Optimizing Pressure Management Strategies for Sustainable Reduction of Non-Revenue Water

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Abstract
This study explores the optimization of pressure management strategies to achieve a sustainable reduction in Non-Revenue Water (NRW) within the Metro Naga Water District (MNWD). NRW, comprising physical leaks, bursts, and commercial losses, poses a significant threat to water security, financial viability, and service reliability. As global water stress intensifies, the necessity for efficient hydraulic management becomes paramount to ensure equitable distribution and resource conservation. The research employed descriptive-correlational and developmental design. Quantitative data were gathered through a survey of 377 concessionaires using a validated five-point Likert scale (Cronbach's alpha = 0.980) to assess service quality, management efficiency, and sustainability. Technical analysis involved reviewing MNWD archival data and hydraulic reports to identify high-loss zones. Qualitative insights were obtained through purposive interviews with key management personnel to evaluate the feasibility of the proposed strategic interventions. The findings reveal a direct correlation between stabilized water pressure and increased public trust in utility sustainability. While MNWD demonstrates a strong "Sustainability-First" organizational profile, localized pressure disparities ranging from 0 psi in peripheral areas to high pressure zones, contribute to recurring pipe bursts and leakage. The study concluded that manual hydraulic corrections are insufficient for long-term NRW control. Consequently, a Strategic Action Plan was developed, focusing on "Smart Water" governance. Key recommendations include the integration of District Metered Areas (DMAs) with automated Pressure Reducing Valves (PRVs), real-time digital monitoring, and enhanced community engagement to shift from reactive maintenance to proactive, data-driven pressure management.

Keywords: Non-Revenue Water (NRW), Pressure Management, Sustainable Water Utility, Metro Naga Water District (MNWD), Hydraulic Optimization

1. Introduction

Water is essential for sustaining life, supporting health, agriculture, industry, and ecosystems. Despite its importance, the world faces a growing water crisis marked by scarcity, pollution, and inefficient management. The Food and Agriculture Organization (FAO, 2017) highlights water's fundamental role in food security, energy, health, and ecosystem stability [1]. However, rapid population growth, urbanization, industrialization, and climate change have intensified pressure on water resources. As demand increasingly outpaces supply, the risk of shortages and environmental degradation rises. The United Nations (UN, 2019) projects that by 2050, nearly two-thirds of the global population may experience water stress, threatening human health, economic stability, and environmental sustainability [2].

A major contributor to this crisis is Non-Revenue Water (NRW), or water lost before reaching consumers due to leaks, illegal connections, meter inaccuracies, and administrative inefficiencies. In many developing countries, NRW exceeds 50%, resulting in significant resource wastage and financial losses (African Water Association, 2017) [3]. The World Bank (2016) reports that utilities lose billions of liters annually due to such inefficiencies [4]. Physical losses, often linked to aging infrastructure and excessive pressure, are a major component of NRW. Managing pressure within distribution systems is therefore critical, as high pressure accelerates pipe deterioration and leakage (Misiunas et al., 2014) [5].
Pressure management has emerged as an effective strategy for reducing NRW by controlling system pressure to minimize leaks and improve performance (Faruqui et al., 2012; IWA, 2014) [6, 7]. Technological advancements, including smart sensors and SCADA systems, have enabled real-time monitoring and dynamic control. However, adoption remains uneven due to high costs, limited technical expertise, and weak institutional frameworks (World Bank, 2016) [3]. Countries such as those in Europe, North America, and Australia have demonstrated NRW reductions of up to 30% through effective pressure management (DEFRA, 2019; Water Services Association of Australia, 2018) [8, 9]. These efforts align with global initiatives such as the UN Decade of Action on Water for Sustainable Development (2018–2028) and contribute directly to Sustainable Development Goals (SDGs), particularly SDG 6 on water efficiency and SDG 9 on resilient infrastructure (UN, 2015; World Bank, 2016) [2, 4].
In the Philippines, water resource management is challenged by rapid urbanization, population growth, and climate variability. Many urban water utilities experience NRW levels of 50–60%, significantly reducing supply and increasing operational costs (NWRB, 2019) [10]. Aging infrastructure, inadequate leak detection, poor metering, and weak institutional coordination further exacerbate losses. Although pilot programs supported by agencies such as the Asian Development Bank (ADB) have introduced leak detection and rehabilitation initiatives, large-scale implementation remains limited due to financial and technical constraints.
National policies provide a framework for addressing these challenges. The Philippine Water Crisis Act of 1995 (Republic Act No. 8041) mandates urgent measures to reduce water waste and pilferage. Similarly, the Philippine Development Plan (2023–2028) and the Philippine Water Supply and Sanitation Master Plan (2019–2030) prioritize NRW reduction and improved governance to achieve universal access to safe water (NEDA, 2019; NEDA, 2023) [11, 12]. These policies emphasize the need to integrate technical solutions with institutional reforms, capacity building, and sustainable financing.
The Bicol Region illustrates the localized nature of these challenges. Its diverse topography and climate, characterized by heavy rainfall, typhoons, and seasonal droughts, affect water availability and infrastructure resilience. Water utilities in the region report NRW levels ranging from 40% to 70%, largely due to leaks, illegal connections, inadequate metering, and lack of pressure regulation (RDC Bicol, 2020) [13]. These losses result in intermittent supply, limited coverage, and high operational costs. Climate-related disruptions further strain already vulnerable systems. Despite these constraints, local initiatives demonstrate the potential of cost-effective interventions. In Legazpi City, targeted leak repairs and simple pressure regulation reduced NRW by 15–20% within one year (Local Water Utility, 2021) [14]. Such cases highlight the importance of context-specific and scalable solutions, particularly for resource-constrained utilities.
Given these conditions, pressure management presents a practical and cost-effective approach to reducing physical water losses, improving system efficiency, and extending infrastructure lifespan. However, its success depends on adapting strategies to local conditions, institutional capacity, and available resources.

