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Regional Case Study

Optimization of District Metered Areas for Reducing Non-Revenue Water

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Abstract

Non-revenue water (NRW) is a significant issue for water supply in Indonesia, with a national NRW rate of 33.7% in 2022 and even higher at PT Air Minum Giri Menang (PT AMGM) at 36.21%. Although District Metered Areas (DMA) were implemented in 2018, their effectiveness has been limited due to poor monitoring. This study evaluates the current DMA conditions by creating a water balance and using EPANET 2.2 software for analysis, along with formulating optimization strategies through technical, financial, and institutional assessments. The research identifies fifteen DMAs, with five being well-established. Two DMAs were chosen for optimization. Simulations showed that many pipes in these DMAs did not meet flow speed standards. Water pressure in DMA Graha Permata Kota was fully satisfied at 100%, while DMA Elit Kota Mataram achieved 84.5%. The study noted a significant NRW reduction by an average of 27.26% in the selected DMAs. The total repair cost was Rp 14,725,300, leading to additional annual revenue of Rp 128,747,424 and a positive feasibility analysis. Institutional performance was rated as "good," but an increase of 14 field staff for water loss control is needed.

Keywords : District meter area; non-revenue water; optimization

1. Introduction

Clean water is an essential source of life for human health and well-being, serving as the foundation for a healthy and prosperous society (Anatolia et al., 2021). In the context of human rights, access to clean water should be recognized as a fundamental principle for a decent life (Masduqi et al., 2023). However, lack of access to clean water can cause serious health problems and worsen the socio-economic conditions of the community (Rasidi and Boediningsih, 2023).

In Indonesia, reports show that access to safe drinking water in rural areas reached 15.1%, while in urban areas it was only 8.3%. Kalimantan had the highest access at 16.9%, while Papua recorded the lowest at 1% (Setiawan et al., 2020). Although the government, through the Regional Drinking Water Enterprise, has made progress, the achievement is still far from the 2030 Sustainable Development Goals (SDGs) target of 100% access to safe drinking water (Bappenas, 2023).

The Drinking Water Supply System plays a central role in ensuring the availability of clean water. However, the challenges include quantity, quality, continuity, and affordability (Kementrian PUPR, 2016). The problem of NRW is a critical issue that can hinder the efficiency of water distribution, with the national NRW rate in 2023 reaching 33.9% (Kementerian PUPR, 2023). This high NRW represents a significant loss in revenue and potential utilization of water resources to the detriment of both service providers and consumers.

On Lombok Island, PT AMGM is committed to improving the water supply. However, the NRW rate of 36.21% is a significant challenge for water management (PT Air Minum Giri Menang, 2023). PT AMGM established the DMA in 2018 as a strategic step to address this issue. Unfortunately, the implementation of the DMA has not yielded significant results and is considered costly, which has led to the DMA being inactive in its monitoring and maintenance.

Previous studies have examined optimizing drinking water distribution networks, focusing on applying DMA to reduce NRW (Indriaty and Hadi, 2023). Optimization of drinking water distribution networks is essential, and previous studies have explored various approaches. Rozaq and Iqbal (2019) implemented the DMA to reduce NRW. Buko et al (2022) technically analyzed the Manyaran 1 air supply system in West Semarang using EPANET software, with the idea that DMA could significantly reduce NRW by up to 20%. Furthermore, Widianto and Hadi (2023) utilized air balance analysis and the Infrastructure Leakage Index (ILI) to understand air loss patterns and develop pressure management strategies to reduce leakage. Buko et al (2022) also highlighted the importance of financial analysis, such as investment feasibility, to ensure project sustainability. However, while these studies offer valuable insights into technical and economic aspects, they often neglect the institutional dimension, such as policies and organizational structures, which are critical factors in effectively reducing non-revenue water (Prastiwi et al., 2024).

The scientific novelty of this article lies in optimizing existing DMAs through a multidimensional approach that systematically integrates technical, financial, and institutional analysis. This research aims to identify DMA priorities based on criteria such This article's scientific novelty is optimizing DMAs formed through a multidimensional approach that systematically integrates technical, financial, and institutional analysis. When optimizing DMAs, several key factors are considered when prioritizing areas for improvement. The primary concern is the NRW percentage, which represents the difference between the air supplied and the air billed, with higher percentages indicating significant losses due to leakage or other issues (Mohammad et al., 2024). Another factor is the number of customers in the DMA, as addressing NRW in densely populated areas can benefit more people and increase revenue potential (Sharma et al., 2023). Finally, the condition of the infrastructure plays a significant role, with ageing or poorly maintained systems often contributing to higher NRW due to frequent leakage (Laucelli et al., 2016). By focusing on DMAs with high NRW, large customer bases, and deteriorating infrastructure, optimization efforts can be strategically targeted for maximum impact. In addition, this study integrates Epanet 2.2 software with technical methods, such as stepwise testing and optimization surveys with water surveyor software. Therefore, this study will analyze the existing condition of PT AMGM DMA by creating an air balance and simulation using EPANET 2.2 software. Furthermore, strategies will be formulated based on analyzing technical, financial, and institutional aspects of PT AMGM's NRW reduction program. This holistic approach is expected to provide significant contributions to air distribution management and offer innovative solutions to reduce NRW reduction.

