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RESEARCH PAPER

Analysis of Non-Revenue Water reduction using the FAVAD method in DMA planning: Case study in Palangka Raya drinking water supply system

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Abstract. Non-revenue water (NRW) is a crucial problem for the Perusahaan Umum Daerah Air Minum (PERUMDAM) Palangka Raya due to its extensive service area, lacking metered divisions that hinder leak detection in the distribution pipe network. This research explores the potential for reducing NRW levels by establishing a district meter area (DMA) within the central drinking water supply system (SPAM) PERUMDAM Palangka Raya service area. DMA configuration, designed to meet specific distribution pipe criteria, is carried out through the EPANET 2.2 program. This study aims to identify the decrease in NRW through the implementation of the Fix and Variable Area Demand (FAVAD) pressure management method. Due to limited resources, a priority assessment for DMA formation was performed using the Weight Sum Model (WSM) method. The analysis results show the possibility of dividing the central drinking water supply system service area into 27 DMAs, with the formation of DMA I/11 identifies as the highest priority DMA. After the DMA was established, the NRW component that decreased was water loss caused by pipe leaks, resulting in a saved amount of 15,261 m^3/month. This reduction contribute to a dicrease in NRW levels by 6.06%, preventing clean water scarcity in Palangka Raya City.

Keywords: district meter area (DMA); non-revenue water (NRW); PERUMDAM Palangka Raya; Water supply

1. Introduction

The high level of Non-Revenue Water (NRW) within the Perusahaan Umum Daerah Air Minum (PERUMDAM) of Palangka Raya poses a severe problem that affect the development of the drinking water supply system (SPAM) in Palangka Raya. In 2021, PERUMDAM Palangka Raya reported an NRS level of 49.92% (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2022). This percentage surpassing the national NRW level of 33.72% and failing to meet the National Medium-Term Development Plan target in 2021. The potential income loss for PERUMDAM Palangka Raya due to NRS, calculated at an average water tariff of IDR 7,322.00/m^3, reaches IDR 19,283,548,596.00 per year. The responsible for NRW management lies within the distribution sub-section, primarily limited to addressing visible leaks. Based on PERUMDAM Palangka Raya's 2021 water balance analysis, physical water loss accounts for the largest share of NRW

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components, reaching 1,522,057 m^3/year. This loss mainly occurs from invisible leaks in the distribution pipe network, posing challenges in detection and repair. Currently, there is no particular section specifically tasked with NRW management. The distribution sub-division handles visible leaks ad hoc. The aging pipes and numerous interconnections between pipe segments worsen the challenge in identifying and repairing invisible leaks. Failure to address this sissues promptly could result in reduce distributed water quantity, reducing water quality due to the siphoning effect, lowered customer pressure, increased operational costs, diminish customer trust, and damaging the environment from high pressure (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2018).

One of successful effort controlling NRW is implementation of District Metered Area (DMA) (Özdemir, 2018). According to Spedaletti et al., (2022), the DMA idea is widely widely adopted by practitioners for determining both physical and non-physical water losses in a designated zone. A method used to identify losses caused by physical water loss is the step test (Saparina & Masduqi, 2016). The step test helps narrow down the water flow or area within a DMA zone to estimate the leak locations. Controlling physical water loss also involves pressure management, known as the most cost-effective means to reduce physical water loss through leaks (Kanakoudis et al., 2014). Kanakoudis et al., (2014) explained that pressure management is applicable only in water distribution networks divided into several DMAs. Research by Marchis and Milici (2019), indicates that monor leaks occur under low water pressure, while significant leaks arise with high water pressure.

The current condition of central drinking water supply system (SPAM) PERUMDAM Palangka Raya has 12,030 customer connections. This connection classified into several DMAs according to the categories given by Palyja (2021). These categories inclued < 300 properties for small DMA, 300 – 700 properties for ideal DMA, 700 – 100 properties for medium DMA, and > 1000 properties for big DMA. According to Farley (2001), pipes with a diameter of > 300 mm should not be included in the DMA. Consequently, the formation of DMA at the central SPAM is design to accommodate pipes ranging from 50 – 200 mm in diameter. Handini (2020) recommendates each DMA is equipped with a single inlet. Several pipe segments, such as the main distribution pipe and sub-services, have been installed with the instrumentation and necessary accessories required to establish a DMA, such as valves, central meters, and pressure sensors. According to Kementerian Pekerjaan Umum dan Perumahan Rakyat (2018), the variation in elevation of the service point does not exceed 40 m within the central SPAM service area. The highest service point stands at +18.08 meters above sea level, while the lowest is +5.25 meters above sea level, this meeting the criteria for DMA formation. Therefore, the PERUMDAM Palangka Raya has the opportunity for the application of DMA within its distribution pipe network, offering potential for reducing NRW.

In this research, the division of locations into metered areas was carried out based on hydraulic analysis of the pipe network using the EPANET 2.2 program, considering the criteria for DMA formation. The formed DMA will be assessed based on certain criteria to determine the priority for development using the Weight Sum Model (WSM) method. Prioritizing DMA formation through the WSM enables the avaluation of NRW potential, oidentifying which DMA holds higher priority for development (Wirawan et al., 2020). Apart from the potential physical water loss, several other criteria are considered, including customer groups and area size. The identification of waster loss reduction after the formation of DMA utilizes the Fix and Variable Area Demand (FAVAD) method. FAVAD is an approach to evaluate leakage levels in tandem with pressure changes (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2018).

2. Material and method

2.1. Study area

Research on reducing water loss with DMAs will be focused on the central drinking water supply system service area, covering a service area is 20,302.45 Ha and serving a population of 61,130 people. PERUMDAM Palangka Rayahas divided the central drinking water supply system service zone into 5 service areas with 82 sub-service areas, catering to 12,030 customers, as of the latest updated in May 2023. The distribution network at the Palangka Raya centra drinking water supply system consists of primary, secondary, and tertiary networks. PERUMDAM Palangka Raya employes Steel, Galvanized Iron Pipe (GIP), Polyvinyl Chloride (PVC), and High-Density Polyethylene (HDPE) pipes for distribution puposes. The distribution pipes at the central drinking water supply system are recorded from 1997 to 2022, featuring various materials and diameter sizes. The total length of the central drinking water supply system distribution pipe spans 715,052.4 meters, consisting of 84,699.96 meters of primary pipe, 71,198.74 meters of secondary pipe, and 559,153.74 meters of tertiary pipe.

2.2. Criteria of DMA design

Farley et al. (2008) explained that the design of a DMA is highly subjective, inevitably resulting in design disparities among different experts, even when working on the same network. However, DMA designs must align with the existing DMA formation criteria. Several references ouline the criteria necessary for establishing a DMA, and these summarized criteria sources from several literatures are presented in Table 1.

