Feasibility Study on Risk-Based Improvement of District Meter Area Project to Reduce Water Loss: Case Study of The Jakarta Drinking Water Supply System

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ABSTRACT: *The world is currently facing the issue of increasing pressure on water resources due to population growth and industrial development. In 2002, the United Nations Environment Programme (UNEP) stated that the Earth's total volume of water is 1.365 billion km³, with 97.5% being seawater and 2.5% being freshwater, including rivers, lakes, wetlands, the two polar ice blocks, glaciers, and groundwater. With the limited amount of freshwater available for human consumption, various efforts are needed to ensure that water use becomes more effective and efficient. In the drinking water supply system, the pipeline network is divided into three components: raw water sources, production units, and service components. In this service component, customer satisfaction must meet the requirements of quality, quantity, continuity, and competitive pricing. Due to the issues surrounding the provision of clean water, the author is conducting a study on the District Meter Area (DMA) improvement project. This research aims to be applied to meet clean water needs and reduce NRW (Non-Revenue Water) by incorporating technology into the system, thereby achieving energy and economic efficiency and enhancing the competitiveness of the project. This aligns with the government's program as one of the countries participating in the SDGs (Sustainable Development Goals), where the related SDG points are clean water and sanitation, as well as Industry, Innovation, and Infrastructure. In this study, risk identification and feasibility calculations will be conducted for the procurement of the DMA improvement project*

KEYWORDS *- Water, DMA, Feasibility Study, Risk Management*

I. INTRODUCTION

The world is currently facing increasing pressure on water resources due to population growth and industrial development [2]. In 2002, the United Nations Environment Programme (UNEP) stated that the Earth's water volume was 1.365 billion km³, consisting of 97.5% seawater and 2.5% freshwater, which includes rivers, lakes, wetlands, polar ice caps, glaciers, and groundwater [3]. Given the limited amount of freshwater available for human consumption, various efforts are needed to ensure more effective and efficient water use [1].

In Indonesia, according to the Ministry of Health, the average water requirement is 75 liters per person per day [7]. According to WHO standards for urban areas, water needs range from 85 to 250 liters per person per day [6]. Based on data from the

Directorate General of Human Settlements, in small cities water needs are estimated at around 125 liters per person per day, while in large cities the figure is between 200 and 250 liters [8].

To meet these drinking water needs, there are two drinking water supply systems (SPAM) used by the Indonesian public. The first is the Piped Water Supply System (SPAM-JP), which consists of raw water units, production units, distribution units, and service units. The second is the Non-Piped Water Supply System (SPAM-BJP), which includes shallow wells, pump wells, rainwater storage tanks, water terminals, and spring catchment structures. SPAM-JP is generally managed by local governments through regional water utilities (PDAMs) [4].

Maryati and Arika identified that key issues facing PDAMs include high leakage rates and limited funding [11]. According to the Strategic Plan Report of the Directorate General of Human Settlements, Ministry of Public Works and Housing (PUPR) for 2020–2024, the average water loss rate in Indonesia remains high at 32.75% [10]. This condition is worsened by the insufficient asset management capacity of the regional water companies (BUMD) responsible for SPAM. In some PDAMs, water loss rates reach up to 70%. Specifically, Bandung has a water loss rate of

37% [14], Makassar 40% [15], Semarang

40.10% [12], Surakarta 29.61% [13], and Sidoarjo

31.4% [16].

Water loss is a major contributing factor. Therefore, developing and implementing effective water loss procedures and strategies is essential for water utilities [9].

II. RESEARCH OBJECTIVES

The objectives of this research are as

follows:

- To analyze the current technical and economic conditions of the District Meter Area (DMA) system at PAM JAYA.

- To analyze potential developments and improvements that can be made to the DMA system in order to enhance the economic value of PAM JAYA.

- To analyze the economic risks associated with the new DMA system.
- To analyze the economic feasibility of the new DMA system.

III. RESEARCH METHODOLOGY

The research conducted in this study consists of a theorization stage and an empirical stage. The theorization stage involves acquiring knowledge about concepts, propositions, and theories to formulate various literature sources related to DMA, investment risks, and investment feasibility studies. Based on the literature review, relevant knowledge and theories are established, from which research variables and the relationships between these theories are formulated.

In the empirical stage, the study involves testing the variables as well as hypothesis testing.