2. Methods

2.1. Definition and criteria of District Metered Area

District Metered Area (DMA) is an essential concept in water distribution management, allowing more efficient monitoring and control of airflow (Romdloni, 2021). DMA is formed by isolating one part of the distribution network using a valve to operate independently without interference from other areas. Ideally, a DMA has one input point for water flow and is equipped with measuring equipment such as a central meter and customer meters (Kowalska et al., 2022). To ensure efficient management, the number of customers in a DMA should range from 500 to 2,000 service requests (Saparina, 2017).

2.2. Location

This research was conducted in the DMA in the Mataram City and West Lombok Regency services under PT AMGM, located at coordinates 8°34'52.3"S and 116°05'26.6"E. 15 DMAs have been installed in this area, each with different characteristics. This study aims to identify and optimize the clean water supply system to increase efficiency and reduce NRW by focusing on this location.

2.3. Primary and Secondary Data Collection

The data in this study were collected through two main approaches: primary data and secondary data. Primary data were obtained through field surveys in fifteen existing DMAs under the management of PT AMGM. Of these fifteen DMAs, two were selected based on predetermined criteria, considering that in-depth field surveys such as step tests, customer optimization surveys, and time-consuming repair work would be focused on these two selected DMAs. Primary data collection involved customer interviews facilitated by the mWater Surveyor software (Yoo and Lenczewski, 2019). The sample of customers interviewed included customers with passive status, water usage of 0 m3, water usage between 1-5 m3, customers with estimated air usage, and customers with problematic water meters (PT Air Minum Giri Menang, 2023). In addition, according to the predetermined criteria, an analysis was carried out on the company's water usage patterns in the selected DMAs. Secondary data, on the other hand, was collected directly from PT AMGM and included relevant documentation, maps, and statistical data. These secondary data include distribution pipe network maps, water tariff data per customer group, customer data, administrative and contour maps, and NRW reports (PT Air Minum Giri Menang, 2023).

2.4. Data Analysis Methods

2.4.1. Evaluation of the Existing DMA

The existing DMA was evaluated by identifying key criteria, including the NRW level, number of customers, and infrastructure condition (Septiani M, Dian S, and Eddy S., 2022), Subsequently, the water balance was calculated using WB-Easycalc software, which collected secondary data related to water sources, physical water losses, non-physical water losses, and consumption from customer meters.

2.4.2. Hydraulics Analysis

Hydraulics analysis was conducted to assess the performance of the water distribution system using Epanet 2.2 software simulation. The primary and secondary data were collected and used to model the water network, focusing on the evaluation of pressure and flow velocity. The simulation results were compared with the Ministry of PUPR Regulation No.27/2016 standards to ensure that the water distribution system operates within safe and efficient limits (Kementrian PUPR, 2016).

2.4.3. Technical Analysis

The technical analysis was carried out using the network isolation method through a step test, which ensured each DMA was separated, and the function of the valves was evaluated to detect the location of leaks. In addition, a ground microphone tool was used to trace the leakage point by listening to the sound of water flow. Furthermore, an optimization survey was conducted with the help of Mwater surveyor software to identify physical and non-physical water losses. Five surveys were categorized to evaluate passive customers, zero m^3 customers, small water usage, estimated customers, and meter problems. Customer data and occupancy status were validated to ensure fair and effective distribution.

2.4.4. Financial Analysis

The technical analysis results were compiled to calculate NRW and its financial impact using several methods, such as Net Present Value (NPV), Internal Rate Of Return (IRR), Benefit Cost Ratio (BCR), and Payback Period (PP), to assess investment feasibility.

NPV calculates the difference between the present value of cash inflows and outflows over the project's life. This method assesses the feasibility of a project by comparing the Present Value (PV) of future net cash flows with the initial investment. It is important to determine the relevant interest rate before the calculation. If the present value of net cash flows is greater than the investment, the project is considered profitable; otherwise, if it is smaller, it is considered unprofitable (Shou, 2022). The NPV formula is:

$$NPV = \sum_{t=0}^{n} \frac{I}{(1+r)} + \frac{C}{(1+r)^t} \quad (1)$$

NPV is the net present value of an investment. (I) the initial capital or initial investment issued. (CF) is the cash flow generated each year, while (r) shows the interest rate in percentage form. (n) describes the number of years or Year n during the investment.

IRR is the flow of returns that results in the NPV of cash inflows and NPV of cash outflows (Kurniawan, 2019). The IRR formula is:

$$IRR = r1 + (r2 - r1) \times \frac{NPV1}{NPV1 - NPV2} \quad (2)$$

IRR is the expected rate of return on an investment. In this case, (r1) refers to the rate of return for the first assignment, while (r2) is the rate of return for the second assignment. (NPV1) is the net present value of the IRR for the first assignment, while (NPV2) is the net present value of the IRR for the second assignment.

BCR is often used to evaluate projects related to the public interest, where the benefits are the most important part (Purba et al., 2023). The formula for calculating BCR:

$$BCR = \frac{(PV)B}{(PV)A} \quad (3)$$

BCR is a ratio used to compare the value of benefits and costs of a project or investment. In this case, (PV)B refers to the present value of the expected benefits, while (PV)A is the present value of the costs incurred.

PP is the time required to pay back the invested capital, calculated from net cash flow (Mauliana et al., 2023). The formula for calculating PP:

$$PP = (n-1) + (Cf - \sum_{n}^{n-1} An \frac{1}{An}) \quad (4)$$

PP is the period required to recover the initial investment. In this context, (Cf) refers to the initial cost or first cost incurred for the investment. (An) is the net cash flow generated each year, while (n) indicates the year in which the investment is paid back.