This study therefore aims to examine how pressure management strategies can be optimized for local contexts, bridging the gap between global best practices and practical implementation. It also seeks to identify adaptable and low-cost approaches, including community-based leak detection and real-time monitoring.

1.1 Objectives of the Study

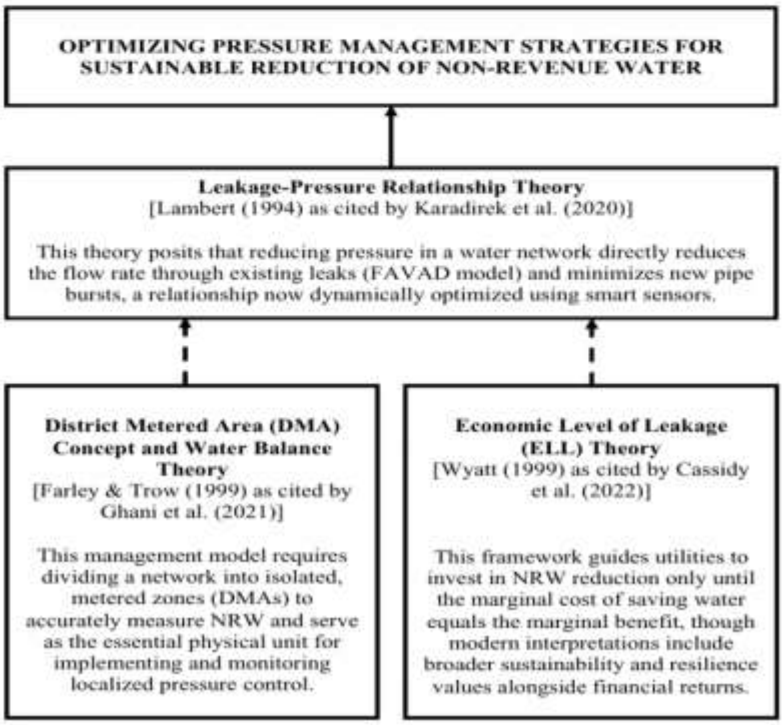
This study aims to develop a sustainable and effective pressure management framework for the Metro Naga Water District (MNWD) water distribution system that ensures long-term control of non-revenue water and enhances service reliability. Specifically, this will achieve the following objectives:

1. To assess existing pressure management practices in the MNWD system in terms of their efficiency, service quality, and sustainability over time.
2. To identify critical pressure zones within the distribution network that significantly contribute to water wastage, such as leakage, pipe bursts, and unauthorized consumption.
3. To analyze the relationship between the average water pressure (ave. PSI) and pressure management practices within these identified zones.
4. To develop a strategic action plan for sustainable pressure management aimed at achieving continuous reductions in non-revenue water and improving overall service performance.
5. To evaluate the level of acceptability and potential adoption of the proposed strategic action plan among key stakeholders and system implementers.

1.2 Theoretical Framework of the Study

Figure 1 show the three complementary theories used to analyze and guide the adoption, implementation, and effectiveness of pressure management strategies for NRW reduction. Specifically, Leakage-Pressure Relationship (LPR), District Metered Area (DMA) Concept and Water Balance, and Economic Level of Leakage (ELL).

Figure 1 Theoretical Paradigm



The LPR Theory explains that leakage is directly influenced by pressure within the distribution system; reducing pressure decreases both the rate of existing leaks and the likelihood of new pipe bursts caused by stress on aging infrastructure (Savić et al., 2008) [15]. Lambert's FAVAD model further quantifies this relationship, showing that leakage flow is proportional to pressure raised to a specific exponent (Lambert, 1994) [16]. Pressure management applies this principle by maintaining the minimum required pressure while ensuring adequate service levels, thereby minimizing system-wide losses. Recent developments highlight a shift from static pressure reduction to Dynamic Pressure Management (DPM), where pressure is continuously adjusted based on demand and time-of-day using smart sensors and SCADA systems. This approach enhances leakage reduction and energy efficiency without compromising service delivery (Karadirek et al., 2020) [17].

The DMA concept complements pressure management by dividing distribution networks into smaller, isolated zones with measured inflows (Farley & Trow, 1999) [18]. Using the IWA Water Balance framework, utilities can quantify NRW within each zone by comparing input volume with billed consumption. This segmentation enables more precise monitoring and control, making it essential for effective pressure regulation through devices such as Pressure Reducing Valves (PRVs) (Liemberger & Wyatt, 2019) [19]. Recent advancements extend the DMA concept into data-driven applications, where high-frequency flow and pressure data support predictive analytics. Integrating digital twins and machine learning allows utilities to detect leaks faster, predict pipe failures, and optimize pressure settings in real time, transforming DMAs into "smart zones" for continuous system optimization (Ghani et al., 2021) [20].