The following is the research flow diagram for this study:

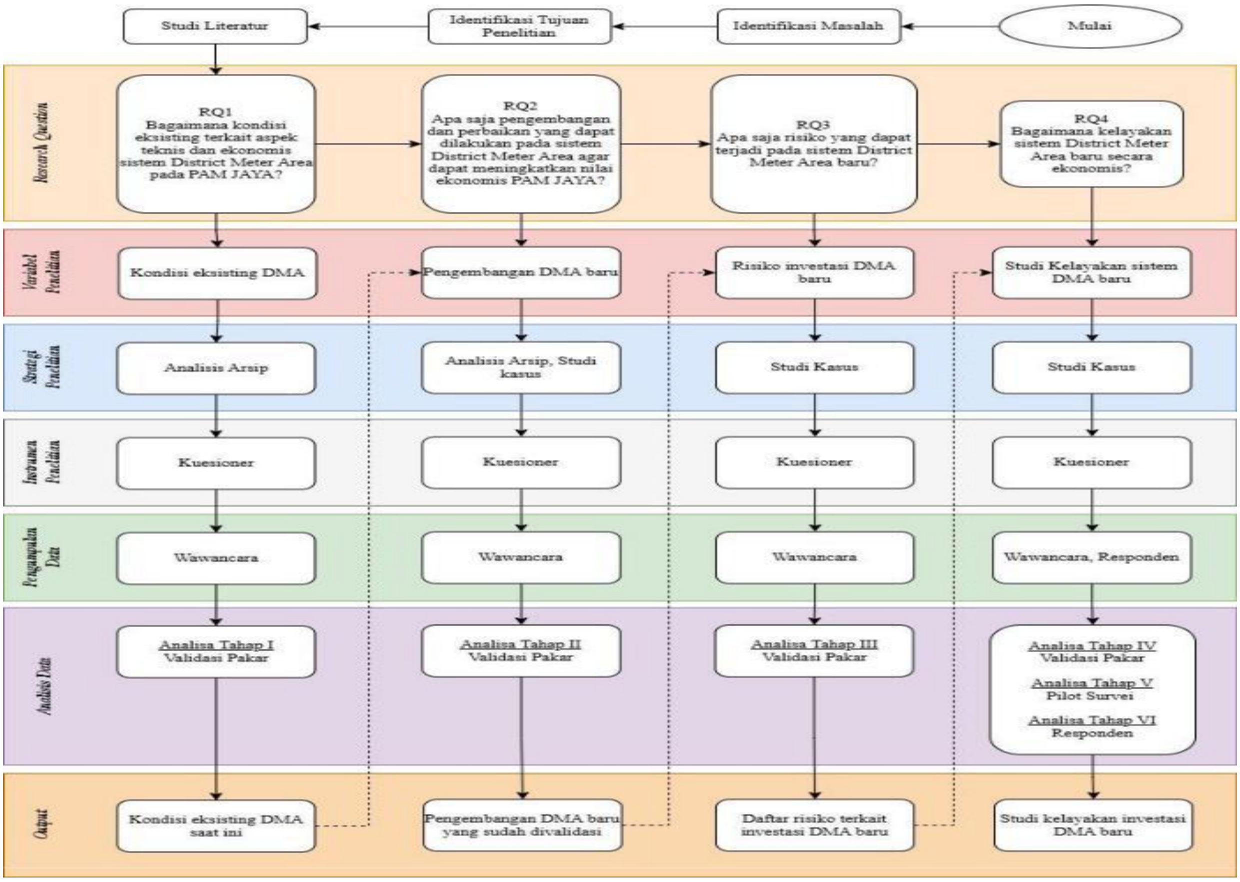

Figure 2. Research Flow Diagram

IV. LITERATURE REVIEW

4.1. Drinking Water Supply System

Government Regulation No. 122 of 2015 concerning Drinking Water Supply Systems (SPAM) defines drinking water as household water that has undergone a treatment process or not, which meets health requirements and is safe for direct consumption [30].

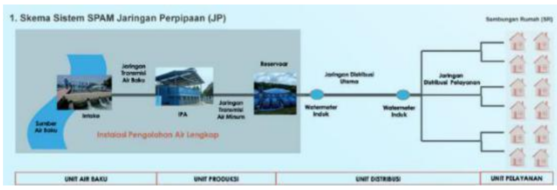

Figure 2. Schematic of Piped Drinking Water Supply System (SPAM-JP)

Source: PAM JAYA, 2023 [29]

The raw water unit refers to the infrastructure and facilities used to extract and/or provide raw water from sources such as springs, groundwater, and surface water bodies (rivers, lakes, seas, reservoirs, and ponds). The production unit refers to facilities used to treat raw water into drinking water through physical, chemical, and/or biological processes. The distribution unit is responsible for channeling the treated water from the storage structures to the service unit. The service unit is the point of water retrieval, which includes house connections (SL), public hydrants (HU), and fire hydrants [25].