2.4.5. Institutional Analysis

Institutional analysis emphasizes human resource management and company performance. This institutional aspect includes performance appraisal, employee-to-customer ratio, and water loss control workload analysis. Based on the results of the data analysis, an effective NRW reduction strategy for PT AMGM can be formulated. This strategy enables PT AMGM to reduce water losses and achieve the set targets significantly, as well as opens up opportunities to design a sustainable investment strategy. With these measures, PT AMGM can improve operational efficiency while making a real contribution to better water resources management in the future.

3. Result and Discussion

3.1. Analysis of The Existing Condition of The DMA

3.1.1. Evaluation of Existing DMAs

By analyzing data from July 2024 as a water balance (WB0), we can gain important insights into the condition and performance of each DMA. This analysis allows us to assess how efficient each DMA is in managing water resources as well as identify aspects that need improvement. The results of this calculation are presented in Table 1.

Table 1. Water balance in Pt Air Minum Giri Menang district metered areas in july 2024

No	Name of Service DMA	Number of Customers (SR)	Pipe Diameter (mm)	Q Inlet (m³)	Q Usage (m³)	NRW		MNF l/dt
						m³	%	
1	Perum Pemda Lobar	632	80	10,144	7,691	2.453	24.18	-
2	Garden View	69	80	2,146	1,033	1.113	51.86	0.7
3	Puncang Hijau	260	100	5,593	3,898	1.695	30.31	-
4	Montong Kedaton	72	80	4,391	909	3.482	79.30	1.09
5	Permata Hijau	18	80	0	133	-133	-	-
6	Lingkar Pratama	476	100	8,631	7,406	1.225	14.19	2.12
7	Mavilla Rengganis	310	100	6,780	4,026	2.754	40.62	2.32
8	Grand Muslim	1.400	100	9,767	14,522	-4.755	-48.68	1.26
9	Rumak Asri	261	80	3,954	2,579	1.375	34.77	0.34
10	Lingkar Manunggal	334	100	6,599	4,586	2.013	30.50	1.12
11	Perembun Asri	261	100	2,146	1,987	159	7.41	0.1
12	Elit Kota Mataram	567	100	11,127	7,890	3.237	29.09	3.23
13	Graha Permata Kota	867	150	20,398	13,086	7.312	35.85	3.1
14	Grand Natura	41	80	1,907	1,265	642	33.67	-
15	Royal Madinah	737	100	10,070	7,559	2.511	24.94	-

The red block mark is the selected District Metered Area

The results of the water balance calculation in each DMA in July 2024 show variations in the level of water loss, with some DMAs showing negative results. This is due to two unmetered source inlets, interconnection of DMAs with other distribution networks, uninstalled resilient valves, and maintenance of loggers that have not been carried out regularly. In addition, the existing pipelines do not match the Geographic Information System (GIS) network map, and some pipelines have not been updated in the Quantum Geographic Information System (QGIS). This is contrary to the basic concept of DMA, where the network must be perfectly isolated, and measurements are taken regularly to monitor the DMA properly (Julius A et al., 2021).

The DMAs analysis highlights various service issues affecting water distribution efficiency and reliability. Perum Pemda Lobar faces challenges with two inlet sources (distribution network and borehole) and an incomplete resilience valve, complicating water flow management. Similarly, Garden View has outdated network and customer point data in the GIS, an incomplete resilient valve, and a primary meter street box buried under asphalt, making maintenance difficult. In Puncang Hijau and Permata Hijau, uncalibrated master meters lead to potential inaccuracies in water measurement. Meanwhile, Lingkar Pratama struggles with pipe network interconnections that are not updated in the GIS, resulting in invalid NRW percentages. Mavilla Rengganis experiences issues with central pipeline interconnections to other residential areas, complicating monitoring efforts. One of the two inlet sources is not metered at Grand Muslim, causing potential unaccounted water loss. Rumak Asri requires maintenance on its main meter logger for accurate monitoring. At the same time, Perembun Asri has pipelines and customer points that need to be updated in the GIS for better data accuracy. Lastly, Royal Madinah faces similar challenges with two inlet sources (distribution networks and boreholes) that require further assessment to ensure optimal functionality. Addressing these issues through infrastructure improvements, meter calibration, and GIS updates is crucial to reducing NRW and enhancing the overall performance of the water distribution system.

This study obtained five DMAs with perfect categories that met the established criteria, ideally, a DMA has one input point for water flow and is equipped with measuring equipment such as a central meter and customer meters. To ensure efficient management, the number of customers in a DMA should range from 500 to 2,000 service requests. The five DMAs are Montong Kedaton, Lingkar Manunggal, Grand Natura, Elit Kota Mataram, and Graha Permata Kota. However, only two DMAs were selected. This selection focused optimization efforts on DMAs with high NRW, many customers, and the need to improve infrastructure conditions (Hanifa et al., 2021). The following DMAs were selected, namely DMA Perum Elit Kota Mataram, NRW located in the city of Mataram with coordinates 8°37'00.6"S and 116°05'06.4"E, with 567 SR customers, has one main metered inlet with a 100 mm diameter input system, the air source comes from the Telaga Sari reservoir, with an NRW percentage of 29.09%. While for Graha Permata Kota, located in West Lombok Regency with coordinates 8°34'49.4"S and 116°09'01.1"E, with 867 SR customers, has one inlet with a system input diameter of 150 mm, the water source comes from a drilled well in the housing complex with an NRW percentage of 35.85%. Both DMAs were analyzed hydraulically with Epanet 2.2 to test the pressure and flow velocity in the existing DMA, then optimized using the step test method, namely leak tracing by reducing the area in the DMA so that it is easier when searching for pipe leaks and customer surveys with mwatersurveyor software are intended to optimize the DMA formed from customer coordinate points, placement status, quantity, quality, continuity, costumers meter and illegal connection. The profiles of the two selected DMAs can be seen in Table 2.