Table 1. DMA design criteria

Criteria	Ideal Condition
Number of Customer Connections	1.000 – 2500 properties (Farley et al., 2008) ; 500 – 3.000 properties (Hajebi et al., 2014) ; 500 – 5.000 properties (Morrison et al., 2007) ; < 300 properties for small DMA , 300 – 700 properties for ideal DMA, 700 – 100 properties for medium DMA., and > 1000 properties for big DMA (Palyja, 2021)
DMA Boundaries	The division of administrative zones includes aspects like regional boundaries, roads, rivers, etc. (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2018)
Number of Inlets	There should only be one DMA inlet to ensure proper isolated (Handini, 2020)
Instrumentation	Establishing a DMA in an existing drinking water distribution network requires equipment in the form of valves, water meters and accessories (Annisa, 2016)
Diameter and Length of The Pipe	The recommended length of DMA pipe is between 3,000 – 8,000 meters with a diameter < 200 mm. Pipes with a diameter > 300 mm are excluded from the DMA (Farley, 2001)
Variations in land surface elevation	It should have an elevation difference < 40 m. (Kementerian Pekerjaan Umum dan Perumahan Rakyat, 2018)

Establishing a DMA by isolating a service zone must consider flow parameters to ensure customers continue to receive excellent service. The pipe criteria refer to PUPR Ministerial Regulation No. 27/PRT/M/2016 (2016) and Badan Standardisasi Nasional (2011). The specific criteria that that need to be met are outlined in Table 2.

2.3. Pressure and leak relationship

During the minimum night flow, the pressure in the pipe network will increase, potentially leading to increase both the volume of water lost due to leaks and the frequency of leaks. FAVAD is an empirical relationship between water loss and pressure in various system scenarios. For practical prediction of the relationship between water leakage discharge and pressure, it is formulated in Equation (1).

Table 2. Distribution pipe design criteria.

Description	Notation	Criteria
Velocity of water in pipe		
a) Minimum velocity	V min	0.3 – 0.6 m/s
b) Maximum velocity		
– PVC or ACP pipe	V max	3.0 – 4.5 m/s
– Steel or DCIP pipe	V max	6.0 m/s
Pressure of water in pipe		
a) Minimum Pressure	h min	(0.5 – 1.0) atm, at the furthest service point
b) Maximum Pressure		
– PVC or ACP pipe	h max	6.0 – 8.0 atm
– Steel or DCIP pipe	h max	10 atm
– PE 100 pipe	h max	12.4 atm
– PE 80 pipe	h max	9,0 atm
Headloss	h max	10 m/km or 80% working pressure according to pipe technical specifications

$$\frac{L_1}{L_0} = \left(\frac{P_1}{P_0}\right)^{N1} \tag{1}$$

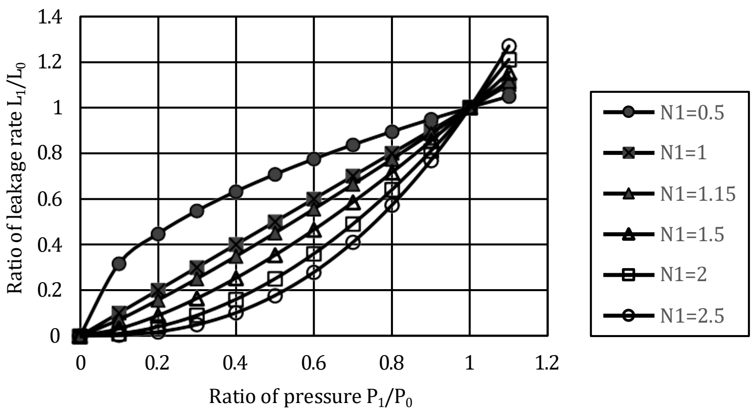


Figure 1. The relationship between pressure and leakage rate is based on the FAVAD concept (Lambert, 2000)

The leak rate (L) varies according to the pressure (P) under N1 conditions. Typically, the N1 value falls within the range of 0.5 to 1.5, although it can reach to 2.5 or more (Thornton et al., 2008). Networks utilizing metal pipes usually have N1= 0.5. Networks with background leaks, connections, and accessories tend to have N1=1.5. Conversely, non-metallic pipe networks show N1 = 2.5. Larger network incorporating various pipe materials often present a linear relationship, resulting in N1 = 1. Refer to Figure 1 for graphical representation of the pressure and leakage rate correlation.

2.4. Determining DMA priority

Determining priorities for DMA formation using the Weight Sum Model (WSM) method the identification of NRW potential within a DMA, enabling the identification of priority DMAs for development (Wirawan et al., 2020). According to Kilinç et al., (2018), physical water loss is attributed to three factors: physical, environmental, and operational. These factor consists of six sub-factors, including pipe age, pipe material, pipe diameter, condition of the road surface above the pipe, pressure within the pipe, and frequency of pipe leaks. The weighting coefficients for these factors are outlined in Table 3, while the corresponding values assign to the sub-factors are detailed in Table 4.

Table 3. The weight coefficients of the main and sub-factors.

Main Factor	Weight (w_i)	Sub-Factor	Weight (W_i)
Physical	0.43	Pipe age	0.65
		Pipe material	0.19
		Pipe diameter	0.16
Environment	0.14	Road surface condition	1.0
Operational	0.43	System pressure	0.72
		Leakage frequency	0.28

Table 4. The scoring categories of factor's components.

Main Factor	Sub-Factor	Attributes	Score (c_i)
Physical	Pipe Age	>40	10
		30 – 40	9
		20 – 30	8
		10 – 20	7
		<10	5
	Pipe Material	ACP	9
		GIP	8
		HDPE	6
		PVC	6
	Pipe Diameter	<100	7
		100 – 125	6
		125 – 150	6
		150 – 250	4
		250 – 300	4
		300 – 350	3
		>350	3
Environment	Road Surface Condition	Asphalt	5
		Concrete	7
		Clay	10
Operational	System Pressure (atm)	>5	9
		4 – 5	8
		3 – 4	7
		2 – 3	6
		1 – 2	3
		<1	2
	Leakage Frequency	>3,5	10
	(number of leaks/ 100 m/year)	2,5 – 3,5	8
		1,5 – 2,5	7

Main Factor	Sub-Factor	Attributes	Score (c_i)
		1,0 – 1,5	5
		<1	3

Calculating potential physical water loss begins with calculating the factor index using Equation (2), (3), and (4). The potential physical water loss is derived by multiplying the factor group's weight with the index value of the three factors using Equation (5) (Triantaphyllou, 2000).

$$Physical\ Factor\ Score\ (PFS) = \sum_{i=1}^{m} w_i . c_i \quad (2)$$

$$Environmental\ Factor\ Score\ (EFS) = \sum_{i=1}^{m} w_i . c_i \quad (3)$$

$$Operational\ Factor\ Score\ (OFS) = \sum_{i=1}^{m} w_i . c_i \quad (4)$$

$$Performance\ Evaluation\ Score\ (PES) = w_i.PFS + w_i.EFS + w_i.OFS \quad (5)$$

The classification of high or low potential physical water loss is obtained from the assessment of pipe network performance, evaluated using scores (Kilinç et al., 2018). The score range for potential physical water loss can be seen in Table 5.