The distribution system is designed to deliver water to consumers either via house connections or public taps. Its objective is to distribute drinking water economically across designated service areas. Key aspects in water distribution include pressure, quantity, quality, and continuity. Several criteria must be met to ensure

proper system operation, including the following [17]: Water should be available in sufficient quantities to meet the needs of the community at any time and location, water quality should be maintained throughout the distribution system, arriving at consumers still within acceptable standards, pipelines should be well-designed to minimize leakage and maintain constant flow pressure, the pipe layout should be as short and direct as possible, with safe placement to avoid damage.

There are two primary classifications of pipe networks in distribution systems: macro systems and micro systems [23]. According to Zipeng Yu et al. [34], pipeline network patterns can be categorized into branched, gridiron, and looped systems. The water delivery system includes gravity, pumped, and combined systems [29]. Water supply operations are categorized into continuous systems and intermittent systems [29].

Key components of the distribution system include distribution reservoirs, pipelines, service pipes, fittings and accessories, water meters, fire hydrants, and pumps [29].

Non-Revenue Water (NRW) is defined as the difference between the volume of water produced and the volume consumed by customers.

It represents both real losses and apparent (commercial) losses [24]. Another definition is the difference between the water that enters the distribution system and the amount billed to customers [19]. NRW remains one of the primary challenges for water utilities, especially in areas with water scarcity. High NRW indicates significant water loss due to leakage or unaccounted consumption [24]. Its economic impacts include direct financial losses and indirect social, environmental, and operational costs [27]. NRW is typically divided into physical losses and Non-physical water loss.

District Meter Area (DMA) formation is an effective strategy to reduce both physical and Non-physical water loss [32]. A DMA is a hydraulically isolated area (either permanently or temporarily) equipped with key instruments such as a district inlet meter and boundary valves. Active NRW management is only feasible through zoning, in which the overall distribution system is divided into smaller subsystems to separately monitor NRW in each subsystem [33].

Various sources offer different criteria for DMA establishment. In general, they include: DMA size (connection range): typically 1,000–2,500 connections [20], though some suggest 500– 1,000 [18], 500–3,000 [22], or even up to 5,000 [26], Inlet isolation: ideally, each DMA has a single inlet to ensure proper hydraulic isolation [21], Metering configuration: the fewer meters used to measure inlet/outlet flow, the lower the setup cost [20], Hydraulic requirements: a pressure of 5–7 meters at critical points and a maximum of 25 meters at downstream inlets over 24 hours [25], [21].

According to Spedaletti et al. [32], DMA components include water meters, pressure relief valves (PRVs), valves, and distribution pipes. In their design, isolation valves are used to define zone boundaries and PRV isolation. Therefore, a zone may contain multiple isolation valves. Inlet and outlet points are monitored using district water meters.

4.2. Drinking Water Supply System – Existing District Meter Area (DMA) Conditions

The existing condition of the District Meter Area (DMA), which includes PAM JAYA's priority areas for Non-Revenue Water (NRW) reduction, covers zones located within Primary Cells (PC) 55, 56, 72, 76, 147, 150, 151, 153, and 160. According to PAM JAYA's 2023 NRW Division Annual Report, these priority areas exhibit NRW levels above the national standard of 20%, as stipulated in the Ministry of Public Works Regulation No. 20/PRT/M/2006 and the Strategic Plan of the Directorate General of Human Settlements of the Ministry of Public Works and Housing (PUPR) for 2020–2024 [31], [10], [29].

From the analysis of these nine priority areas discussed in Chapter 1, the total water loss is approximately 786 liters per second (lps) or equivalent to 24.3 million cubic meters per year (m^3/year). According to Nurhasanah et al. (2011), the average daily drinking water consumption is approximately 135–145 liters per person for low-income households, 146–155 liters per person for middle-income households, and 156–245 liters per person for high-income households [28].

If the annual water loss of 24.3 million m^3 is divided by the average daily consumption of 145 liters per person, the water loss is equivalent to the daily water needs of approximately 167,000 people.

