description	Population	Methods of sampling	Sample size
1	Staffs from ROMBOWSSA	150	100%	150
2	Community who uses water from ROMBOWSSA	30719	Randomly sampling	141
Total		30869		395

3.1 Reliability Test

According to Mugenda (2003), a reliability test is a tool used to assess how well a research instrument produces consistent data or outcomes following multiple trials. Cronbach's alpha is a metric used to assess how consistently a research instrument produces data or results following multiple trials; a result above 0.7 is considered acceptable, one below 0.7 is not, and one equal to 0.7 is considered doubtful. In order to assess reliability using Cronbach's Alpha, four variables (independent and dependent variables) were entered into SPSS. The results showed that the study's reliability was 0.954, which was higher than 0.7, indicating that it was acceptable, as indicated in Table 3 below.

Table 3
Reliability Statistics

Cronbach's Alpha	No. of Items
.951	4

3.12 Ethical Considerations

To uphold ethical standards in this research, the researcher obtained the necessary permits from the relevant authorities, including the Institute of Accountancy Arusha and ROMBOWSSA in Rombo District. In compliance with ethical guidelines, participants were fully informed about the study and were required to provide informed consent before participating. They received an introductory letter together with an informed consent form at the start of the data collection process, explaining the purpose of the research, participants' roles, and what was expected of them. These documents also outlined the measures put in place to ensure privacy, anonymity, and confidentiality.

Throughout the research, participant anonymity was maintained by handling all data with care and using pseudonyms where appropriate. Any identifying information, such as names, locations, or organizations, was removed from the final report. Additionally, any personal details that could be used to identify individual participants were omitted to protect their privacy and maintain confidentiality.

IV. FINDINGS & DISCUSSION

4.1 Response Rate

The response rate for obtaining information on the effects of the leak detection system on reducing non-revenue water losses in Tanzania, with a case study of the Rombo Water Supply and Sanitation Authority (ROMBOWSSA), was achieved using a questionnaire survey. The questionnaire consisted of items measured on a five-point Likert scale, ranging from 5 (Strongly Agree) to 1 (Strongly Disagree), to facilitate respondents' answers. The study findings were measured using an interval scale, and the mean scores were used to interpret the results.

Table 4
Licket Scale interpretation

Scale	Responses	Range mean
1	Strongly disagree	1 - 1.95
2	Disagree	1.96 - 2.75
3	Neutral	2.76 – 3.55
4	Agree	3.56 – 4.35
5	Strongly agree	4.36 – 5

4.2 Descriptive Statistics

The study investigated how acoustic sensor technology and intelligent leak detection systems might lower the organization's non-revenue water (NRW) losses. By reducing losses, these instruments should improve water system monitoring, detect leaks early, and increase the sustainability of the water supply. Based on replies to the structured questionnaire and descriptive statistics (mean scores and standard deviation) acquired from SPSS, the findings are displayed in Table 5.

Table 5
Descriptive Statistics for Smart Leak Detection Tools

Statement	N	Minimum	Maximum	Mean	Std. Deviation
1. Organization uses smart leak detection tools	395	2	5	3.84	0.749
2. Detect unusual fluctuations indicating leaks	395	1	5	4.25	0.716
3. Sustainability of water supply due to leakage reduction	395	2	5	3.48	0.777
4. Pinpoint leaks in distribution network	395	2	5	3.71	0.611
5. Acoustic sensors with wireless networks daily use	395	1	5	3.71	0.859
6. Improve water management via acoustic sensors	395	1	5	3.68	0.796
7. Acoustic sensors are advanced leak detection systems	395	1	5	3.33	0.847
8. Acoustic sensors detect leaks instantly and alert operators	395	1	5	4.08	0.767