Table 5. Assesment classes in evaluating the pipe performance

Class	Score Range	Pipe Condition
A	[0 – 2]	Good performance, Potential risk may not occur
B	[2 – 4]	Moderate performance
C	[4 – 6]	Poor performance, Damage observable
D	[6 – 8]	Bad performance, High risk of damage
E	[8 – 10]	Quite bad performance, The risk of significant damage is very high

According to Hanifa et al. (2021), the criteria considered influential in selecting priority DMA include pressure with a weight of 0.373, water loss with a weight of 0.368, pipe length with a weight of 0.147, customer group with a weight of 0.059, and area with a weight of 0.053. However, parameters like pressure, water loss, and pipe length have been considered in assessing the potential for physical water loss, contributing to a weigh of 0.888 in the evaluation of physical NRW potential. The weights used in assessing DMA priority are detailed in Table 6.

Table 6. The weight of DMA priority criteria

Criteria of DMA Priority	Weight
Physical water loss potential	0.888
Customer group	0.059
Area of service	0.053

3. Result and discussion

3.1. Analysis of existing conditions

Technical data and information essential for establishing a DMA at the central SPAM PERUMDAM Palangka Raya includes as-built drawings, pipe specifications, number of customers, geographic data, water consumption by category, and water balance. The as-built drawing for central SPAM PERUMDAM Palangka Rayaillustrates the pipe network and the location of installed valves, depicted in Figure 2. The central SPAM has an overall pipe length of 715,052.4 meters, consisting of 84,699.96 meters of primary pipe, 71,198.74 meters of secondary pipe, and 559,153.7 meters of tertiary. Pipes materials utilized include Steel, Galvanized Iron, PVC and HDPE with detailed lengths categorized by pipe type available in Table 7.

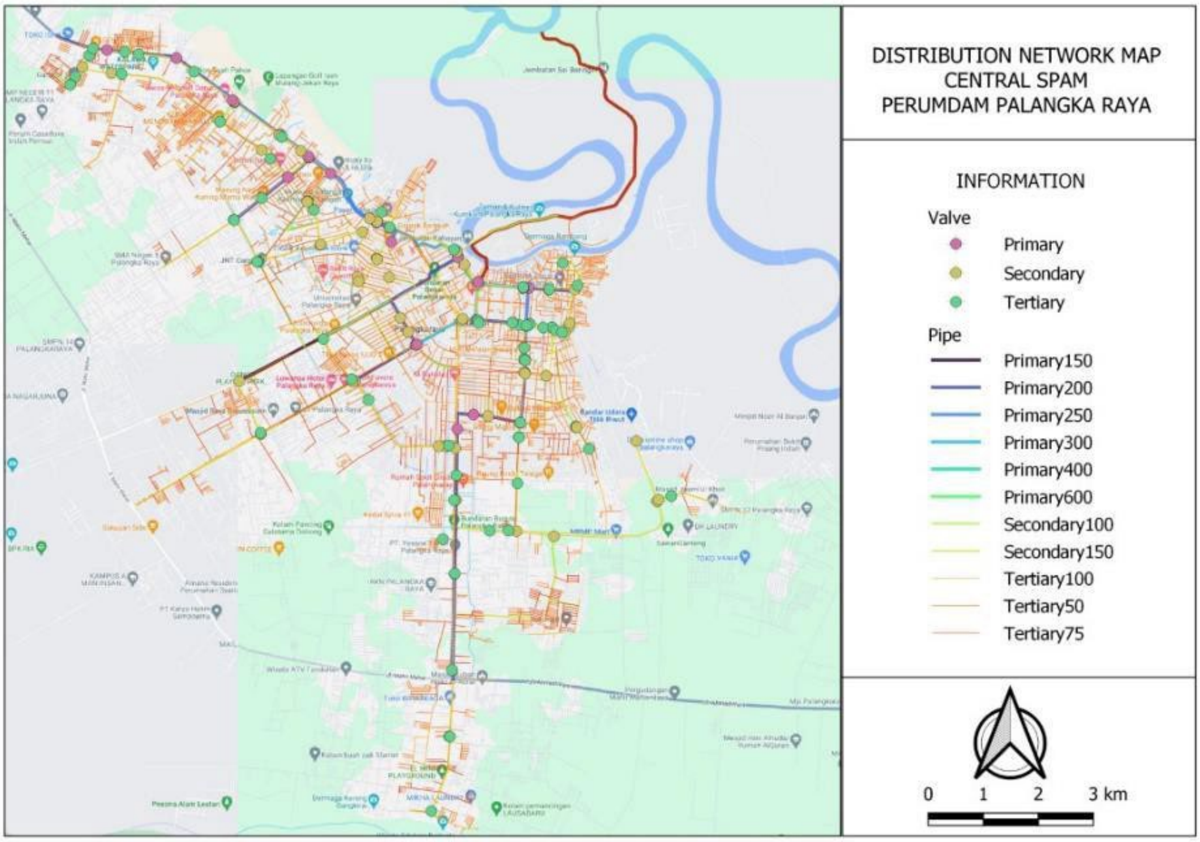


Figure 2. Central SPAM distribution network map

PERUMDAM Palangka Raya has divided the central SPAM service area into five primary service zones, comprising a total of 82 sub-service and servicing 12,030 customer connections as of May 2023. This division is based customer expansion potential, calculated from the area's population, aiming to streamline customer data collection. Information related to each regional zone are outlined in Table 8. Zone I includes three subdistricts – Panarung, Pahandut, and Tanjung Pinang – serving 2,156 customers. Zone II includes five subdistricts – Panarung, Langkai, Menteng, Bereng Bengkel, and Sabaru - with total customer based of 5,746. Zone III includes three subdistricts =- Palangka, Tumbang Rungan, and Bukit Tunggal - with 4,073 customers. Zone V includes parts of Tumbang Rungan and Pahandut Seberang Subdistrict, serving 55 customers. Zone VI consists of Bukit Tunggal and the Petuk Katimpun Subdistrict, but presently lack a pipe network in this area.

The amount of water usage is obtained from the accounts billed in May 2023. Table 9 shows that water consumption is grouped based on customer categories, including social, household, government, and commercial needs. The obtained water consumption data represents the monthly consumption in m^3 units. The total amount of water reaching customers in May 2023 is 233,997 m^3. This customer classification data will be used to determine the priority level of a DMA based on the income generated per customer category within a DMA.

In this research, water balance calculations were carried out in May 2023 to obtain the existing water loss at the central SPAM, establishing a baseline for water loss before DMA planning. Calculations using WB-EasyCalc revealed that water loss at the central SPAM in May 2023 was 51.84%. This included 2.19% for non-revenue official consumption, 6.97% for non-physical water loss, and 42.67% for physical water loss. For detailed breakdown of each sub-component of water loss, refer to Figure 3.