The ELL Theory provides an economic framework for NRW reduction, proposing that investments in leakage control should continue only until the marginal cost of reduction equals the marginal benefit (Liemberger & Wyatt, 1999) [19]. Since leakage reduction exhibits diminishing returns, the goal is not zero loss but an optimal, cost-effective level. Pressure management contributes to achieving a lower ELL by improving the cost-efficiency of leakage reduction (Lambert et al., 2014) [21]. Contemporary interpretations expand this framework by incorporating sustainability and resilience considerations, including reduced energy use, lower carbon emissions, improved drought resilience, and enhanced social equity. These broader benefits suggest that a socially and environmentally optimal ELL may be lower than the purely economic threshold, strengthening the case for advanced pressure management strategies even when immediate financial returns are limited (Cassidy et al., 2022) [22].

2. Methodology

This study employed a descriptive–correlational design with a developmental component to examine Non-Revenue Water (NRW) in the Metropolitan Naga Water District (MNWD). The descriptive phase profiled existing pressure management practices in terms of efficiency, service quality, and sustainability using archival data, hydraulic modeling, and key performance indicators (Mutikanga et al., 2011) [23]. It also identified critical pressure zones within the distribution network that significantly contribute to water wastage, including leakage, pipe bursts, and unauthorized consumption (Al Washali et al., 2017) [24]. The correlational phase analyzed the relationship between the average water pressure (ave. PSI) and pressure management practices within these identified zones, establishing an empirical basis for intervention (Tušar et al., 2014) [25]. The developmental component then utilized these findings to develop a strategic action plan for sustainable pressure management aimed at reducing NRW and improving service performance (Savić et al., 2011) [26]. Finally, qualitative methods, including structured interviews, were used to evaluate the level of acceptability and potential adoption of the proposed strategic action plan among key

stakeholders and system implementers (Lee et al., 2019) [27].
A multi-tiered sampling approach was used. For assessing service quality, 377 concessionaires were selected through probability sampling based on a 95% confidence level and 5% margin of error, ensuring representative data on customer perceptions of pressure adequacy and supply reliability. For evaluating pressure management practices and the acceptability of the proposed strategic action plan, purposive sampling was used to select key MNWD personnel, including Water Resources Engineers, the General Manager, and the Board of Directors (Liwanag et al., 2019; Lavado, 2010) [28, 29]. These respondents provided technical, managerial, and policy-level insights. The triangulation was achieved through documentary analysis of hydraulic reports, NRW logs, and pipeline records, integrating quantitative system data with qualitative perspectives (International Budget Partnership, 2018/2019; Tamondong-Lachica et al., 2024) [30, 31].
Data was collected using mixed instruments. A self-structured survey questionnaire was administered to concessionaires via hard copy and Google Forms to assess pressure management practices in terms of efficiency, service quality, and sustainability. The instrument used a five-point Likert scale and demonstrated high validity (CVI = 5.0) and reliability (Cronbach's alpha = 0.980) following expert validation and pilot testing. An interview protocol was used with engineers, the General Manager, and the Board of Directors to evaluate the acceptability and potential adoption of the Strategic Action Plan, focusing on perceived strategic value, financial commitment, and institutional readiness.
Data collection began with the administration of survey questionnaires to concessionaires through face-to-face and online platforms to assess pressure management practices in terms of efficiency, service quality, and sustainability. Responses were analyzed using weighted means to determine overall performance levels (Salkind, 2019) [32]. Utility records, including daily water pressure data, hydraulic reports, and pipeline records, were then collected and examined through document analysis to identify critical pressure zones contributing to water wastage, such as leakage and pipe bursts (Bowen, 2009) [33]. The resulting quantitative data were integrated and analyzed using the Pearson Product-Moment Correlation Coefficient to determine the relationship between pressure management practices and average water pressure (Gravetter & Wallnau, 2017) [34]. Based on these findings, a modified ADDIE model was applied to develop a strategic action plan for sustainable pressure management (Branch, 2009) [35]. Structured interviews with MNWD Board members and management were subsequently conducted, and the responses were analyzed using thematic analysis to assess the acceptability and potential adoption of the proposed plan (Braun & Clarke, 2006) [36].
Ethical clearance was obtained, along with formal approval from MNWD. All procedures complied with the Philippine Data Privacy Act of 2012 (RA 10173). Informed consent was secured from all participants, emphasizing voluntary participation and the right to withdraw at any time. Confidentiality was strictly maintained: survey responses were anonymized, and key informants were identified using pseudonyms or role descriptors. A Data Use Agreement ensured that archival utility data were used only for aggregated analysis. The study adhered to principles of beneficence and research integrity, ensuring transparency and minimizing bias (Shamoo & Resnik, 2015) [37].

3. Results and Discussion

3.1 Assessment of Pressure Management Practices in MNWD

3.1.1 Efficiency

Table 1 presents the assessment of pressure management practices at the Metropolitan Naga Water District

(MNWD) in terms of efficiency, yielding an overall mean of 3.75, interpreted as "Often Observed." Among the indicators, the provision of sufficient advance notice before scheduled maintenance obtained the highest mean (3.86), while the observation of fewer visible water leaks on the streets received the lowest (3.67), although both fall within the same descriptive category. The high rating for advance notice reflects effective communication and operational transparency, suggesting that MNWD minimizes service disruption through proactive information dissemination. In contrast, the lower rating for visible leak reduction points to persistent issues in physical infrastructure, indicating that efficiency is more evident in administrative and communicative processes than in preventive system maintenance.