Table 2. Profile of selected district metered areas pt air minum giri menang (water balance 0)

No	Name of Service DMA	Number of Customers (SR)	Pipe Diameter (mm)	Q Inlet (m^3)	Q Usage (m^3)	NRW (%)	DMA Status
1	Perum Elit Kota Mataram	567	100	11,127	7,890	29.09	Perfect
2	Graha Permata Kota	867	150	20,398	13,086	35.85	Perfect

3.1.2. Hydraulics Analysis

The DMA Elit Kota Mataram and Graha Permata Kota DMA network systems were modeled using EPANET 2.2. The distribution network model of DMA Elit Kota Mataram and DMA Graha Permata Kota used the Hazen-Williams (H-W) headloss formula with flow in liters per second and was carried out through 40 iterations. The pipe roughness value is 140 for PVC and HDPE pipes and 130 for ABS pipes (Da Rocha et al., 2017). Depicted in the epanet network design, there are 142 junctions/nodes and 146 pipes in the Kota Elite DMA, while the Kota Graha Permata DMA has 381 junctions/nodes and 421 pipes. Water demand patterns were measured using data loggers, with an analysis duration of 24 hours (PT Air minum Giri Menang, 2023), providing a comprehensive picture of the characteristics and performance of the water distribution network in both DMAs. The results of the hydraulics analysis of the Graha Permata Kota DMA and Elit Kota Mataram DMA can be seen in Figure 2.

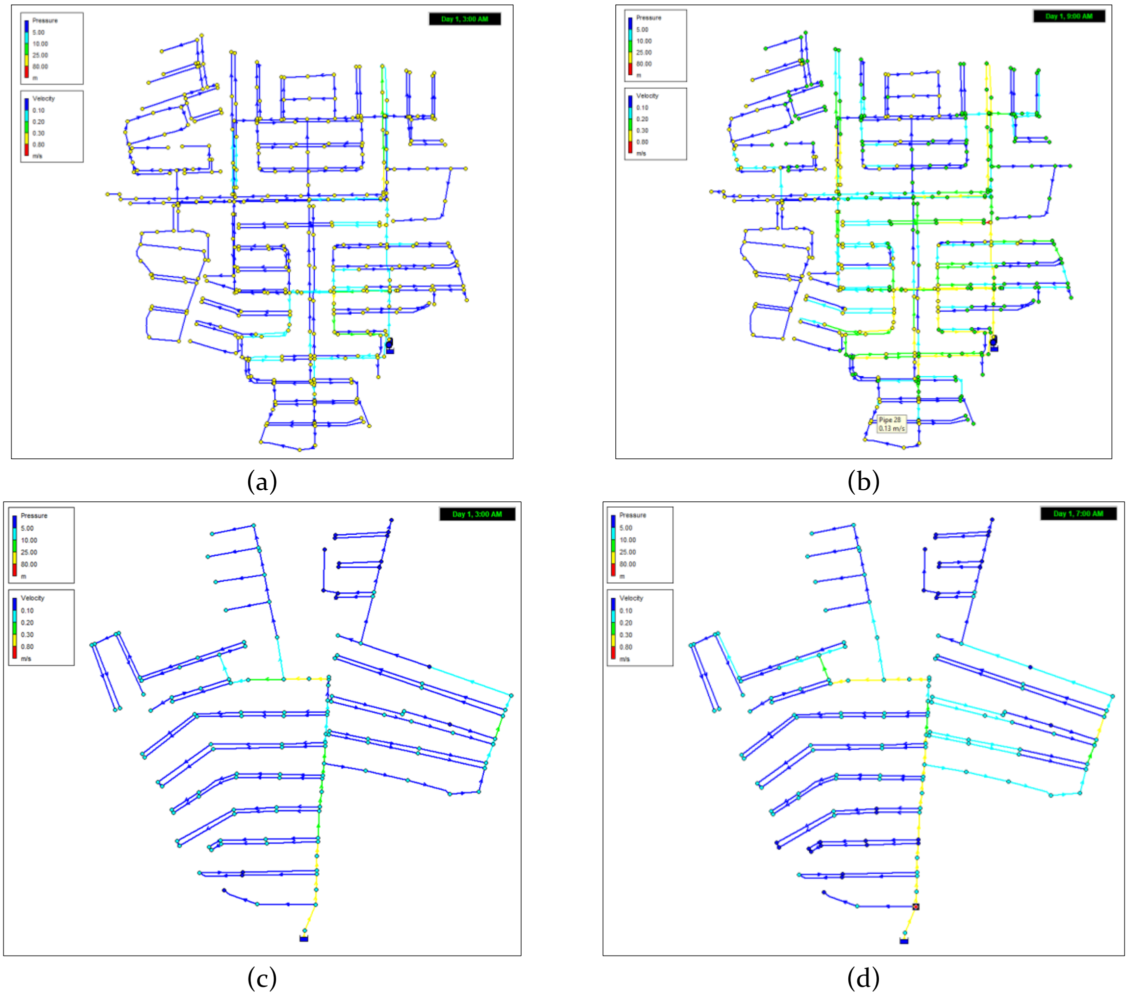

Figure 2. Epanet hydraulics simulation (a) Graha permata kota dma minimum hours (b) Graha permata kota dma peak hours (c) Elit kota mataram dma minimum hours (d) Elit kota mataram dma peak hour

Graha Permata Kota DMA data shows that the Minister of PUPR Regulation No. 27/2016 sets a maximum pressure of 5 meters. At 03:00, the lowest pressure was recorded at 25.93 meters, while the highest reached 37.06 meters. At 09:00, during peak hours, the minimum pressure dropped to 14.09 meters, with a maximum of 30.36 meters. The simulation results show that 85.3% of the distribution pipes in the region do not reach the standard flow velocity in PVC pipes (0.3-3 m/s), with velocities below 0.3 m/s during peak water consumption hours.