Table 7. Central SPAM distribution pipeline information

Diameter (mm)	Material	Pipe length (m)			Total length (m)
		Primary	Secondary	Tertiary	
600	Steel	55,77	-	-	55,7
400	PVC	1.215,32	-	-	1.215,32
300	PVC	38.819,92	-	-	38.819,92
250	PVC	15.706,27	-	-	15.706,27
200	PVC	27.153,48	-	-	27.153,48
150	PVC	1.749,2	49.362,82	13,49	51.125,51
	GI	-	718,01	-	718,01
	HDPE	-	5.327,71	-	5.327,71
100	PVC	-	15.790,2	116.095,8	131.886
	HDPE	-	-	3.527,19	3.527,19
75	PVC	-	-	142.285,8	142.285,8
	HDPE	-	-	5.290,96	5.290,96
50	PVC	-	-	261.019,7	261.019,7
	HDPE	-	-	30.920,8	30.920,8
Total length		84.699,96	71.198,74	559.153,7	715.052,4

Table 8. Number of customers central SPAM regional zone

Zone	Sub-zone	Number of Customers
Regional Zone I	11, 12, 13, 14, 15, 16, 17, 18	2,156
Regional Zone II	21, 22, 23, 24, 25, 26, 27, 28, 29, 31, 32, 33, 34, 35, 41, 42, 43, 44, 45, 46	5,746
Regional Zone III	51, 52, 53, 54, 55, 56, 57, 58, 59, 61, 62, 63, 70, 71, 72, 73, 74, 76, 75, 76, 77, 79	4,073
Regional Zone V	10, 9	55
Regional Zone VI	80, 81, 82	0
	Number of customers	12.030

Table 9. Water consumption based on customer groups at central SPAM

Customer Group	Number of Customers	Used water (m^3)	Water consumption per connection	
			(m^3/month/conn.)	(l/s/conn.)
Social	232	15,468	66.672	0.025
Household	10,054	148,980	14.800	0.006
Government	227	34,334	151.251	0.058
Commerce	1,517	35,215	23.214	0.009

<table>
<tr><td rowspan="7">System Input Volume
485,950 m³
Error Margin [+/-]: 0.5%</td><td rowspan="4">Authorized Consumption
244,643 m³
Error Margin [+/-]: 2.2%</td><td rowspan="2">Billed Authorized Consumption
233,997 m³</td><td>Billed Metered Consumption
233,997 m³</td><td rowspan="2">Revenue Water
233,997 m³</td></tr>
<tr><td>Billed Unmetered Consumption
0 m³</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption
10,646 m³
Error Margin [+/-]: 50.0%</td><td>Unbilled Meterd Consumption
0 m³</td><td rowspan="5">Non-Revenue Water
251,953 m³
Error Margin [+/-]: 1.0%</td></tr>
<tr><td>Unbilled Unmetered Consumption
10,646 m³
Error Margin [+/-]: 50.0%</td></tr>
<tr><td rowspan="3">Water Losses
241,307 m³
Error Margin [+/-]: 2.4%</td><td rowspan="2">Commercial Losses
33,907 m³
Error Margin [+/-]: 14.0%</td><td>Unauthorized Consumption
5,948 m³
Error Margin [+/-]: 12.2%</td></tr>
<tr><td>Customer Meter Inaccuracies and Data Handling Errors
27,959 m³
Error Margin [+/-]: 16.7%</td></tr>
<tr><td colspan="2">Physical Losses
207,400 m³
Error Margin [+/-]: 3.6%</td></tr>
</table>

Figure 3. Water balance analysis of PERUMDAM Palangka Raya central SPAM in May 2023

The hydraulic simulation of the distribution pipe network has considered the water loss magnitude by inputting an emitter coefficient of 0.3 at several nodes, aiming to align the modelling's pressure and discharge with actual field conditions. This simulation aimed to obtain a master model for DMA planning, approximating the simulated hydraulic conditions to the actual hydraulic conditions in the field conditions. Flow and pressure measurements within the distribution pipe network at the central SPAM distribution pipe network were conducted over a 24 hours period using a magnetic flowmeter and pressure sensor connected to a logger. This field measurement served to calibrate the EPANET 2.2 simulation, ensjuring it closely mirrored real field conditions. Discharge and pressure data from Jati and Suwarno areas, along woth pressure data from the Hiud area, were used for calibration, and instrumentation location are illustrated in Figure 4.

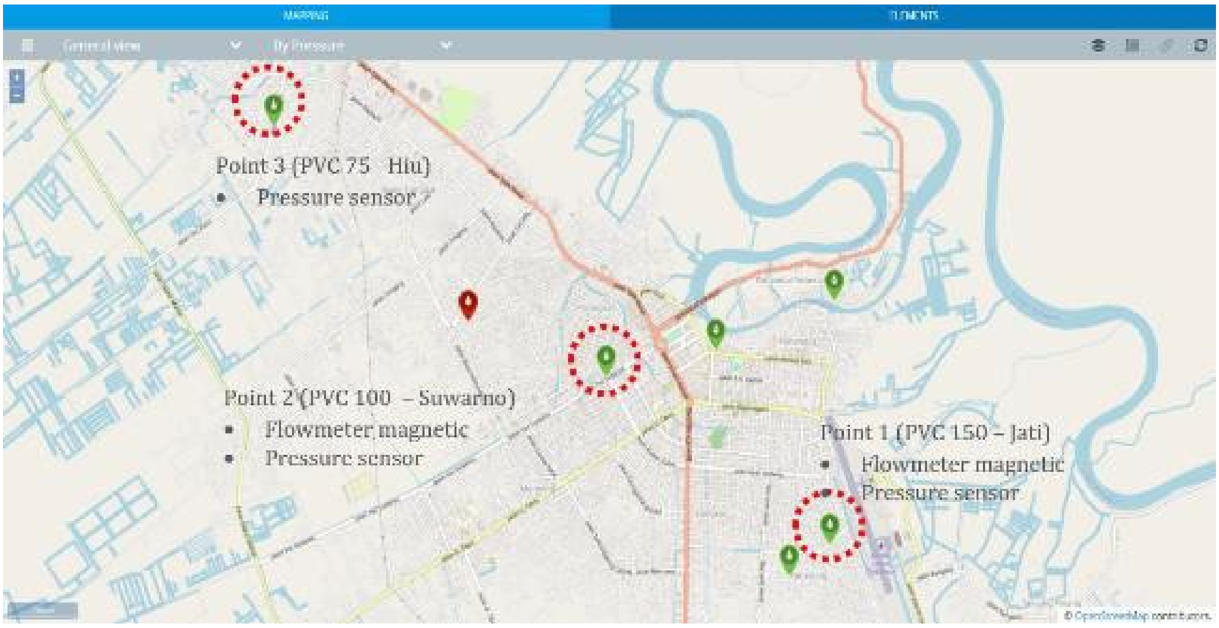


Figure 4. Location of central SPAM instrumentation

After modelling in EPANET 2.2, Table 10 indicates that the most significant difference in discharge persentage between field measurements and modelling results ranges from 0.842%. Table 11 demonstrates that the most significant pressure difference percentage between field measurements and modelling results ranges from 1.163%. These results show deviation value below the significance level outlined by Everitt & Skrondal (2006), set at 5%. Consequently, the model is deemed acceptable and will proceed for DMA planning.