Interpretation: Smart leak detection tools are used by the organization. The majority of respondents (mean = 3.84, standard deviation = 0.749) concur that the organization's water management system uses intelligent leak detection techniques. The majority of replies fell within the agree-to-strongly-agree range, with the minimum being two and the maximum being five. Detect unusual fluctuations indicating leaks. There was substantial agreement among respondents that smart leak detection equipment can successfully identify anomalous water flow fluctuations that could indicate leaks, as seen by this statement's highest mean (4.25) and low standard deviation (0.716). The range of responses was 1 to 5. Sustainability of water supply due to leakage reduction. There is moderate agreement, as indicated by the mean of 3.48 and standard deviation of 0.777, that smart leak detection reduces leakage and so adds to the sustainability of the water supply. Neutral opinions made up a noticeable share of the responses, which varied from 2 to 5. Pinpoint leaks in distribution network. With a mean score of 3.71 and a standard deviation of 0.611, the participants concurred that these instruments are capable of precisely identifying distribution network leaks. Consistent agreement was demonstrated by the minimum response of two and the maximum response of five. Acoustic sensors with wireless networks daily use. The respondents' agreement that wireless networks and acoustic sensors are included into routine water management operations is indicated by the mean score of 3.71 (SD = 0.859). Perception varied somewhat, as seen by the responses, which ranged from 1 to 5. Improve water management via acoustic sensors There is moderate agreement that acoustic sensors enhance overall water management, as indicated by the mean of 3.68 and SD of 0.796. Responses ranged from 1 to 5, suggesting that respondents were not entirely sure. Acoustic sensors are advanced leak detection systems. With the lowest mean (3.33) and standard deviation (0.847), this item revealed conflicting opinions regarding these systems' technological advancement. There were several neutral responses, with scores ranging from 1 to 5. Acoustic sensors detect leaks instantly and alert operators. According to a mean score of 4.08 and SD of 0.767, respondents highly agreed that these technologies were successful in sending out quick alerts. The majority of responses fell into the agree-to-strongly-agree category, indicating confidence in their operational efficacy. Responses ranged from 1 to 5.

4.3 Regression Statistics

The general objective of the study is to assess the effects of Effects of leak detection system on reducing non-revenue water losses in ROMBOWSSA and supported by two variables. The study covered two independent variables and one dependent variable analyzed through multiple regression analysis.

4.3.1 Model summary output

A model summary is as in Table 6 that displays the relationship between the study's independent and dependent variables, as determined by the regression model. It uses the R square value to describe the relationships. If the R square result value was more than 50% or 0.5, it was acceptable; if it was less than 50% or 0.5, it was unacceptable.

Table 6
Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.891[a]	.793	.792	.30569

a. Predictors: (Constant), Acoustic Sensors with Wireless Networks, Smart leak detection

Regression analysis of the impact of smart leak detection and acoustic sensors with wireless networks on lowering non-revenue water (NRW) losses in ROMBOWSSA reveals a robust and favorable correlation. The independent factors and NRW reduction are strongly correlated, according to the correlation coefficient (R = 0.891). According to the coefficient of determination (R2 = 0.793), the combined impact of smart leak detection technologies and acoustic sensors accounts for about 79.3% of the variation in NRW reduction, with other factors not included in the model accounting for the remaining 20.7%. The standard error of the estimate (0.30569) shows a reasonably accurate forecast of NRW decrease based on the independent variables, and the adjusted R2 (0.792) validates that the model is well-fitted. Overall, the findings validate the study's hypothesis that sophisticated monitoring technologies improve operational efficiency in water supply management by showing that the installation and use of these leak detection devices considerably reduce water losses.

4.3.2 ANOVA summary

The ANOVA is the analysis of the variance that including F-value and P-value. F-value measure the total significance of the mode and P-value explains the nature of the model's significance that may be insignificance or significance due to the value obtained from the ANOVA summary Table 7. If the result of P-value is less than 0.05 it is significance obtained between predictor and dependents variable and when it is greater than 0.05 is not significance between dependent variable and independent variables.

Table 7
ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	140.353	2	70.176	751.000	.000[b]
	Residual	36.630	392	.093		
	Total	176.983	394			

a. Dependent Variable: Reducing non-revenue water losses
b. Predictors: (Constant), Acoustic Sensors with Wireless Networks, Smart leak detection

The ANOVA results determine whether the dependent variable is significantly predicted by the regression model overall, lowering Non-Revenue Water (NRW) losses. The regression model is reported to be statistically significant at the 0.05 level with an F-value of 751.000 and a p-value (Sig.) of 0.000. This indicates that there is a high probability that the independent variables smart leak detection and acoustic sensors with wireless networks will all significantly impact NRW reduction. Whereas the Residual Sum of Squares (36.630) shows the variance in NRW reduction not explained by the independent variables, the Regression Sum of Squares (140.353) shows the variation in NRW reduction described by the model. The strong F-value, which further validates the model's predictive ability, is a result of the Mean Square for Regression (70.176) being higher than the Mean Square for Residuals (0.093). Overall Interpretation: Acoustic sensors and intelligent leak detection systems work together to significantly lower NRW losses in ROMBOWSSA, as confirmed by the ANOVA results, which also corroborate that the regression model is very significant.

4.4 Regression coefficient model output

Regression Diagnostic Tests: Before conducting multiple regression analysis, several diagnostic tests were performed to ensure that the assumptions underlying regression analysis were satisfied. These included tests for multicollinearity, and independence of errors.