4.3. Intelligent Water Network (IWN)

An Intelligent Water Network (IWN) is a water distribution system equipped with sensors, modeling, and control technologies that provide information on events that may occur before, during, or after they happen. It enables planning, mitigation, and prevention of negative impacts [40]. This system is critical to modern water distribution networks as it enhances service quality, optimizes asset management, reduces damage, and supports automation of digital-based decision-making processes [40]. Implementing IWN also extends asset life, delays infrastructure expansion needs, lowers operational costs, and minimizes the impact of system failures on communities and the environment [40].

Through real-time monitoring, IWN enables early leak detection and distribution issues, thereby allowing water authorities to improve network control [45]. For example, the water utility in Pimpri-Chinchwad, India, successfully reduced NRW from 40% to around 15% after implementing

smart meters and a SCADA system [35]. The main benefits of IWN include operational cost savings, improved revenue efficiency, extended asset life, and enhanced customer satisfaction, though some benefits are indirect [36], [39].

4.3.1. Smart Water Meter Integration Smart water meters are devices that record

and transmit water consumption data at regular intervals with high accuracy, even at low flow rates [46]. In contrast, traditional meters are typically read manually on a monthly or annual basis [46]. Smart meters provide real-time data, enabling a proactive approach to leak detection and water management planning [37].

Smart Water Meters at Household Connections: the installation of smart meters at household connections enables high-resolution consumption data collection, which is integrated into meter zoning and synchronized reading systems to support real-time leak monitoring [39], [38]. While early detection potential is high, this method remains underutilized and can be enhanced through validation with historical data [50], [44], [Kim et al., 2014; Gurung et al., 2016]*.

Electromagnetic Smart Meters for Distribution Pipes: electromagnetic smart meters operate based on Faraday's law of induction to measure the flow of conductive water with an accuracy of ±0.5% within a range of 0.1– 10 m/s [42], [43]. Key advantages of this technology include stability under varying media and pressure conditions, along with remote data transmission capabilities via telecommunication networks.

4.3.2. Smart Pressure Sensor & Leak Detection Integration

Smart pressure sensors are installed at critical points to monitor real-time pressure and detect leaks or potential pipe failures [41], [47]. This technology has proven effective in reducing NRW while maintaining low maintenance costs

[49], [48]. Advanced pressure control (I²O–PRV) systems use machine learning algorithms and pilot valves to optimize pressure, reducing nighttime leakage by 20–30% and significantly extending asset lifespan [51], [52].

periodically monitor leak noise without requiring direct physical access [40]. The data is transmitted to a cloud platform for automatic leak mapping using correlation algorithms, displaying probability scores and leak locations on a map, complete with SMS/email alerts and analytical reports.

4.4. Risk Management

Risk is defined as an uncertain event or condition that, if it occurs, can have either a positive or negative impact on the achievement of project

objectives and goals [60]. According to Kerzner [58], risk refers to any activity or factor that, if realized, may increase the likelihood of failing to meet project objectives in terms of time, cost, or quality. Soeharto [55] defines risk as the possibility of an undesired event occurring. Project risk management, as outlined in the PMBOK® Guide [59], is a systematic process consisting of risk identification, analysis, response, and control, aimed at maximizing the probability and impact of positive events, and minimizing the probability and impact of negative events on project objectives.

Each project activity inherently contains risks, which may vary in significance and potentially increase activity costs—resulting in budget deviations or reduced project profitability [61]. Risk management does not function independently but is integrated with other project management areas, as emphasized by Wideman [62]. According to the PMBOK® Guide [59], the risk management process comprises six stages: (1) risk management planning; (2) risk identification; (3) qualitative risk analysis;

(4) quantitative risk analysis; (5) risk response planning; and (6) risk monitoring and control.

Beyond the PMBOK® framework, risk management is also governed by ISO 31000, which outlines five main activities: communication and consultation, context establishment, risk assessment

4.3.3. Smart Leak Monitoring Integration
The Zone-Scan NB-IoT logger utilizes

acoustic sensors and NB-IoT technology to

(identification, analysis, and evaluation), risk treatment, and monitoring and review [56].

In the context of District Metered Area (DMA) projects, risk management serves as a crucial approach to identify, evaluate, and control potential risks affecting the smooth implementation of zoned water distribution systems [53], [54], [57]. DMA divides the water distribution network into smaller zones to facilitate pressure monitoring, leakage detection, and water use efficiency.

The first step in DMA project risk management is risk identification, covering technical risks (e.g., technology mismatch and sensor installation failures), financial risks (e.g., budget overruns), environmental risks (e.g., impact on existing infrastructure), and human resource risks (e.g., lack of skilled labor) [57]. The next stage involves risk assessment using a risk matrix to determine the impact level and likelihood of each risk, followed by prioritization based on significance and probability [54].