Table 10. Differences in discharge from field measurement results and modeling results

Observation Location	Average discharge (l/s)		Average deviation (%)
	Measurement results	Modeling results	
Suwarno	3.714	3.689	0.654
Jati	2.915	2.939	0.842

Table 11. Differences in pressure from field measurement results and modeling results

Observation Location	Avarage pressure (m)		Average deviation (%)
	Measurement results	Modeling results	
Suwarno	13.761	13.659	0.739
Jati	9.541	9.630	0.934
Hiu	6.924	6.843	1.163

Apart from that, pressure checks are also carried out at critical points during peak hours. In the central SPAM service area, one of these critical points is Region II in Zone 35, Jalan Maduhara, where pressure data was collectedat 07.00 WIB, registering 0.5 bar. According to the 2022 performance evaluation of PERUMDA Palangka Raya by BPKP, approximately 82.82% of customers receive water pressure > 0.7 bar. The average pressure at other critical points has reached 0.5 bar, while the lowest is 0.3 bar, ensuring that even customers situated farthest away still receive water. For more details on the pressure and discharge simulation under existing conditions, please refer to Figure 5.

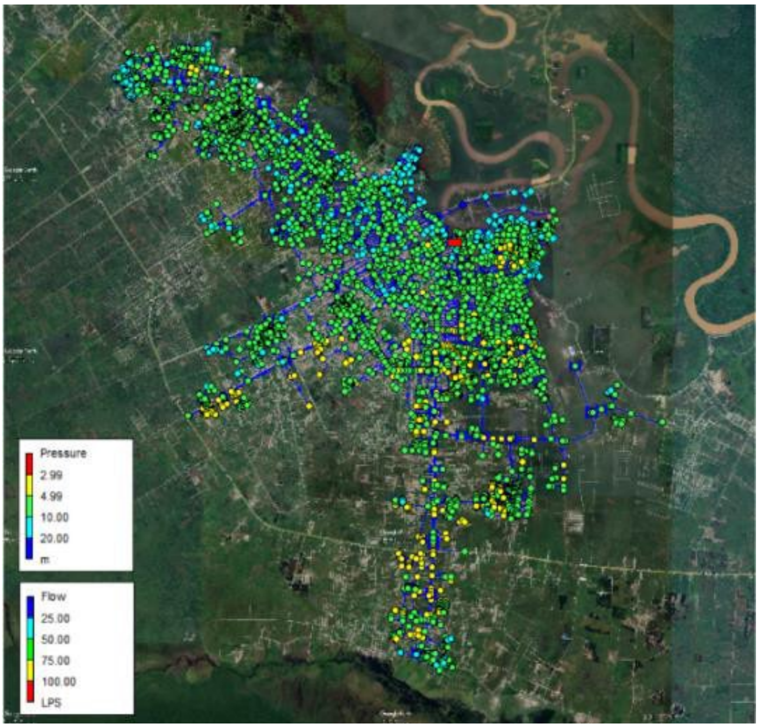


Figure 5. Simulation of existing conditions during peak hours at 07.00 AM

3.2. DMA formation

The planned DMA consists of one or a combination of a combination of several zones that forming an isolated area, with one inlet equipped with a master meter. Considering the condition of the central SPAM network, which takes into account administrative boundaries and the hydraulic conditions of the existing pipe network, the central SPAM service area can be divided into 27 DMAs. The DMA central SPAM location plan is revealed in Figure 6.

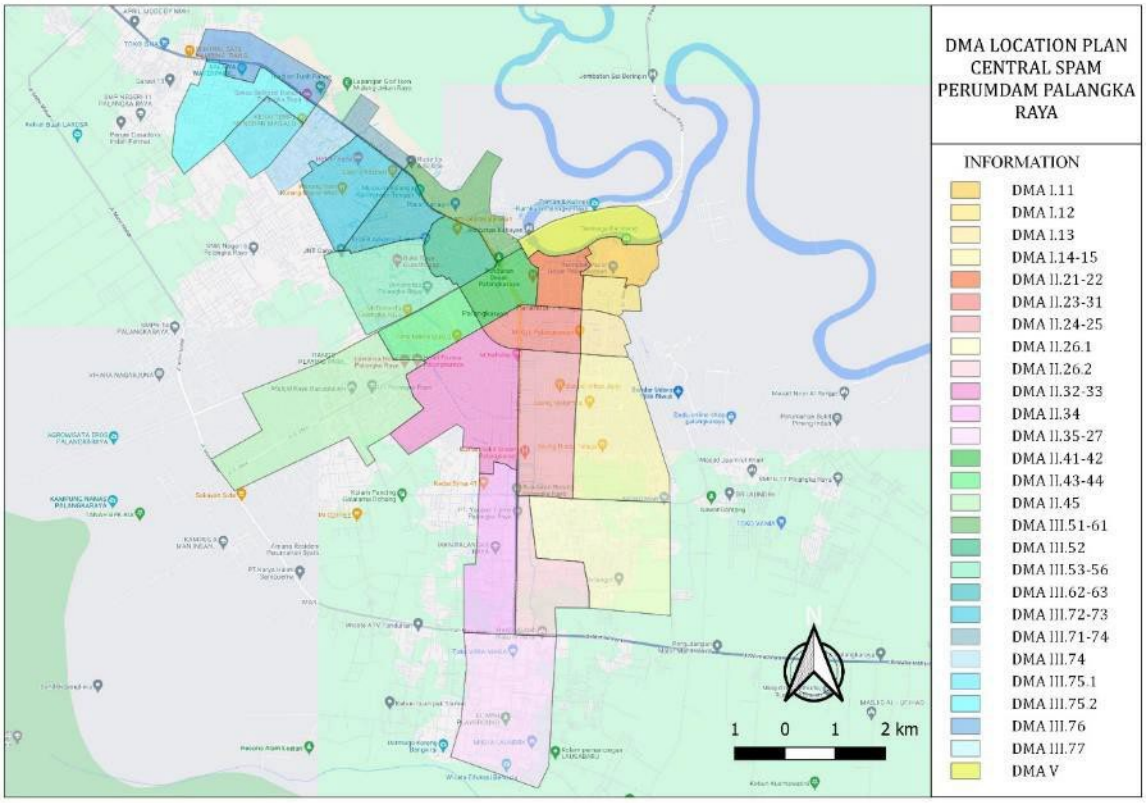


Figure 6. DMA central SPAM location distribution plan

In Table 12, it is evident that that the planned DMA locations fulfil the criteria outlined in various references for establishing a DMA. Considering the criteria for the number of home connections initiated by Palyja (2021), the formation of DMAs in central SPAM classifies into seven small DMAs (<300 properties), sixteen ideal DMAs (300 – 700 properties), and four medium DMAs (700 – 1000 properties). If the number is too small, pipe length serves as a guideline for DMA establishment. This applies to DMA III/71-74 with 73 properties subscribers and DMA V with 55 properties. Even though the customers numbers in these DMAs remains relatively low, the length of tertiary pipes in these areas meets Farley (2001) recommended pipe length range of 3,000 – 8,000 m.