Based on the Epanet simulation, at 03:00, 7% of the DMA Elit area of Mataram City experienced water pressure below the standard (≤ 5 meters), according to the Minister of PUPR Regulation No. 27/2016. At the peak of 07:00, this figure increased to 15.5%, resulting in 84.5% of customers meeting the pressure criteria. This lack of pressure can increase the risk of contamination when a leak occurs, this is because water that should come out of the pipe enters the pipe due to low pressure so that contaminated water and mud from outside can enter the pipe and flow to customers (Palma et al., 2024). The selection of technology, especially for pipes, that can maintain good drinking water and meet quality standards is highly recommended as a priority strategy (Razif and Persada, 2016). In addition, the flow velocity in this area also does not reach the PVC pipe standard (0.3-3 m/sec), with 85.9% of pipes having velocities of less than 0.3 m/sec in the peak hour.

Several factors influence flow rates that do not reach standards. This is because low system pressure, small DMA area, length of pipe network, and interconnection between pipes cause problems in air distribution. Pipe flow velocity is proportional to flow rate, the higher the usage, the higher the flow velocity (Siti H et al., 2021). Low flow velocity can cause sediment deposition in the pipe network. Periodic flushing of the network is required to remove the formed sediment (Rubby I et al., 2019).

3.2. Optimization of Selected DMA

3.2.1. Technical Analysis

The step test activity for the Graha Permata Kota DMA was carried out with full preparation on July 26, 2024 at 23:15 WIB, followed by the Elit Kota Mataram DMA on August 3, 2024 at 22:00 WIB. The team involved consisted of ten people who were divided into strategic roles: three people on duty at the inlet, three people monitoring the manometer, and four others managing the opening and closing of valves according to a predetermined scenario. This step test is an effective method to identify the location of leaking pipes. By closing the valves sequentially, the data obtained from the logger can provide a clear picture of the flow in the system (Azwar et al., 2021). In addition, manometers are used to calibrate pressure in water distribution systems and to detect interconnections between steps. Manometers help identify leaks or problems in pipe connections by measuring pressure. The results of the step test tracing can be seen in Table 3 and Table 4.

Table 3. Results of step test tracing in district metered area graha permata kota

Step	Valve Status					Time	Pressure	DSR	Discharge	Water Loss (DQ) (L/s)	(DQ/DSR)	Leak class
	V1	V2	V3	V4	V5-8	(Hour)	(Bar)		(L/s)			
Start	O	O	O	O	**O**	23:15	2.5	873	4.928	-	-	-
Step 1	O	O	O	O	**C**	23:30	2.5	873	3.965	0.963	0.00110	Low
Step 2	O	O	O	**C**	**C**	23:41	2.5	37	3.780	0.185	0.00499	Medium
Step 3	O	O	**C**	**C**	**C**	23:55	2.5	290	2.268	1.512	0.00521	Medium
Step 4	O	**C**	**C**	**C**	**C**	00:11	2.5	142	0.000	2.268	0.01597	Medium
Finish	**C**	**C**	**C**	**C**	**C**	00:19	0	404	0	0.000	0.00000	Low
	O	**O**	**O**	**O**	**O**			873		4.928		

The classification of leaks in the water distribution system can be divided into three categories based on the leakage flow rate. Low-class leaks have a flow rate between 0.001 L/second to 0.0049 L/second. Meanwhile, medium-class leaks have a flow rate between 0.005 L/second and 0.019 L/second. Finally, leaks that fall into the high category have a flow rate of more than 0.02 L/second (Saparina, 2017). The results of searching for water loss using the step test method have successfully identified the pipe sections leaking in the Graha Permata Kota DMA, namely steps 2, 3, and 4, which have a medium leakage class. The results of the step test carried out on the elite city DMA can be seen in table 4.

Table 4. Results of step test tracing in district metered area elit kota mataram

Step	Valve Status				Time	Pressure	DSR	Discharge	Water Loss (DQ) (L/s)	(DQ/DSR)	Leak class
	V1	V2	V3	V4	(Hour)	(Bar)		(L/s)			
Start	O	O	O	O	00:24	0.8	603	4.640	-		
Step 1	O	O	O	**C**	00:29	1.3	107	2.425	2.215	0.0207	High
Step 2	O	O	**C**	**C**	00:44	1.4	160	1.506	0.918	0.0057	Medium
Step 3	O	**C**	**C**	**C**	01:35	1.6	237	0.599	0.907	0.0038	Low

Step	**Valve Status**				**Time (Hour)**	**Pressure (Bar)**	**DSR**	**Discharge (L/s)**	**Water Loss (DQ) (L/s)**	**(DQ/DSR)**	**Leak class**
	V 1	**V 2**	**V 3**	**V 4**							
Step 4	**C**	**C**	**C**	**C**	02:00	1.6	99	0.000	0.599	0.0061	Medium
Finish	**C**	**C**	**C**	**C**	02:19	0	99	0.000	0.000	0.0000	Low
	O	**O**	**O**	**O**	02:28		603		4.640		

The step test results at the DMA Elit Kota Mataram showed that water loss occurred at step 1, which is included in the high category. Meanwhile, steps 2 and 4 are in the moderate water loss category, while step 3 is in the low category. An acoustic tool, a ground microphone, was used to further explore the search for water loss points. This tool allows for more accurate and efficient leak detection. The use of the ground microphone acoustic tool can be seen in Figure 3.