Risk mitigation strategies include selecting proven technologies, planning budgets with contingency reserves, and providing technical training for personnel [53]. Monitoring and evaluation are conducted regularly to ensure the effectiveness of mitigation measures and to adjust strategies as new risks emerge. The final stage is risk control, which involves the implementation of rapid response actions and standard procedures to minimize the overall impact of risks on project objectives [60].

V. Research Findings And Discussion

In collecting data for Research Question 1, which focuses on the existing condition of the District Meter Area (DMA), the process was carried out in two stages. Stage 1 involved expert validation, while Stage 2 involved respondent validation within the operational scope of PAM JAYA Jakarta.

The results from the first stage of the research are as follows:

Table 1. Expert Validation on Variables Related to the Existing Condition of the DMA

Kode	**Pernyataan**	**Deskripsi**	**Referensi**
X1	**Desain Rangkaian DMA**		
X1.1	Bentuk DMA terdiri dari 500-1000 sambungan	Ukuran yang disajikan cukup kecil untuk memungkinkan kontrol yang ketat terhadap aliran dan tekanan air serta deteksi kehilangan air secara cepat dan akurat, Pro: respon bisa lebih cepat untuk deteksi kebocoran	BSN,2011
X1.2	Bentuk DMA terdiri dari 500-3000 sambungan	Cakupan area lebih luas, biasa diterapkan di daerah dengan kepadatan penduduk mmenengah atau dengan kondisi geografis yang mempersulit pemisahan area	Hajebi et al., 2014
X1.3	Bentuk DMA terdiri dari 500-5000 sambungan	Biasanya diterapkan di area yang sangat luas atau pada sistem distribusi lama yang belum memungkinkan pemisahan area yang lebih kecil. Pengawasan dan analisis data lebih sulit, sehingga	Morrison et al., 2007 dan Bui et al., 2022

Kode	**Pernyataan**	**Deskripsi**	**Referensi**
		butuh teknologi monitoring real-time.	
X2	**Terdapat katup yang harus ditutup untuk menginsolasi DMA (jumlah katup tidak terdapat batasan) dan terdapat satu inlet DMA**	Terdapat katup pembatas yang harus ada dalam mengisolasi DMA untuk jumlah katup tidak terdapat batasannya sehingga menyesuaikan dengan kondisi sistemjaringan DMA tersebut. Untuk Inlet sebaiknya menggunakan satu inlet gar lebih mudah untuk mengontrol DMA	**Handini, 2020**
X3	**Tinggi hidraulis pipa 5-7 m di critial point pressure, dan maksimal 25 m di downstream inlet DMA**	Rentang tekanan yang ideal dalam DMA adalah 5–7 m di titik kritis dan maksimal 25 m di sisi hilir inlet, guna menjamin pelayanan optimal kepada pelanggan sekaligus meminimalis	**PUPR, 2016 dan Handini, 2020**

Kode	Pernyataan	Deskripsi	Referensi
		ir risiko kerusakan jaringan.	
X4	**Komponen DMA**		
X4.1	Water meter	Water meter adalah alat ukur utama yang digunakan untuk mencatat volume air yang masuk ke dalam suatu DMA.	Bui et al., 2022 dan Spedaletti et al., 2022
X4.1.1	Water meter input / inlet DMA	Water meter input (inlet) DMA adalah alat ukur aliran air yang dipasang di pintu masuk (input) sebuah DMA dalam sistem jaringan distribusi yang berfungsi untuk mengukur total volume air yang masuk ke dalam area DMA	Validasi Pakar
X4.1.2	Water meter pelanggan DMA	alat ukur yang dipasang di setiap sambungan pelanggan dalam area	Validasi Pakar

Kode	Pernyataan	Deskripsi	Referensi
		DMA (District Meter Area) jaringan. Fungsinya untuk mengukur volume air bersih yang dikonsumsi oleh pelanggan	
X4.2	Pressure Relief Valve (PRV)	PRV adalah katup otomatis yang digunakan untuk menurunkan dan menstabilkan tekanan air di dalam jaringan pipa DMA.	Spedaletti et al., 2022 dan Kayama et al., 2004
X4.3	Valve	Valve atau katup adalah komponen yang digunakan untuk membuka, menutup, atau mengatur aliran air dalam jaringan pipa.	Dorbani et al., 2022 dan Harahap et al., 2023
X4.3.1	Valve Input DMA	Katup atau sistem pengatur aliran air masuk ke dalam suatu	Dorbani et al., 2022 dan Haraha