The proposed DMA consist of a single inlet with a main meter size ranging between 100 – 200 mm, installed on either the primary or secondary pipe. With this planned DMAs, several tertiary pipe connections are established, with varying diameters between 50 – 100 mm. This fulfills the criteria for pipe diameter in a DMA, which is < 300 mm. Upon identifying the availability of master meters and pressure sensors in the field, three locations, namely DMA I/14-15, DMA II/43-44, and DMA V, already have these instruments. In addition, among these locations, two locations have pressure sensors. To facilitate monitoring, selecting a relatively flat location can maintain stable and easy-to-control pressure. Palangka Raya city is relatively flat terrain, meeting the criteria for an elevation difference of <40 m.

Table 12. The scoring categories of factor's components

DMA	Num. of Cust. Conn.	Flow-meter	Mano-meter	Pipe Diameter	Pipe Length	Elevation Difference	DMA Categories
DMA I/11	530	×	×	50 – 100	25,475.6	16.73	Ideal
DMA I/12	486	×	×	50 – 150	11,949.2	14.41	Ideal
DMA I/13	596	×	×	50 – 150	13,0634.0	4.68	Ideal

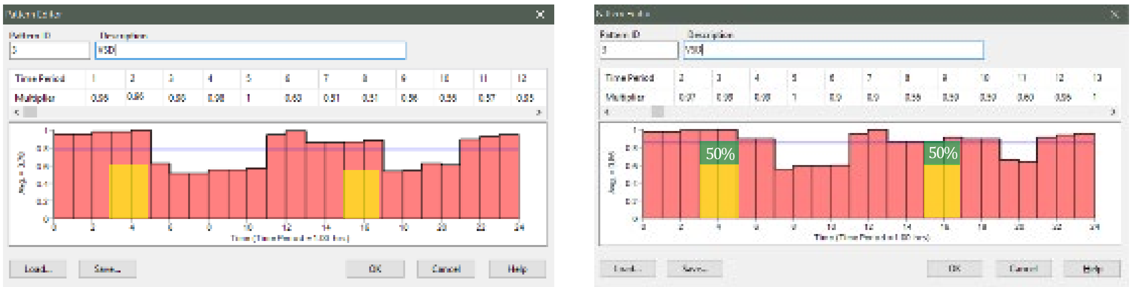
DMA	Num. of Cust. Conn.	Flow-meter	Mano-meter	Pipe Diameter	Pipe Length	Elevation Difference	DMA Categories
DMA I/14-15	544	✓	✓	50 – 150	36,498	6.57	Ideal
DMA II/21-22	399	×	×	50 – 150	18,489.9	14.25	Ideal
DMA II/23-31	819	×	×	50 – 150	22,371.8	6.20	Moderate
DMA II/24-25	949	×	×	50 – 150	16,408.5	6.87	Moderate
DMA II/26.1	328	×	×	50 – 100	22,593.8	8.08	Ideal
DMA II/26.2	309	×	×	50 – 150	12,421.2	7.87	Ideal
DMA II/32-33	902	×	×	50 – 150	35,795.7	6.70	Ideal
DMA II/34	56	×	×	50 – 150	14,720.5	9.75	Small
DMA II/35-27	201	×	×	50 – 150	25,519.2	11.96	Small
DMA II/41-42	399	×	×	50 – 150	16,436.7	5.98	Ideal
DMA II/43-44	787	✓	✓	50 – 200	21,982.8	3.85	Moderate
DMA II/45	597	×	×	50 – 150	44,923.9	9.17	Ideal
DMA III/51-61	406	×	×	50 - 150	21,137.9	16.01	Ideal
DMA III/52	747	×	×	50 – 100	18,110.5	9.69	Moderate
DMA III/53-56	313	×	✓	50 - 150	18,044.1	6.91	Ideal
DMA III/62-63	561	×	×	50 – 150	18,730.1	6.83	Ideal
DMA III/72-73	553	×	×	50 – 100	28,683.0	7.79	Ideal
DMA III/71-74.1	73	×	×	50 – 100	4,859.4	6.07	Small
DMA III/74.2	232	×	×	50 – 100	14,273.0	6.68	Small
DMA III/75.1	550	×	×	50 – 150	24,769.9	7.54	Ideal
DMA III/75.2	319	×	✓	50 – 150	19,420.6	10.53	Ideal
DMA III/76	119	×	×	50 – 100	16,842.2	11.60	Small
DMA III/77	200	×	×	50 – 150	15,842.2	10.44	Small
DMA V	55	✓	✓	50 - 150	3,073.5	3.48	Small

3.3. Hydraulic analysis after DMA is formed

The implementation of DMA formation at central SPAM needs careful attention to hydraulic criteria for distribution pipe networks outlined in PUPR Ministerial Regulation No. 27/PRT/M/2016 (2016) and Badan Standardisasi Nasional (2011). The criteria include a headloss value is not greater than 10 m/km, a minimum speed range of 0.3 - 0.6 m/s, and a pressure above 1.5 bar at the furthest service point. However, the formation led to pressure losses in some pipe segments exceeding 10 m/km, failing to meet the requirements. Approximately 4028 m of pipes, with the longest being Pipe L5168 at 510.06 m. The highest recorded headloss was 47.06 m/km on the L4702 pipe in DMA II/21-22. After pipe replacement, the greatest headloss shifted to the L4905 pipe in DMA I/11, with the measurement of 9.29 m/km. Apart from that, several pipe segments maintain a water flow speed of less than 0.3 m/s, falling short of the minimum requirement of 0.3 – 0.6 m/s. This segments, characterized by speed below 0.3 m/s, primarily serve a limited number of customers. Considering the availability of tertiary pipe lengths across several DMAs and the relative low service coverage, the formation of these DMAs and the relatively low service coverage, the formation of these DMAs holds the potential to connect new customers, potentially increasing flow speeds within the pipes.

The pressure at several service points is expected to decrease because areas initially served by several inlets are being redesigned to consolidate into a single inlet. Figure 8 (a) diplays the simulation outcomes for DMA formation using EPANET 2.2, where yellow dots/nodes indicate pressure received by the customer below 0.5 atm, failing to comply with the pressure stipulations outlined in PUPR Ministerial Regulation No. 27/PRT/M/2016. Adjusting pump operating patterns is an alternative to ensure meeting the critical point's pressure within the DMA during peak hours.

To achieve the minimum pressure in the DMA formation simulation, pump capacity is increased by 50% of the existing setting during peak hours, specifically from 06.00 – 07.00 and 18.00 – 19.00, using Variable Speed Drive (VSD). This increasing in pump capacity using VSD is simulated using a pattern editor, as depicted in Figure 7, where the pump pattern during peak hours is elevated from 60% to 90%.