Overall, the results indicate that MNWD demonstrates strong responsiveness and service-oriented efficiency but has room to improve technical efficiency, particularly in leak prevention. While the consistent "Often Observed" ratings reflect a generally reliable system, the findings suggest a tendency toward reactive management rather than proactive pressure stabilization. Strengthening pressure management as a preventive strategy may reduce infrastructure stress and improve long-term performance. These findings align with existing literature emphasizing the role of proactive pressure management in reducing leak occurrence and extending infrastructure lifespan (Thornton & Lambert, 2005), as well as the importance of effective communication in enhancing service efficiency (Liemberger & Wyatt, 2019) [38, 19].

3.1.2 Service Quality

For service quality, Table 1 shows an overall mean of 3.69, interpreted as "Often Observed." Among the indicators, the quality and clarity of water remaining good even after periods of low pressure obtained the highest mean (3.77), while the experience of consistent water pressure regardless of the time of day received the lowest (3.61), although both fall within the same descriptive category. The high rating for water clarity indicates that pressure fluctuations do not significantly disturb pipe sediments or biofilms, reflecting effective management of water quality. In contrast, the lower rating for pressure consistency suggests that peak-hour demand still results in noticeable pressure variations. These results indicate that

Table 1: Assessment of Pressure Management Practices in terms of Efficiency, Service Quality, & Sustainability

Parameters - Efficiency	**Mean**	**Rank**	**Int.**
MNWD provides sufficient advance notice before scheduled maintenance that might affect water pressure.	3.86	1	OO
When I report a leak or a pressure issue, MNWD personnel respond and resolve it quickly.	3.78	2	OO
I feel that the water pressure I receive is worth the amount I pay on my monthly bill.	3.69	4	OO
MNWD uses modern methods (like social media or SMS) to keep customers updated on pressure-related issues.	3.76	3	OO
I have seen fewer visible water leaks on the streets in my area over the past year.	3.67	5	OO
Overall Mean - Efficiency	**3.75**		**OO**

Parameters – Service Quality	Mean	Rank	Int.
The water pressure in my home is strong enough to meet all my daily needs (showering, laundry, etc.).	3.69	2	OO
I experience consistent water pressure regardless of the time of day.	3.61	5	OO
My water supply is rarely interrupted by sudden pipe bursts or leaks in my neighborhood.	3.67	4	OO
When I turn on the tap, the water flow is steady and does not sputter or fluctuate.	3.68	3	OO
The quality/clarity of my water remains good even after a period of low pressure.	3.77	1	OO
Overall Mean – Service Quality	**3.69**		**OO**
Parameters – Sustainability	**Mean**	**Rank**	**Int.**
I trust that MNWD is managing our water supply well enough to prevent future water shortages.	3.86	5	OO
I believe MNWD is actively upgrading its pipes and equipment to provide better service for the future.	3.88	4	OO
I am confident that my household will continue to have adequate water pressure five years from now.	3.90	3	OO
MNWD effectively encourages customers to conserve water and report wastage.	3.98	1	OO
Overall, I am satisfied with how MNWD balances providing strong pressure while protecting our local water sources.	3.94	2	OO
Overall Mean - Sustainability	**3.91**		**OO**

Note. 1.00-1.50 Not Observed (NO); 1.51-2.49 Rarely Observed (RO); 2.50-3.49 Sometimes Observed (SO); 3.50-4.49 Often Observed (OO); 4.50-5.00 Always Observed (AO)

MNWD provides reliable service in terms of water safety and aesthetics but lacks consistency in delivery pressure. While consumers are generally satisfied with water quality, they experience variability in flow between peak and off-peak periods, indicating that current practices have not fully stabilized pressure levels. This suggests that, although filtration and system controls are adequate, pressure regulation during high-demand cycles remains a concern. The findings align with the SERVQUAL model, where reliability and tangibles influence user satisfaction (Ismail & Yunan, 2016), and support evidence that consistency in supply is a key driver of consumer trust (Ogata et al., 2026), while effective management of transient events contributes to maintaining water clarity (West Virginia University, 2024) [39, 40, 41].

3.1.3 Sustainability

Table 1 presents the assessment of pressure management practices at the Metropolitan Naga Water District (MNWD) in terms of sustainability, with an overall mean of 3.91, interpreted as “Often Observed.” The highest-rated indicator is the effective encouragement of customers to conserve water and report wastage (mean = 3.98), while trust in the water district’s ability to prevent future shortages received the lowest rating (mean = 3.86), although both remain within the same category. The high ranking for conservation efforts indicate strong community engagement and effective demand-side management, reflecting an active partnership between the utility and its consumers. In contrast, the lower rating on shortage prevention suggests a gap in public confidence regarding the system’s long-term reliability.

These findings indicate that MNWD’s sustainability efforts are perceived as effective in promoting conservation but less convincing in ensuring long-term water security. While consumers actively participate in conservation initiatives, concerns remain about whether these efforts are sufficient to address broader environmental and population pressures. This suggests that, although communication and outreach are strong, greater emphasis on demonstrating long-term system capacity and resilience is needed. The results align with the Integrated Water Resources Management framework, which highlights the need to balance technical infrastructure and social participation (GWP, 2024), and with studies emphasizing that demand-side strategies must be supported by visible, climate-resilient infrastructure to strengthen public trust (World Bank, 2025; United Nations, 2024) [42, 43, 44].