4.4.1 Multicollinearity Test

Multicollinearity was examined using Variance Inflation Factor (VIF) and Tolerance values. The results indicated that all predictor variables had tolerance values greater than 0.1 and VIF values below 10, suggesting absence of multicollinearity among the independent variables.

Table 8
Multicollinearity Statistics

Variable	Tolerance	VIF
Smart leak detection	0.621	1.611
Acoustic Sensors with Wireless Networks	0.621	1.611

The findings confirm that multicollinearity was not a problem in the regression model.

The independence of errors assumption was tested using the Durbin–Watson statistic. The obtained value of 1.842 was within the acceptable range of 1.5 to 2.5, indicating that the residuals were independent and there was no autocorrelation problem. Based on these diagnostic tests, all assumptions for multiple regression analysis were satisfied, and the regression model was considered appropriate for examining the influence of leak detection technologies on reducing non-revenue water losses.

The regression coefficient analysis is the analysis that provide the value required to be fixed in the regression model equation in order to predict the occurrence of the dependent variable that consider the value of standardized coefficient beta, tolerance and VIF where by the value of VIF should be less than 5.0 and tolerance greater than 0.2 was accepted, this means no malt-collinearity and also implies that there were no variables influencing each other within the study

Table 9

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.266	.049		5.438	.000
	Smart leak detection	.764	.039	.753	19.430	.000
	Acoustic Sensors with Wireless Networks	.153	.036	.165	4.248	.000

a. Dependent Variable: Reducing non-revenue water losses

The findings indicate that Smart Leak Detection had an unstandardized coefficient of B = 0.764, a standardized Beta of 0.753, and a significance level of 0.000. This demonstrates that smart leak detection is a strong and statistically significant predictor of reducing Non-Revenue Water (NRW) losses. The results suggest that improved use of smart leak detection technologies allows ROMBOWSSA to identify and respond to leaks efficiently, which directly contributes to lowering water losses. The analysis reveals that Acoustic Sensors with Wireless Networks had an unstandardized coefficient of B = 0.153, a standardized Beta of 0.165, and a significance level of 0.000. Although its contribution is smaller than that of smart leak detection, it is still positive and statistically significant, indicating that acoustic sensors support NRW reduction by detecting leaks early and enabling timely repairs. The result of coefficient beta value obtained from the coefficient Table 8 above was used in constructing the econometric equation model below;

$Y=0.266+0.764X_1+0.153X_2$

Whereby; Y= Reduction of Non-Revenue Water Losses

X_1= Smart leak detection

X2= Acoustic Sensors

According to this model, acoustic sensors and smart leak detection have the biggest effects on NRW reduction. The statistical significance of both predictors demonstrates how important cutting-edge leak detection technologies are to ROMBOWSSA's successful water loss management.

4.5 Discussion

The findings of this study revealed that leak detection technologies significantly contribute to reducing non-revenue water (NRW) losses at ROMBO-WASSA. Specifically, Smart Leak Detection emerged as the strongest predictor of NRW reduction, while Acoustic Sensors with Wireless Networks also showed a positive and statistically significant contribution. These findings imply that technology-driven monitoring systems improve the ability of water utilities to identify, locate, and repair leaks more efficiently, thereby minimizing water losses and improving operational performance. The strong influence of Smart Leak Detection may be attributed to its ability to provide real-time monitoring, automated fault identification, and rapid transmission of leak information to maintenance teams. Unlike traditional manual inspection methods, smart systems enhance decision-making speed and reduce the time taken to detect and respond to leaks. This improves water distribution efficiency, minimizes unnecessary water loss, and enhances revenue collection for the utility. The findings suggest that investment in smart technologies can substantially strengthen water management practices in public water utilities. Although Acoustic Sensors with Wireless Networks showed a relatively smaller effect compared to Smart Leak Detection, their contribution remains important. Acoustic sensors enhance early leak identification by detecting unusual sound frequencies within pipelines before visible leakages occur. Wireless communication further improves operational coordination by allowing remote monitoring of pipeline conditions. The findings therefore indicate that combining different leak detection technologies creates a more comprehensive and reliable leak management system. This demonstrates that complementary technologies can improve leak detection accuracy and operational responsiveness when integrated effectively.