(a) (b)

Figure 7. Existing pump pattern (a) Pump pattern with 50% increase in pump performance (b)

It is evident in Figure 8 (b) that the pressure within the distribution pipe network has increased, changing the yellow pressure indicators to green. After the adjustment in pump operation patterns, the lowest pressure within the DMA plan at the central SPAM during peak hours is at 5.15 m or 0.5 atm, meeting the minimum required pressure. However, efficient management of the pump operating pattern needs to be ensured, coupled with active leak control. Excessive pressure might elevate background leakage, necessitating prioritized analysis in DMA formation.

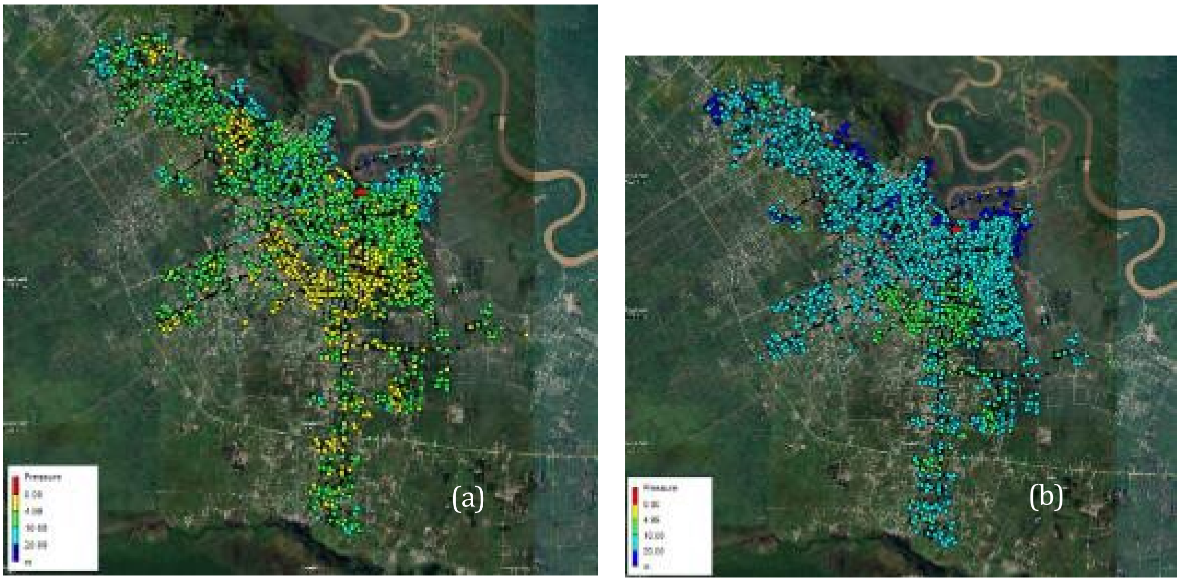


Figure 8. Pressure at peak hours (07.00 AM) after DMA formation (a) and peak hour (07.00 AM) pressure after DMA formation with pump performance increased by 50% (b)

3.4. FAVAD Analysis

The simultaneous formation of DMA leads to a decrease in pressure because several inlets serving an area are closed and diverted to a single inlet. This reduction in pressure can reduce water loss resulting from background or undetected leaks. Hence, the DMA formation can effectively reduce physical water loss through pressure management.

$$L_1 = \left(\frac{8.953}{9.421} \right)^{1,5} \times 207,400$$
$$= 192,139 \ m^3 / month$$

Based on the calculations above, physical water loss in the distribution pipe network decreased by 7% after the DMA was established, dropping from 207,400 m^3/month to 192,139 m^3/month. The water saved due to the impact of DMA formation amounts to 15,261 m^3/month.

3.5. Priority DMA Analysis

DMA formation can be conductedsimultaneously, but it has the potential to result in a decrease in pressure at several customer points. Therefore, the formation of DMA is executed in stages, considering the priority level of the planned locations. The priority assessment of a location is based on several criteria, including the potential for physical water loss, customer groups, and service areas. After applying Equation (5) and calculating the weighted average according to the piple length, the average potential for physical water loss in each DMA is obtained, which is displayed in Table 13. The potential value of physical water loss from all pipes for each DMA competition can be represented as a map, which visible in Figure 9.

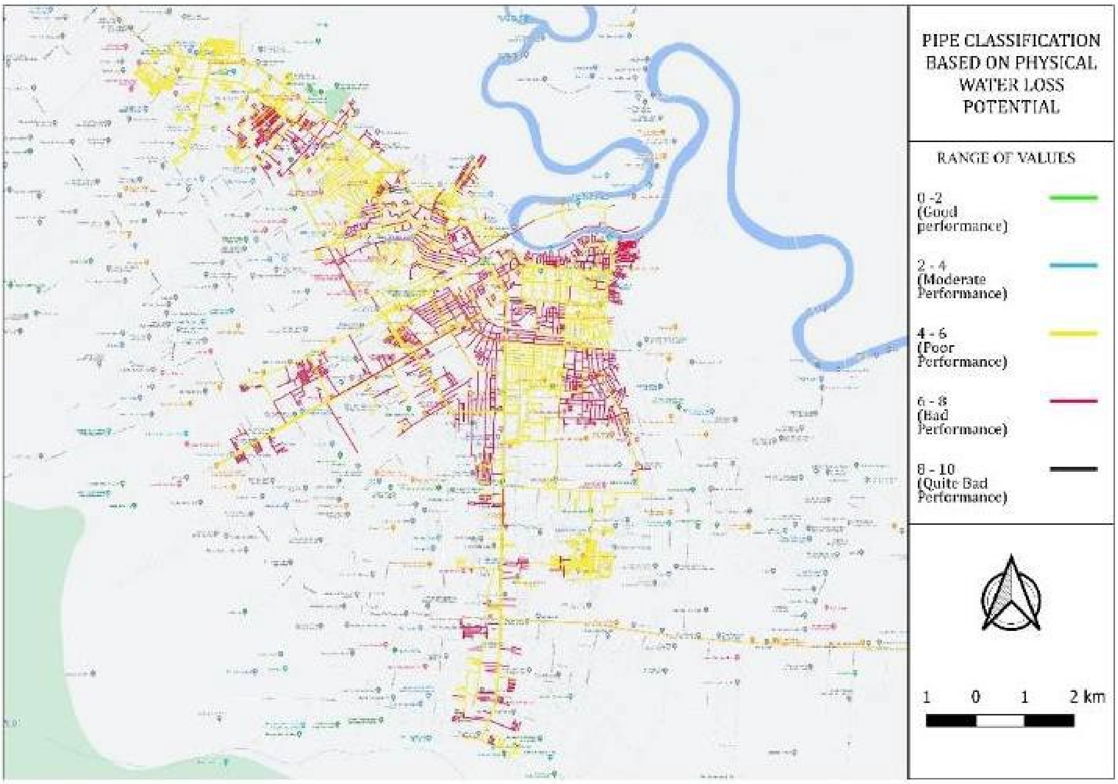


Figure 9. Classification of central SPAM pipes based on physical water loss potential values