3.2.Identification of Critical Pressure Zones Within the Distribution Network

Table 2 presents the results of a pressure survey across 36 locations, revealing clear hydraulic stratification into three zones: high-pressure (above 30 psi), moderate or fluctuating (10–29 psi), and critical low-pressure (0–9 psi). The highest sustained pressure was recorded in San Juan, Magarao (62 psi average; 76 psi peak), while the most severe deficits were observed in Gainza Proper and Malbong, Gainza, both consistently registering 0 psi. The distribution highlights significant disparities across locations, with core areas such as Km-9 Pacol (45 psi) and Carolina Proper (42 psi) maintaining stable pressure, while mid-tier areas like Villa Corazon (28 psi) and Cor. Magsaysay (24 psi) show moderate levels. In contrast, fringe areas—including Poro, Canaman (4 psi), Del Rosario (4 psi), and parts of Gainza (0–9 psi)—experience critically low pressure. Additionally, locations such as Bell, Magarao exhibit significant diurnal variation, with pressure rising from 29 psi in the morning to 52 psi in the afternoon, indicating instability during demand shifts.

These findings suggest that MNWD's pressure management is hydraulically centralized, with high-pressure concentrations near supply sources and inadequate distribution toward peripheral areas. The presence of 0 psi readings indicates a failure in achieving equitable service delivery, reflecting imbalances in pressure zoning that result in over-pressurization in some areas and insufficient supply in others. This pattern aligns with the "Pressure-Service Gap" in urban systems, where peripheral zones experience reduced service due to friction loss and lack of boosting (Mounce et al., 2025) [45]. Such disparities are often associated with the absence of District Metered Areas (DMAs) needed to regulate and redistribute pressure (Arfanuzzaman, 2024), as well as the lack of pressure control mechanisms such as Pressure Reducing Valves (ADB, 2023) [46, 47]. Without these interventions, the observed variability in pressure levels poses risks to both infrastructure and equitable water access, potentially affecting overall system sustainability (World Water Council, 2024) [48].

Table 2: Pressure Survey Results

Location	Average			Daily Average
	6:00am-1:00pm	1:00pm-11:00pm	11:00pm-6:00am	
Palestina, Pili	23	30	31	28
Villa Corazon	20	31	34	28
V.S.S Gate Valve	30	36	40	35
V.S.S Nat'l H-Way	25	34	37	31
Almeda H-Way	17	23	29	22
Fronting Mother Seton	13	20	26	19
Fronting Bombo Radyo	7	12	17	11

Boundary Mabolo	8	13	18	12
San Miguel Mabolo	10	14	23	15
CBD II Terminal	7	12	18	12
Fronting Mother Seton	6	8	15	9
J. Hernandez (Princeton)	6	8	16	9
Felix Plazo	6	8	15	9
Peñafrancia Ave. (Pnp Subs)	12	18	23	17
Cor. Magsaysay/Dyd	19	25	28	24
Cor.B-Bayan Sur/Liboton	16	23	25	21
Capilihan, Calauag	16	22	24	20
Lomeda, San Felipe	16	21	25	20
Km-9 Pacol N.C	50	47	35	45
Cor. Carolina/Hacienda	29	24	13	23
Carolina Proper	42	42	42	42
Panicuason Proper	14	15	16	15
San Isidro Proper	26	39	18	30
Cararayan Proper	31	39	23	33
Villa Obiedo	20	30	18	24
Carangcang, Magarao	28	45	25	35
Pechelitos	15	27	26	23
San Juan , Magarao	52	76	52	62
Bell, Magarao	29	52	29	39
Casuray, Magarao	18	47	26	32
Poro, Canaman	3	5	3	4
Fronting Mother Seton	17	15	15	16
Pnp Dinaga, Canaman	17	15	15	16
Del Rosario, Canaman	4	5	3	4
San Roque, Camaligan	5	6	10	6
Marupit, Camaligan	3	7	10	7
San Pablo, Camaligan	5	7	10	7
Gainza Flow Meter	7	12	20	12
Dahilig, Gainza	3	9	16	9
Gainza Proper	0	0	0	0
Malbong, Gainza	0	0	0	0

3.3 Relationship Between Average Water Pressure and Pressure Management Practices

Table 3 presents Pearson's correlation between average water pressure (Ave. PSI) and key indicators of pressure management practices, namely efficiency, service quality, and sustainability. The results show consistent positive correlations: efficiency ($r = 0.312$, $p = 0.036$), service quality ($r = 0.306$, $p = 0.039$), and sustainability ($r = 0.302$, $p = 0.041$), all statistically significant at the 0.05 level. These findings indicate a weak to moderate positive relationship, suggesting that improvements in average water pressure are associated with corresponding increases in operational efficiency, service quality, and system sustainability. These results suggest that physical pressure performance serves as a key basis for public perception of utility effectiveness. Even small improvements in pressure can enhance perceptions of efficiency, service quality, and sustainability, while weaknesses in one area, such as in efficiency, may affect the others, possibly in perceived service quality and sustainability, due to their strong interrelationship.