Kode	Pernyataan	Deskripsi	Referensi
		zona pengukuran distribusi air (DMA) di jaringan	p et al., 2023
X4.3.2	Valve jaringan distribusi (valve step test)	Valve jaringan distribusi dalam konteks step test adalah komponen penting yang digunakan untuk mengatur atau menutup aliran air ke segmen - segmen kecil dalam jaringan distribusi air, secara bertahap dan sistematis, selama proses step test	Dorbani et al., 2022 dan Harahap et al., 2023
X4.3.3	Valve Pembatas	Valve pembatas (boundary valve) dalam jaringan DMA (District Meter Area) adalah katup yang berfungsi untuk membatasi dan mengontrol aliran air antara satu	Dorbani et al., 2022 dan Harahap et al., 2023

Kode	Pernyataan	Deskripsi	Referensi
		DMA dengan DMA lainnya atau dengan jaringan utama. Katup ini digunakan untuk mengisolasi setiap DMA agar aliran air yang masuk dan keluar bisa terukur dan terkendali secara akurat	
X4.3.4	Wash out Valve	Wash Out Valve (juga dikenal sebagai katup pembilas) pada jaringan DMA (District Meter Area) adalah katup yang digunakan untuk mengeluarkan atau membuang air dari pipa distribusi, biasanya saat proses Pembersihan jaringan (flushing)	Dorbani et al., 2022 dan Harahap et al., 2023
X4.4	Pipa dan aksesoris	Pipa distribusi adalah jaringan pipa yang menyalurkan air dari inlet ke seluruh pelanggan dalam suatu DMA. Untuk jaringan pipa tersebut juga terdapat aksesosris yang saling terhubung dengan pipa jaringan tersebut	Spedaletti et al., 2022 dan Alvisi and franchine, 2014
X4.4.1	Pipa jaringan distribusi	saluran pipa yang digunakan untuk mendistribusikan air bersih dari pusat	Spedaletti et al., 2022 dan Alvisi and

		distribusi ke pelanggan melalui sistem yang terstruktur	franchine, 2014
X4.4.2	aksesoris pipa jaringan (elbow, tee, reducer, flange, saddle clamp, end cap dan coupling)	Aksesoris pipa jaringan distribusi air adalah komponen tambahan yang dipasang pada sistem perpipaan untuk mendukung fungsi utama pipa	Spedaletti et al., 2022 dan Alvisi and franchine, 2014

Kode	Pernyataan	Deskripsi	Referensi
X4.5	Strainer pada Input DMA	stariner merupakan penyaring (filter) yang dipasang di jalur masuk (inlet) suatu DMA dalam jaringan distribusi PDAM, yang berfungsi untuk menyaring kotoran atau partikel padat sebelum air masuk ke dalam area distribusi (DMA)	Bui et al., 2022 dan Dorbani et al., 2022
X4.6	Pemantauan Critical Point Pressure	untuk memantau titik kritis tekanan air yang berada pada suatu DMA dan menjadi titik acuan tekanan air yang seharusnya diperoleh area tersebut.	Validasi Pakar

Kode	Pernyataan	Deskripsi	Referensi
X5	**Zoning DMA**		
X5.2	Batas zona disesuaikan dengan batas geografis yang ada di daerah distribusi	Batasan zona DMA sebaiknya mengikuti batas geografis alami seperti sungai, jalan besar, rel kereta, atau kontur wilayah.	PP No. 122 Tahun 2015
X5.4	Elevasi zona diusahakan pada elevasi yang relatif dasar	Zona DMA sebaiknya berada dalam area dengan elevasi yang relatif datar untuk menghindari variasi tekanan yang ekstrem.	PP No. 122 Tahun 2015
X5.5	Panjang pipa zona disesuaikan dengan wilayah yang ter-cover DMA	Panjang total pipa dalam satu zona DMA disesuaikan dengan luas wilayah dan jumlah pelanggan yang dilayani.	PP No. 122 Tahun 2015
X5.6	Perpipaan zona disesuaikan dan dipisahkan berdasarkan pipa induk/primer, pipa sekunder, pipa tertier, pipa retikulasi dan pipa servis/dinas	Pembagian ini membantu efisiensi distribusi dan mempermudah perencanaan serta perawatan jaringan.	PP No. 122 Tahun 2015

The following is the interpretation of the respondent profile data in the second stage of this research:

Figure 3. Respondent Data Percentage

The results from the responses of the 35 respondents are as follows:

Table 2. Respondent Validation on Variables Related to the Existing Condition of the DMA

Kode	**Pernyataan**	**Deskripsi**	**Referensi**

Kode	**Pernyataan**	**Deskripsi**	**Referensi**
	menginsolasi DMA (jumlah katup tidak terdapat batasan) dan terdapat satu inlet DMA	DMA untuk jumlah katup tidak terdapat batasannya sehingga menyesuaikan dengan kondisi sistemjaringan DMA tersebut. Untuk Inlet sebaiknya menggunakan satu inlet gar	

X1	**Desain Rangakaian DMA**		
X1.2	Bentuk DMA terdiri dari 500-3000 sambungan	Cakupan area lebih luas, biasa diterapkan di daerah dengan kepadatan penduduk mmenengah atau dengan kondisi geografis yang mempersulit pemisahan area	Hajebi et al., 2014
X2	**Terdapat katup yang harus ditutup untuk**	Terdapat katup pembatas yang harus ada dalam mengisolasi	Handini, 2020

		lebih mudah untuk mengontrol DMA	
X3	**Tinggi hidraulis pipa 5-7 m di critial point pressure,**	Rentang tekanan yang ideal dalam DMA adalah 2-7 m di titik kritis dan maksimal 25 m di sisi hilir inlet, guna menjamin	Validasi respond

	dan maksimal 25 m di downstream inlet DMA	pelayanan optimal kepada pelanggan sekaligus meminimalisir risiko kerusakan jaringan.	en
X4	**Komponen DMA**		
X4.1	Water meter	Water meter adalah alat ukur utama yang digunakan untuk	Bui et al., 2022 dan Spedalet

Kode	**Pernyataan**	**Deskripsi**	**Referensi**
		mencatat volume air yang masuk ke dalam suatu DMA.	ti et al., 2022
X4.1.1	Water meter input / inlet DMA	Water meter input (inlet) DMA adalah alat ukur aliran air yang dipasang di pintu masuk (input) sebuah DMA dalam sistem jaringan distribusi yang berfungsi untuk mengukur total volume air yang masuk ke dalam area DMA	Validasi Pakar
X4.1.2	Water meter pelanggan DMA	alat ukur yang dipasang di setiap sambungan pelanggan dalam area DMA (District Meter Area) jaringan. Fungsinya untuk mengukur	Validasi Pakar

		volume air bersih yang dikonsumsi oleh	

Kode	**Pernyataan**	**Deskripsi**	**Referensi**
X4.2	Pressure Relief Valve (PRV)	PRV adalah katup otomatis yang digunakan untuk menurunkan dan menstabilkan tekanan air di dalam jaringan pipa DMA.	Spedaletti et al., 2022 dan Kayama et al., 2004
X4.3	Valve	Valve atau katup adalah komponen yang digunakan untuk membuka, menutup, atau mengatur aliran air dalam jaringan pipa.	Dorbani et al., 2022 dan Harahap et al., 2023
		Katup atau	

		pelanggan	

X4.3.1	Valve Input DMA	sistem pengatur aliran air masuk ke dalam suatu zona pengukuran distribusi air (DMA) di jaringan	Dorbani et al., 2022 dan Harahap et al., 2023
X4.3.2	Valve jaringan distribusi (valve step test)	Valve jaringan distribusi dalam konteks step test adalah komponen penting yang digunakan untuk	Dorbani et al., 2022 dan Harahap et al., 2023

Kode	Pernyataan	Deskripsi	Referensi
		mengatur atau menutup aliran air ke segmen - segmen kecil dalam jaringan distribusi air, secara bertahap dan sistematis, selama proses step test	
		Valve pembatas (boundary valve) dalam jaringan DMA (District Meter Area)	

Kode	Pernyataan	Deskripsi	Referensi
X4.3.2	Wash out Valve	Wash Out Valve (juga dikenal sebagai katup pembilas) pada jaringan DMA (District Meter Area) adalah katup yang digunakan untuk mengeluarkan atau membuang air	Dorbani et al., 2022 dan Harahap et al., 2023