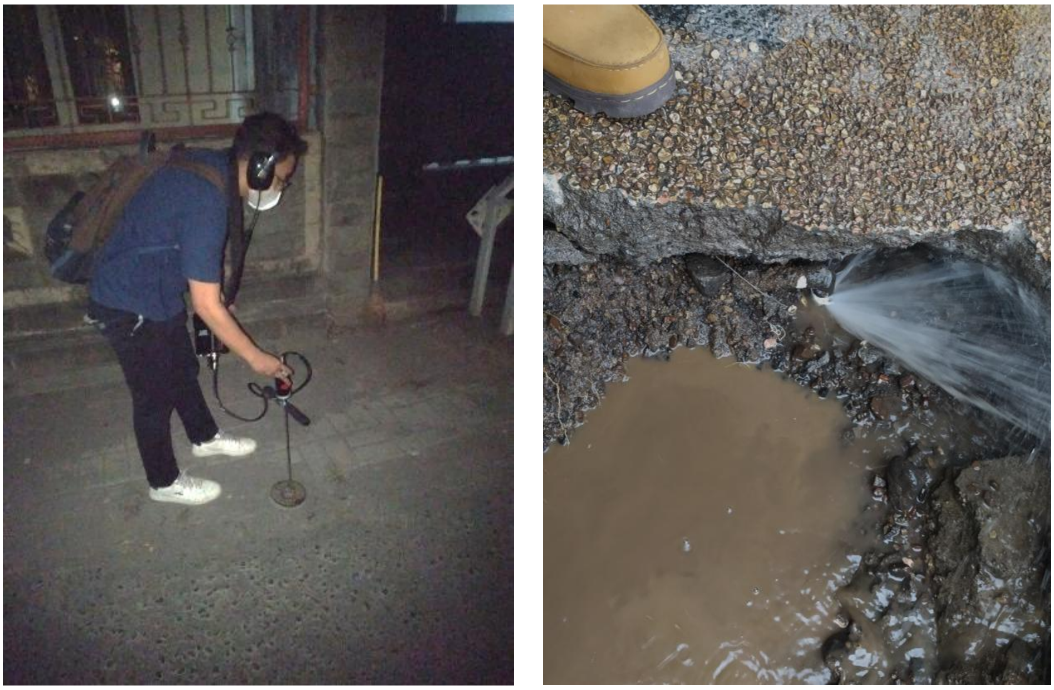

Figure 3. Leakage tracking using a ground microphone

The results of the Mataram City Elite DMA trial stage showed a leak in the stage 1 section with two leak points. One occurred in the subscription meter circuit found from the survey results in the stage with a high leak class, while the other occurred in the resistance valve circuit in stage 2 with a moderate leak class. Meanwhile, more leaks were found in the Graha Permata Kota DMA. Namely one leak point in front of the BF-01 block house from the leak detector search results in stage 1, two leak points in the BM-11 and DB-02 blocks with leak detector searches in stage 2, two leak points in the AM-07 block caused by tree roots and the AM-10 block which experienced seepage in the SR series in stage 3, and three leak points were found in the CI-02 block with a bokor detector, the AG-08 block experienced seepage in the subscription connection and EJ-02 was found from the seepage detector search results in stage 4. Some of these leaks are included in the damage report category. However, low public awareness causes many cases not to be reported to local authorities, such as PT AMGM. This situation shows the need to increase public awareness about the importance of reporting leaks so that authorities can take immediate corrective action.

Furthermore, efforts made by PT Air Minum Giri Menang were to conduct an optimization survey at the DMA using a Mwater Surveyor software. In this survey, data was collected from various categories of customers, ranging from zero usage to low usage, as well as estimates and problematic meters. In addition, passive customers were also the focus of data collection. The results of the optimization survey showed that the Graha Permata Kota DMA showed better efficiency than DMA Elit Kota Mataram, with 390 coordinate points in accordance and only nine inconsistencies. At the same time, the Elite DMA had 61 inconsistencies out of a total of 173. Inaccuracies in the Elite DMA can hamper the response to leaks, potentially increasing water loss. This finding aligns with case studies showing that database systems and GIS utilization are best practices for assessing water loss at each house connection (Abueltayef et al., 2023). In terms of tariffs, all 339 units surveyed in the GPK DMA and all 173 units in the Elite DMA showed tariff compliance, reflecting adjustments based on the community's economic capacity. The economic indicators of the community as customers of PT AMGM are the area of residential buildings that are divided into customer groups (PT Air minum Giri Menang, 2023). The occupancy status in the GPK DMA recorded 66 units rarely occupied, 8 locked, 71 occupied, and 194 unoccupied, while the Elite DMA had 22 units rarely occupied, 12 locked, 51 occupied, and 88 unoccupied. Several customers in both DMAs use wells as their primary water source, indicating why customers do not use water from PT AMGM. Unoccupied units, rarely occupied and the presence of alternative water sources such as wells will affect water consumption in the DMA, and if there is damage to the SR circuit, it will not be handled quickly. This is in line with research conducted, namely that empty residences will affect city water usage (Pan et al., 2021).