Table 3: Relationship Between Average Water Pressure and Pressure Management Practices

		Efficiency	Service Quality	Sustainability
Ave. PSI	Pearson's r	0.312*	0.306*	0.302*
	p-value	0.036	0.039	0.041

Note. H_a is positive correlation; * $p < .05$, ** $p < .01$, *** $p < .001$, one-tailed; df = 32

This supports the view that management interventions should be implemented holistically rather than independently. The findings are consistent with the Hydraulic Perception Model, which emphasizes technical reliability as a driver of institutional trust (Mounce et al., 2025), and with studies indicating that pressure stability is linked to perceived long term water security and service value (Arfanuzzaman, 2024) [45, 46]. Furthermore, the exceptionally high internal correlation between efficiency and service quality aligns with the Service-Profit Chain theory applied to public utilities, where internal operational efficiency is the direct antecedent to external service value (Asian Development Bank, 2023) [47]. This statistical evidence reinforces that maintaining a stable hydraulic gradient is not merely a technical requirement but a strategic necessity for maintaining high community approval ratings (World Water Council, 2024) [48].

3.4 Development of a Strategic Action Plan for Sustainable Pressure Management

The development of the Short-Term Sustainable Pressure Management Proposal began with the analysis phase, which focused on interpreting empirical findings to identify key system issues. Although efficiency (3.75), service quality (3.69), and sustainability (3.91) were all rated as "Often Observed," underlying gaps were evident. Service quality ranked lowest, particularly in terms of pressure consistency, indicating technical instability despite strong administrative performance. The pressure survey revealed significant disparities, with readings ranging from 76 psi in central zones to 0 psi in fringe areas such as Gainza Proper and Malbong, and several locations consistently experiencing critically low pressure. These results indicate hydraulic centralization and distribution imbalance, with zero-pressure zones reflecting service failure and equity concerns. Correlation analysis further showed that average PSI has a significant positive relationship with efficiency, service quality, and sustainability, confirming that pressure conditions directly influence overall system performance. These findings indicate that pressure imbalance, rather than supply shortage, is the primary issue requiring intervention.

The design phase translated these findings into targeted strategies to address identified gaps. To correct hydraulic imbalance, the proposal incorporated system sectorization through District Metered Areas (DMAs), installation of Pressure Reducing Valves (PRVs) in high-pressure zones, and booster systems for critically low-pressure areas. The presence of zero-pressure zones led to the inclusion of priority rehabilitation measures for the Gainza cluster, including dedicated supply support, DMA isolation, and focused leak detection. To address inconsistencies in pressure, pump scheduling optimization and automated pressure regulation were also proposed. In response to lower ratings in leak reduction, the strategy emphasized a shift from reactive repairs to proactive pressure management. Additionally, performance monitoring and reporting mechanisms were included to strengthen public trust and address concerns regarding long-term water security.

The development phase consolidated these interventions into a structured and time bound proposal to ensure feasibility and measurability. The strategy was organized into key implementation areas, including hydraulic stabilization, infrastructure optimization, critical zone rehabilitation, community strengthening, and monitoring and governance. Interventions were scheduled within a 0-24 month timeline, prioritizing urgent actions such as eliminating zero pressure zones and intensifying leak detection in the first 6 months, followed by broader system improvements. Performance indicators, including minimum pressure thresholds, elimination of 0 psi readings, reduced pressure variability, regular non-revenue water monitoring, and improved service quality ratings, were integrated to track progress. This phase ensured that the proposal remains aligned with empirical findings while providing a clear framework for improving system performance and reliability.

3.5 Level of Acceptability of the Proposed Strategic Plan

The assessment of the strategic action plan reveals a high level of acceptability across all five emergent themes revealed through thematic analysis: Strategic and Governance Alignment, Technical Viability and Customization, Resource Accountability, Operational Risk and Service Equity, and Governance and Transparency, with all three managers consistently affirming its relevance to MNWD's current challenges.

Under the theme of Strategic and Governance Alignment, the managers emphasized that the plan mirrors MNWD's core priorities of reducing non-revenue water, improving service, and ensuring long term water security, particularly in the context of severe hydraulic disparities where pressures range from 76 psi in San Juan to 0 psi in areas like Gainza Proper. They confirmed that the focus on pressure stabilization, elimination of zero pressure zones, and leak prevention is strongly aligned with the district's strategic goals.

In terms of Technical Viability and Customization, the proposed tools, District Metered Areas (DMAs), Pressure Reducing Valves (PRVs), and booster systems, were viewed as acceptable, provided they are carefully planned, monitored, and tailored to local hydraulic conditions, reflecting the managers' emphasis on context specific technical appropriateness.

At the same time, the themes of Resource Accountability and Operational Risk and Service Equity highlight important conditions for implementation. The managers stressed that support for the plan depends on clear cost–benefit analysis, performance guarantees, and phased implementation, indicating that willingness to fund the proposal is contingent on demonstrable benefits and prudent resource use. They also identified infrastructure stress and unintended service disruptions as key operational risks when redistributing pressure from high zones to fringe areas, underscoring that equity in pressure distribution is a core governance concern rather than a purely technical issue. These insights show that acceptability is tied not only to the soundness of technology but also to how carefully the rollout is managed.

Finally, under the Governance and Transparency theme, managers emphasized the need for rigorous monitoring mechanisms and transparent reporting, supporting the inclusion of a Transparent Pressure Dashboard and digital maintenance alerts as tools to bridge the perception gap in fringe communities like Gainza and to maintain endorsement over time.