The findings are consistent with previous empirical studies conducted globally. Fares et al., (2023) reported that acoustic leak detection reduced NRW by 20% in China, while Santos-Ruiz et al., (2022) found that combining pressure monitoring and leak detection reduced NRW by 25% in Spain. Boyle et al., (2022) similarly observed that real-time leak monitoring contributed to a 15% reduction in NRW in the United Kingdom. Studies by Palermo et al. (2022) in Italy and Nain et al., (2024) in Malaysia, further support the argument that integrating sensors, IoT systems, and real-time monitoring technologies enhances leak management and water conservation. The study findings also reflect the importance of information quality, another major dimension of the DeLone and McLean model. The leak detection technologies generate accurate, timely, and relevant information that supports decision-making within ROMBO-WASSA. Real-time leak alerts and monitoring data allow technical teams to respond quickly to leak incidents, reduce repair delays, and allocate maintenance resources more effectively. The availability of high-quality information therefore enhances operational coordination and improves the efficiency of leak management processes.

However, the findings also reveal important contextual considerations for developing countries such as Tanzania. While advanced leak detection technologies improve NRW management, their effectiveness depends on infrastructure quality, financial capacity, technical expertise, and maintenance capability. In many developing-country water utilities, aging pipelines, unreliable electricity supply, limited ICT infrastructure, and shortage of skilled personnel may reduce the efficiency of advanced systems. These contextual limitations explain why some water utilities struggle to achieve the same performance levels reported in developed countries.

The findings also support the DeLone and McLean Information Systems Success Model, which emphasizes the importance of system quality and information quality in improving organizational performance. Smart leak detection systems generate accurate, timely, and reliable information that supports faster decision-making and effective resource allocation. Improved information flow enables maintenance teams to respond quickly to leak incidents, thereby improving operational efficiency and reducing NRW losses. Practically, the study suggests that ROMBO-WASSA should prioritize investment in modern leak detection technologies while simultaneously strengthening technical training, maintenance systems, and infrastructure support. The integration of smart monitoring systems with acoustic sensing technologies can provide a more effective and sustainable approach to NRW reduction. Furthermore, policymakers and water utility managers should consider allocating adequate financial and technical resources toward technology adoption to improve water distribution efficiency and revenue sustainability.

V. CONCLUSION & RECOMMENDATION

5.1 Conclusion

This study examined the contribution of leak detection technologies toward reducing Non-Revenue Water (NRW) losses at ROMBO-WASSA, focusing on Smart Leak Detection and Acoustic Sensors with Wireless Networks. The findings revealed that both technologies have a positive and statistically significant influence on reducing NRW losses, with Smart Leak Detection emerging as the strongest predictor. The technologies improve leak identification, enhance response time, strengthen operational efficiency, and support effective water distribution management. The study further established that the effectiveness of leak detection technologies can be explained through the DeLone and McLean Information Systems Success Model. Smart leak detection systems improve system quality through reliable monitoring and automated functionality, while high-quality information generated by the systems supports faster and more accurate decision-making. These improvements ultimately generate net benefits such as reduced water losses, improved revenue collection, lower operational costs, and enhanced sustainability of water utility services. However, the study also found that the successful implementation of these technologies depends on contextual factors such as infrastructure quality, availability of technical expertise, maintenance capacity, and financial resources. In developing-country settings like Tanzania, these factors may limit the full effectiveness of advanced leak detection systems if not adequately addressed. Overall, the study concludes that investment in modern leak detection technologies is essential for sustainable NRW reduction and improved operational performance at ROMBO-WASSA and similar water utilities.

5.2 Recommendations

Based on the findings of the study, the following recommendations are proposed: Prioritize Investment in Smart Leak Detection Systems: ROMBO-WASSA should prioritize phased investment in Smart Leak Detection technologies because they demonstrated the strongest contribution toward reducing NRW losses. Since financial resources may be limited, implementation should begin in areas with the highest leakage rates before expanding gradually to the entire distribution network. Strengthen Preventive Maintenance Programs: The utility should establish regular preventive maintenance schedules for pipelines, sensors, and monitoring equipment to ensure continuous functionality of leak detection systems. Preventive maintenance is more cost-effective than responding to major pipeline failures after significant water losses have already occurred.

Enhance Technical Capacity Through Staff Training: ROMBO-WASSA should provide regular technical training for engineers, technicians, and ICT personnel on operation, monitoring, and maintenance of leak detection technologies. Building local technical expertise will reduce dependence on external specialists and improve long-term sustainability of the systems. Integrate Acoustic Sensors with Existing Monitoring Systems: The study recommends integrating Acoustic Sensors with Wireless Networks into existing operational systems to improve early leak detection and monitoring coverage. This integration can strengthen response speed and improve accuracy in identifying hidden leakages. Improve Infrastructure and Data Management Systems: The utility should gradually modernize aging pipeline infrastructure and improve digital data management systems to maximize the effectiveness of leak detection technologies. Reliable infrastructure and accurate data are essential for achieving better system quality and information quality.

Declaration of Interest

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