From the customer survey results, it was obtained that the water service in DMA GPK and DMA Elit was considered good, with 71 and 49 customers represented. However, there were reports of cloudy water quality in DMA Elit. This proves that the results of the planet analysis are right on the pressure in DMA Elit Kota Mataram, which reached 84.5%, meeting the criteria. If the pressure in the water distribution pipe is low, the risk of contamination increases when a leak occurs. In this condition, water cannot push dirt out, so dirt from outside can enter the pipe (Renwick et al., 2019). DMA GPK has 200 meters installed for water meters, with 199 functioning normally, while DMA Elit has 64 meters installed, with 61 functioning normally. Abnormalities were found in several meters in both DMAs. Although there were no leaks before the meter, an illegal connection was recorded, with three cases in DMA GPK and one in DMA Elit, indicating weaknesses in monitoring passive customers (Loch et al., 2020). A summary of improvements that have been made based on the step test and optimization survey results is a summary of enhancements to selected DMAs shown in Table 5.

Table 5. Improvements to the Elite Kota Mataram district metered areas and Graha Permata City district metered areas

No	Name of Service DMA	Type of Repair
1	Graha Permata Kota	Physical Losses 1. Valve resilience repair 3 inches 1 pcs 2. Repair of Leaking HDPE Pipe 1 Inch Block EJ-02 3. Repair of leaking HDPE pipe 2-inch block CI-02 4. Leak Repair of 0.5 Inch GI Pipe Block BF-01 5. Leak Repair of HDPE Pipe 2 Inch Block BM-11 6. Reposition of HDPE 1 Inch Pipe Clamped by Tree Roots Block AM-07 7. Replacement of Stopkrant 0.5 Inch Block AM-10 8. Replacement of GI Service Pipe Porous Block DB-02 9. eplacement of Stopkrant 0.5 Inch Blok AG-08 Commercial Losses 10. replacement of customer meters (1 point) 11. Enforcement of Illegal Conection (3 points)

2	Elit Kota Mataram	Physical Losses 1. SR circuit connection 2. Repair of 2 Inch Stopkrant Installation Commercial Losses 3. Customer Meter Replacement (2 points) 4. Buried Meter Relocation (1 point) 5. Enforcement of Illegal Conection (1 point)

After implementing the improvements, PT AMGM evaluated its effectiveness by calculating the Water Balance (WB1). The results of WB1 will be compared with the initial Water Balance (WB0) data taken in July 2024 to measure the reduction in water loss. The optimization survey from September to October also supports this analysis. This evaluation aims to measure the effectiveness of the improvements and understand their impact on water resource management in the Elit DMA of Mataram City and the Graha Permata DMA of Kota. The comparison of WB0 and WB1 will determine the success of the water loss reduction strategy. If there is no reduction, the strategy will be evaluated and improved (Berg, 2020). The results of this evaluation will form the basis for formulating a more effective improvement strategy, increasing operational efficiency, and improving the quality of customer service (Rahman, 2024). Details of the WB1 calculation are presented in Table 6.

Table 6. Water balance district metered areas selected period november 2024 (water balance 1)

No	Name of Service DMA	Number of Customers (SR)	Pipe Diameters (mm)	Q Inlet (m^3)	Q Usage (m^3)	NRW (%)	NRW Decrease (%)
1	Perum Elit Kota Mataram	571	100	12,008	8,847	26.32	9.5
2	Graha Permata Kota	870	150	17,407	13,975	19.72	45.0

The improvement results show that the efforts to reduce water loss that have been carried out in the selected DMA have resulted in a decrease. In the Elite DMA of Mataram City, water loss was recorded at WB0 of 29.09% in July 2024, which decreased in WB1 to 26.32% in October 2024, indicating a decrease of 9.5% in the Elite DMA of the City. On the other hand, the Graha Permata Kota DMA experienced a higher decrease, from WB0 of 35.85% in July 2024 to WB1 of 19.72% in November 2024, which reduced water loss by 45%. On average, the reduction from the water loss reduction program in the selected DMA reached 27.26%. These results prove that a perfectly formed DMA, according to the criteria described, is considered effective in reducing water loss in existing DMAs (de Freitas Anchieta, Meirelles and Brentan, 2024). Then, programs such as gradual testing and optimization surveys with water surveyor software can be conducted to detect leaks, meter damage, and illegal connections.

3.2.2. Financial Analysis

Various improvement efforts have been successfully implemented based on the water loss reduction survey results in selected DMAs. Connections and components were repaired by replacing adapters, bend longs, and seal tapes to prevent leakage. Repair of accessories and pipes was also done, including replacing rusty stopcocks and pipes and rearranging HDPE pipes pinched by tree roots. In addition, non-functioning customer meters were replaced to improve measurement accuracy, and strict action was taken against Illegal Connections. From the efforts made in selected DMAs, a Budget Plan of Rp 14,725,300 was obtained. The company can receive additional income from water sales during the water loss reduction period. With an average rate of Rp 5,812 per m³ (PT Air minum Giri Menang, 2023), PT AMGM can calculate an increase in revenue, as shown in Table 7.