The proposed strategy and manager feedback align with established water utility management frameworks, particularly the Pressure–Performance Conversion Model, which links pressure stabilization with perceived efficiency and service quality (Fantozzi et al., 2011) [49]. The use of District Metered Areas (DMAs) and Pressure Reducing Valves (PRVs) is recognized as a core approach for reducing physical water loss and extending asset life (Lambert et al., 2014) [50]. Moreover, the plan's emphasis on integrated performance governance through regular reviews reflects modern smart water principles that prioritize data driven accountability and community engagement to ensure long term water resource viability (Gleick, 2018; Liemberger & Wyatt, 2019) [51, 19].

4. Conclusions

Firstly, the MNWD system demonstrates a communication-heavy, infrastructure-light management profile, where strengths in operational transparency and logistical planning, such as advance notices, are not matched by the physical stabilization of the network. This indicates that current practices are more effective in managing customer expectations than in preventing system failures.

Secondly, the distribution network exhibits a pattern of periphery vulnerability, with fringe areas such as Gainza emerging as critical zones. These locations reflect overall system performance, as they experience the greatest effects of hydraulic instability, leading to increased water wastage and higher levels of non-revenue water.

Thirdly, a cycle of damage exists within the system, where technical instability drives physical losses. The absence of effective hydraulic correction not only results in immediate leaks but also contributes to cumulative asset degradation, ultimately weakening the long-term sustainability of the water supply.

Fourthly, addressing these challenges requires a transition from a reactive maintenance approach to an integrated performance governance framework. By prioritizing the implementation of District Metered Areas (DMAs) and Pressure Reducing Valves (PRVs), pressure management can be repositioned as a strategic tool for improving system performance and resource conservation.

Finally, the adoption of the proposed strategic plan is strongly influenced by data-driven trust. The plan's high level of acceptability reflects the importance of transparency and measurable outcomes, indicating that stakeholders are more willing to support technical interventions when they lead to observable improvements in service reliability.

5. Recommendations

Firstly, the MNWD should pivot from a communication-led strategy to an infrastructure-first model by prioritizing the replacement of aging pipes in areas with the lowest efficiency ratings. This will ensure that physical system stability aligns with the district's strong logistical planning and communication practices.

Secondly, the district should formalize fringe communities as high-priority intervention zones by deploying localized sensor networks in areas such as Gainza. This approach will enable the collection of high-frequency pressure data and transform these vulnerable locations into early warning hubs for the entire system.

Thirdly, MNWD should institutionalize a pressure life cycle policy that positions hydraulic stabilization not only as a leak reduction measure but as a core asset preservation strategy. This policy will support the extension of the functional lifespan of the distribution network's infrastructure.

Fourthly, the district should adopt a smart water governance roadmap that integrates District Metered Areas (DMAs) with automated Pressure Reducing Valves (PRVs). This will shift operations from manual oversight to a more efficient, data-driven system of continuous hydraulic regulation.

Finally, MNWD should implement a transparent pressure dashboard accessible to system implementers and key stakeholders. By providing real-time pressure data, this initiative can strengthen stakeholder confidence and support sustained organizational adoption of the proposed strategies.

References

1. Food and Agriculture Organization. (2017). Water for sustainable food and agriculture: A report produced for the G20 presidency of Germany. Rome: FAO.
2. WWAP, World Water Assessment Programme, UNESCO. (2019). The United Nations world water development report 2019: Leaving no one behind. Paris: UNESCO. . https://unesdoc.unesco.org/ark:/48223/pf0000367306
3. African Water Association. (2017). Water loss reduction strategies in developing countries. AWAJournal, 12(3), 45–59.
4. World Bank. (2016). The challenge of reducing non revenue water in developing countries. Washington, DC: World Bank Group.
5. Misiunas, D., Kapelan, Z., & Maksimovic, C. (2014). Leak detection and pressure management for non revenue water reduction. Water Science and Technology, 69(4), 845–852.
6. Faruqui, N., Shrestha, A., & Al Washali, T. (2012). Pressure management as a tool for non revenue water reduction. Water Resources Management, 26(8), 1927–1941.
7. International Water Association. (2014). Water loss management: Pressure control strategies. London: IWA.
8. Department for Environment, Food and Rural Affairs. (2019). Water efficiency and pressure management in the UK. London: DEFRA.
9. Water Services Association of Australia. (2018). Best practices in pressure management for water utilities. Sydney: WSAA.
10. National Economic and Development Authority. (2019). Philippine water supply and sanitation master plan (PWSSMP) 2019–2030: Abridged version. Quezon City: NEDA.
11. National Economic and Development Authority. (2023). Philippine development plan 2023–2028. Quezon City: NEDA.
12. Savić, D.A., Kotevski, S., & Bakić, V. (2008). Water distribution network optimization using genetic algorithms. Journal of Water Resources Planning and Management, 134(2), 173–180.
13. Lambert, A.O. (1994). The role of pressure management in the effective control of leakage. Water and Environment Journal, 8(2), 162–170.
14. Karadirek, İ.E., Kapelan, Z., & Karadirek, O.K. (2020). Dynamic pressure management in water distribution systems for sustainable non revenue water reduction: A review. Water Supply, 20(8), 3465–3479.
15. Farley, M., & Trow, S. (1999). Losses in water distribution networks: A practitioner's guide to assessment and control. London: International Water Association Publishing.
16. Liemberger, R., & Wyatt, A. (2019). Non revenue water management: A comprehensive strategy for reducing water loss. London: IWA Publishing.
17. Ghani, I., Mohamed, O., & Mohamad, S. (2021). A review of smart water management in distribution systems: Towards a digital twin approach. Water Resources Management, 35(11), 3845–3865.
18. Lambert, A.O., Fantozzi, M., & Hirner, W. (2014). The concept of the economic level of leakage. Water Practice and Technology, 9(3), 361–370.
19. Cassidy, S., Walski, T., & Kunkel, G. (2022). Including resilience and sustainability in the economic level of leakage. Journal – American Water Works Association, 114(7), 35–42.
20. Mutikanga, H.E., Sharma, S.K., & Vairavamoorthy, K. (2011). Measuring and modeling non revenue water. Water Resources Management, 25(14), 3615–3625.