X4.3.3	Valve Pembatas	adalah katup yang berfungsi untuk membatasi dan mengontrol aliran air antara satu DMA dengan DMA lainnya atau dengan jaringan utama. Katup ini digunakan untuk mengisolasi setiap DMA agar aliran air yang masuk dan keluar bisa terukur dan terkendali secara akurat	Dorbani et al., 2022 dan Harahap et al., 2023

		dari pipa distribusi, biasanya saat proses Pembersihan jaringan (flushing)	
X4.4	Pipa dan aksesoris	Pipa distribusi adalah jaringan pipa yang menyalurkan air dari inlet ke seluruh pelanggan dalam suatu DMA. Untuk jaringan pipa	Spedaletti et al., 2022 dan Alvisi

		tersebut juga terdapat aksesosris yang saling terhubung dengan pipa jaringan tersebut	and franchine, 2014
X4.4.1	Pipa jaringan distribusi	saluran pipa yang digunakan untuk	Spedaletti et al., 2022 dan

Kode	**Pernyataan**	**Deskripsi**	**Referensi**
		mendistribusikan air bersih dari pusat distribusi ke pelanggan melalui sistem yang terstruktur	Alvisi and franchine, 2014
X4.4.2	aksesoris pipa jaringan (elbow, tee, reducer, flange, saddle clamp, end cap dan coupling)	Aksesoris pipa jaringan distribusi air adalah komponen tambahan yang dipasang pada sistem perpipaan untuk mendukung fungsi utama pipa	Spedaletti et al., 2022 dan Alvisi and franchine, 2014
	Strainer	stariner merupakan penyaring (filter) yang dipasang di jalur masuk (inlet) suatu DMA dalam jaringan distribusi	Bui et al., 2022 dan

X4.5	pada Input DMA	PDAM, yang berfungsi untuk menyaring kotoran atau partikel padat sebelum air masuk ke dalam area distribusi (DMA)	Dorbani et al., 2022
X4.6	Pemantauan Critical	untuk memantau titik kritis	Validasi Pakar

Kode	Pernyataan	Deskripsi	Referensi
	Point Pressure	tekanan air yang berada pada suatu DMA dan menjadi titik acuan tekanan air yang seharusnya diperoleh area tersebut.	
X5	**Zoning DMA**		
X5.2	Batas zona disesuaikan dengan batas geografis yang ada di daerah distribusi	Batasan zona DMA sebaiknya mengikuti batas geografis alami seperti sungai, jalan besar, rel kereta, atau kontur wilayah.	PP No. 122 Tahun 2015
X5.4	Elevasi zona diusahakan pada elevasi yang relatif dasar	Zona DMA sebaiknya berada dalam area dengan elevasi yang relatif datar untuk menghindari variasi tekanan yang ekstrem.	PP No. 122 Tahun 2015
X5.5	Panjang pipa zona disesuaikan dengan wilayah yang ter-cover DMA	Panjang total pipa dalam satu zona DMA disesuaikan dengan luas wilayah dan jumlah	PP No. 122 Tahun 2015

Kode	Pernyataan	Deskripsi	Referensi
		pelanggan yang dilayani.	
X5.6	Perpipaan zona disesuaikan dan dipisahkan berdasarkan pipa induk/primer, pipa sekunder, pipa tertier, pipa retikulasi dan pipa servis/dinas	Pembagian ini membantu efisiensi distribusi dan mempermudah perencanaan serta perawatan jaringan.	PP No. 122 Tahun 2015

VI. CONCLUSION

6.1 Conclusion for RQ1 – Stage I
Based on the data analysis conducted with three experts regarding indicators of the existing condition of the DMA, the following results were obtained:

- Three sub-indicators related to the DMA network design were approved by the experts.
- One indicator regarding the number of valves required to isolate the DMA was revised and approved by the experts.
- One indicator related to the hydraulic head at the critical point pressure was approved by the experts.
- Fourteen sub-indicators concerning DMA components were approved. These include one additional sub-indicator on critical point pressure monitoring, and one revised sub-indicator specifying water meters as DMA inlet/input water meters and customer water meters.
- Four sub-indicators regarding DMA zoning were approved, while three sub-indicators related to zone size, customer connection density, and zoning were not approved by the experts.

4.4.2 Conclusion for RQ1 – Stage II
In the second stage of data collection, conducted after the expert validation in Stage I, the following results were obtained from the validation involving 35 respondents:

- One sub-indicator related to DMA network design was approved by the respondents, specifically regarding the DMA configuration consisting of 500–3000 service connections.
- One indicator regarding the number of valves required to isolate the DMA was approved by the respondents.
- One indicator concerning the hydraulic head at critical point pressure was not approved by the respondents. Consequently, an expert revision was made, adjusting the recommended hydraulic head range to 2–7 meters, with a

maximum of 25 meters at the downstream inlet.

- Fourteen sub-indicators regarding DMA components were approved by the respondents.

- Four sub-indicators related to DMA zoning were approved by the respondents.

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