Table 7. Additional income from non-revenue water decrease

No	Name of Service DMA	Average Tariff (Rp)	NRW Decrease (M3)	Additional Income (Rp)	Additional Income Per Year (Rp)
1	Elit Kota Mataram	5,812	957	5,562,084	66,745,008
2	Graha Permata Kota	5,812	889	5,166,868	62,002,416
Total			**1,846**	**10,728,952**	**128,747,424**

The decrease in NRW in DMA Graha Permata Kota and DMA Elit Kota Mataram gave significant results for PT AMGM. The total reduction in NRW reached 1,846 m³, generating additional revenue of Rp 10,728,952 with an average tariff of Rp 5,812. The estimated additional annual revenue details show that DMA Elit Kota Mataram contributed Rp 66,745,008, while DMA Graha Permata Kota contributed Rp 62,002,416. Thus, the total estimated additional revenue from the decrease in NRW of the two DMAs estimated reached Rp 128,747,424. Overall, if the estimated additional revenue is totalled with the estimated annual revenue, then PT AMGM from the sales of water in DMA Elit Kota Mataram reached 251,712 m³ and generated revenue of Rp 550,280,160. From the decrease in NRW of 22,152 m³, additional revenue of Rp 66,745,008 was obtained.

Meanwhile, at DMA Graha Permata Kota, water sales reached Rp 912,669,984 with additional revenue from 22,152 m³ of Rp 62,002,416. Overall, the total revenue from these two DMAs reached Rp 1,591,697,568, which contributed to the company's financial performance. In the feasibility analysis of this project, several economic indicators gave positive results. The NPV was calculated at Rp 47,796,127, which shows the difference between the present value of income and costs during the project life of 1 year with a discount rate of 15%. A positive NPV indicates that the project is feasible to implement (Shou, 2022). The IRR obtained through the trial and error method is 75.86%, far exceeding the prevailing interest rate, so this project is profitable (Kurniawan, 2019). In addition, the BCR reached 7.44, indicating that the benefits obtained from this project far outweigh its costs, confirming the feasibility of the project (Purba et al., 2023). Finally, the PP shows an investment return period of 1.3 months, or about 1 month and 9 days, indicating that the investment can be returned quickly (Mauliana et al., 2023). Overall, the results of this analysis suggest that this project has the profit potential.

3.2.3. Institutional Analysis

PT AMGM achieved a good performance assessment in 2023 with a score of 73.01, according to the "Good" category, according to Kepmendagri No. 47 of 1999 (Kepmendagri, 1999). The company shows efficiency in using labor, with a ratio of employees to 1,000 customers of 1.5, resulting in a score of 5. Most employees, namely 85%, have undergone training to improve their competence. However, the analysis of the workload in the water loss control sector shows the need for an additional 14 employees for field officers so that performance can be optimized and various tasks can be completed more effectively.

3.3. Strategy and Recommendations

Analysis of water loss reduction at PT AMGM reveals several essential strategies that can be applied to improve the efficiency of the water distribution system. First, optimization of the DMA by using one calibrated inlet and installation of permanent isolation using a blind valve is essential to ensure the accuracy of water flow measurements, thus facilitating loss detection. Optimal DMA will enable decision-makers to determine water loss reduction (Bui et al., 2021). Second, accelerating infrastructure improvements by calibrating customer meters is needed to ensure correct meter readings and reduce physical and non-physical water losses. The research conducted Karadirek (2019) was a study on water meters. The study explained that meter accuracy affects the reading results, so an accurate meter is needed for reading customer water usage. Third, the application of the step test method and the use of acoustic tools, such as ground microphones, for rapid leak detection is highly recommended, accompanied by increasing public awareness to be willing to report leaks found, the leak detector and step test methods are considered adequate in tracing leaks in the DMA (Romero-Ben et al., 2023). Furthermore, adequate budget support is essential to ensure the success of this strategy, including involving trained technical teams and increasing field staff in the field of water loss control, as well as providing training in the use of technology such as Epanet and GIS, as explained in Babamirie et al (2020) investment and asset management are needed to support the water loss reduction program. Finally, for PT AMGM, an annual target for reducing Non-Revenue Water (NRW) is required, and quarterly evaluations are needed to ensure practical actions and deliver expected results.

4. Conclusions

Based on the analysis conducted, it can be concluded that NRW reached 39.17% in July; analysis of two selected DMAs (DMA Elit Kota Mataram and DMA Graha Permata Kota) showed that many pipes did not meet the flow rate standards, but could be overcome by flushing regularly. Water pressure in DMA Graha Permata reached 100% during peak hours, while it reached 84.5% in DMA Elit. Optimization of NRW showed a decrease in DMA Elit Kota Mataram from 29.09% to 26.32% and in DMA Graha Permata Kota from 35.85% to 19.72%, with an average decrease reaching 27.26%. From the financial side, the total repair cost of Rp 14,725,300 resulted in an additional annual income of Rp 128,747,424 with yearly total income in both DMAs of Rp 1,591,697,568, with a positive NPV, IRR of 75.86%, BCR of 7.44, and a PP of only 1.3 months. In the institutional aspect, PT AMGM scored 73.01 (category "Good"), with an employee-to-customer ratio of 1.5, which earned 5 points. However, an additional 14 field employees were required in Water Loss Control. From the research that has been carried out, further research needs to be carried out, namely a comparative analysis of DMA characteristics to identify success factors and replicable strategies, as well as an in-depth analysis of pipes that do not meet flow standards, including identification of causes, hydraulic modelling, and repair priorities.

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