21. Al Washali, T.M., Sharma, S.K., & Al Nozaily, F. (2017). Assessment of water losses and current non revenue water reduction strategies in the municipality of Sana'a. Water Practice and Technology, 12(3), 546–558.
22. Tušar, M., Kaluža, B., & Džeroski, S. (2014). Predictive modeling of pipe bursts in water distribution networks using machine learning. Water Resources Management, 28(11), 3749–3761.
23. Savić, D.A., Kotevski, S., & Bakić, V. (2011). Optimization of water distribution networks for leakage reduction using evolutionary algorithms. Journal of Water Resources Planning and Management, 137(2), 173–180.
24. Lee, S.H., Park, J.H., & Kim, M.C. (2019). A smart water management system development and application based on data analysis. Journal of Water Supply: Research and Technology – AQUA, 68(8), 613–622.
25. Liwanag, H.G., Dator, B.F.M., Ricasio, V.B., & Lagrada, H.R. (2019). Determinants of public health spending at the local level in the Philippines. Philippine Journal of Health Research and Development, 23(1), 10–21.
26. Lavado, R.S. (2010). Fiscal decentralization in the Philippines: Synthesis of case studies. Quezon City: Philippine Institute for Development Studies.
27. International Budget Partnership. (2019). Open budget survey: Philippines 2019 report. Washington, DC: International Budget Partnership. . https://www.internationalbudget.org/publications/open-budget-survey-2019
28. Tamondong Lachica, G., delos Trinos, C., & Riego, L.S. (2024). Case study on local health governance in the Philippines. Quezon City: Philippine Institute for Development Studies.
29. Salkind, N.J. (2019). Exploring research. 10. Boston, MA: Pearson.
30. Bowen, G.A. (2009). Document analysis as a qualitative research method. Qualitative Research Journal, 9(2), 27–40.
31. Gravetter, F.J., & Wallnau, L.B. (2017). Statistics for the behavioral sciences. 10. Boston, MA: Cengage Learning.
32. Branch, R.M. (2009). Instructional design: The ADDIE approach. Dordrecht: Springer.
33. Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2), 77–101.
34. Shamoo, A.E., & Resnik, D.B. (2015). Responsible conduct of research. 3. New York, NY: Oxford University Press.
35. Thornton, J., & Lambert, A. (2005). Progress in practical prediction of pressure: Leakage, specialized techniques in water supply. Water 21, 7(5), 12–18. International Water Association.
36. Ismail, A., & Yunan, Y.S.M. (2016). Service quality as a predictor of customer satisfaction and customer loyalty. LogForum, 12(4), 349–360.
37. Ogata, R., Matsumoto, S., Otsuka, T., Hattori, Y., & Kitawaki, H. (2026). Influence of customer satisfaction and perceived water service quality on urban water supply management: A systematic review. Cleaner and Responsible Consumption, 1, 100045. . https://doi.org/10.1016/j.clrc.2026.100045
38. West Virginia University. (2024). Water quality in distribution systems. Morgantown, WV: Appalachian Community Technical Assistance and Training.
39. Global Water Partnership. (2024). Integrated water resources management: A strategy for sustainability. Stockholm: GWP.

40. World Bank. (2025). Resilient water systems: Balancing infrastructure and demand side management. Washington, DC: World Bank Publications.
41. United Nations, UN Water. (2024). The United Nations world water development report 2024: Water for prosperity and peace. Paris: UNESCO.
42. Mounce, S.R., Boxall, J.B., & Shepherd, W.J. (2025). Smart water networks: Integrating pressure management and data analytics for service excellence. Boca Raton, FL: CRC Press.
43. Arfanuzzaman, M. (2024). Sustainable water management in the Anthropocene: Challenges and opportunities for resilient urban systems. Cham: Springer Nature.
44. Asian Development Bank. (2023). Water utility performance in Southeast Asia: Benchmarking efficiency and service quality. Manila: ADB Publishing.
45. World Water Council. (2024). World Water Cities Forum 2024: Urban water policy brief. Marseille: World Water Council. . https://www.worldwatercouncil.org/wp-content/uploads/2025/11/WWCF_2024_Urban_WaterPolicy_Brief.pdf
46. Fantozzi, M., Kanakoudis, V., & Almeida, M.C. (2011). Pressure management for leakage reduction and asset life extension: Benefits and practical experience. Water Science and Technology: Water Supply, 11(2), 158–165. . https://doi.org/10.2166/ws.2011.026
47. Gleick, P.H. (2018). Transitions to sustainable water systems. Proceedings of the National Academy of Sciences, 115(35), 8663–8670. . https://doi.org/10.1073/pnas.1812165115