Table 13. Average potential physical water loss DMA plan

DMA	Average Potential Physical Water Loss	Category
DMA I/11	6,52	Bad performance
DMA I/12	5,73	Poor performance
DMA I/13	5,15	Poor performance
DMA I/14-15	6,33	Bad performance
DMA II/21-22	5,65	Poor performance
DMA II/23-31	5,86	Poor performance
DMA II/24-25	5,58	Poor performance
DMA II/26.1	5,50	Poor performance
DMA II/26.2	5,68	Poor performance
DMA II/32-33	5,85	Poor performance
DMA II/34	5,77	Poor performance
DMA II/35-27	5,95	Poor performance
DMA II/41-42	5,72	Poor performance
DMA II/43-44	5,68	Poor performance
DMA II/45	5,99	Poor performance
DMA III/51-61	6,06	Bad performance
DMA III/52	5,94	Poor performance
DMA III/53-56	5,82	Poor performance
DMA III/62-63	5,92	Poor performance
DMA III/72-73	5,50	Poor performance
DMA III/71-74.1	6,14	Bad performance
DMA III/74.2	5,94	Poor performance
DMA III/75.1	5,90	Poor performance
DMA III/75.2	5,55	Poor performance
DMA III/76	5,39	Poor performance
DMA III/77	5,45	Poor performance
DMA V	6,10	Bad performance

Referring to Table 5, which details the assessment in pipe performance evaluation, the calculation of the average potential physical water loss for each DMA in Table 13 indicates that the central SPAM pipe exhibits poor or even bad performance. DMA I/11 displays the highest average potential physical water loss with a value of 6.52 in the bad performance category (high risk of damage), while DMA I/13 shows the lowest average potential physical water loss with a value of 5.15 in the category poor performance (damage observable).

The next criterion is the customer group, where the identification of the customer group in the DMA that shows the highest water price per m^3 is DMA II/24-25, valued at IDR 6,230,962 per m^3. In contrast, DMA V has the lowest water price per m^3, with a value of IDR 363,185. In terms of area, DMA II/45 has the largest area of 637.67 Ha, while DMA III/71.41 is the DMA with the smallest area, covering 64.96 Ha. Each criterion's value range is scored on a scale of 1 to 5, as seen in Table 14. After scoring the DMAs according to the criteria and weights, the DMA with the highest priority value was obtained, namely DMA I/11, with a score of 3.994 and the DMA with the lowest priority value, namely DMA II/35-27 with a score of 2.829. DMA assessment priorities according to criteria is detailed in Table 15.

Table 14. The value range of priority DMA criteria

Criteria DMA Priority	Range of Value	Score
Physical water loss potential [weight: 0.888]	0 – 2	1
	2 – 4	2
	4 – 6	3
	6 – 8	4
	8 – 10	5
Water prices are based on customer groups.	< 1.400.000	1
(IDR/m^3)	1.400.000 – 2.800.000	2
[weight: 0.059]	2.800.000 – 4.200.000	3
	4.200.000 – 5.600.000	4
	5.600.000 <	5
Services area (Ha)	560 <	1
[weight: 0.053]	420 – 560	2
	280 – 420	3
	140 – 280	4
	< 140	5

Table 15. DMA assessment of priority DMA criteria

DMA	Average potential physical water Loss	Water prices are based on customer groups (IDR/m^3)	Services Area (Ha)	Criteria 1 Score	Criteria 2 Score	Criteria 3 Score	Total Score
DMA I/11	6.52	3,523,439	104.19	4	3	5	3.994
DMA I/12	5.73	3,195,397	75,.70	3	3	5	3.106
DMA I/13	5.15	3,939,028	77.85	3	3	5	3.106
DMA I/14-15	6.33	3,586,992	447,.50	4	3	2	3.835
DMA II/21-22	5.65	2,643,390	104.40	3	2	5	3.047
DMA II/23-31	5.86	5,403,735	148.04	3	4	4	3.112
DMA II/24-25	5.58	6,230,962	333.63	3	5	3	3.118
DMA II/26.1	5.50	2,153,340	501.84	3	2	2	2.888
DMA II/26.2	5.68	2,028,478	219.48	3	2	4	2.994
DMA II/32-33	5.85	5,946,765	451.90	3	5	2	3.065
DMA II/34	5.77	369,196	291.24	3	1	3	2.882
DMA II/35-27	5.95	1,318,748	504.99	3	1	2	2.829
DMA II/41-42	5.72	2,605,940	138.68	3	2	5	3.047
DMA II/43-44	5.68	5,214,908	163.32	3	4	4	3.112
DMA II/45	5.99	3,929,075	637.67	3	3	1	2.894
DMA III/51-61	6.06	2,665,914	173.61	4	2	4	3.882
DMA III/52	5.94	4,886,817	135.38	3	4	5	3.165
DMA III/53-56	5.82	2,052,383	283.66	3	2	3	2.941
DMA III/62-63	5.92	3,699,259	153.44	3	3	4	3.053
DMA III/72-73	5.50	3,652,920	242.42	3	3	4	3.053
DMA III/71-74.1	6.14	469,461	64.964	4	1	5	3.876
DMA III/74.2	5.94	1,518,758	137.66	3	2	4	2.994
DMA III/75.1	5.90	3,612,642	132.66	3	3	4	3.053
DMA III/75.2	5.55	2,083,783	273.63	3	2	3	2.941
DMA III/76	5.39	781,076	171.75	3	1	4	2.935
DMA III/77	5.45	1,312,733	157.82	3	1	4	2.935
DMA V	6.10	363,185	174.23	4	1	4	3.823

3.6. The impact of DMA formation

The pressure at several service points will decrease because the water distribution, initially served by several inlets, was designed to be consolidated into one inlet, resulting in critical service points maintaining pressure levels below 0.5 atm. Therefore, an alternative to overcome low pressure is to increase pump performance by 50%. However, there is a potential to increase background leaks, so DMA formation needs to be execute in stages while actively detecting leaks and pipe repairs. As a result, the average pressure in the central SPAM distribution network has decreased from 9,421 m to 8,953 m. Using the FAVAD approach, this pressure reduction can reduce physical water loss by 7% dropping from 207,400 l/month to 192,139 m^3/month, saving 15,261 m^3/month of water. Examining the reduction percentage in physical water loss within the overall water balance reveals the decline in non-revenue water volume from 251,953 m^3 to 236,692 m^3, equal to a 6.06% reduction. This significantly benefits the company and prevents water scarcity in Palangka Raya City.

4. Conclusion

The central SPAM PERUMDAM Palangka Raya has the opportunity to establish a DMA. The planning for central DMA SPAM has fulfilled the criteria for DMA planning and distribution network. A total of 27 DMAs can be formed, with DMA I/11 identified as the highest priority for establishment. The potential reduction in NRW after the DMA establishment is estimated at 6.06%, saving a water volume of 15,261 m^3/month.

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