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Planning for the Development of Drinking Water Distribution System Based on District Metered Area in Gedong Tataan Subdistrict, Pesawaran Regency, Lampung Province

Perencanaan Pengembangan Sistem Distribusi Air Minum Berbasis Distrik Metered Area di Kecamatan Gedong Tataan, Kabupaten Pesawaran, Provinsi Lampung

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ABSTRAK

Air tak berekening (NRW) akibat kebocoran merupakan tantangan kritis dalam sistem distribusi air minum di Indonesia, dengan tingkat NRW nasional mencapai 33,51% pada tahun 2024 yang jauh di atas target RPJMN sebesar 25%. Di Kecamatan Gedong Tataan, Kabupaten Pesawaran, Provinsi Lampung, cakupan pelayanan air minum perpipaan hanya sebesar 6,95%, merupakan salah satu persentase terendah di Provinsi Lampung. Penelitian ini mengusulkan rencana pengembangan jaringan distribusi berbasis district metered area (DMA) untuk periode 2024–2027, dengan kebaruan berupa integrasi desain zonasi DMA dan pemodelan hidraulis EPANET 2.2 dalam ibukota kecamatan di wilayah perdesaan, pendekatan yang belum pernah diterapkan sebelumnya di Kabupaten Pesawaran. Proyeksi penduduk dilakukan menggunakan metode kuadrat terkecil (dipilih berdasarkan standar deviasi minimum sebesar 1.050), dan kinerja hidraulis dievaluasi berdasarkan Permen PUPR No. 27 Tahun 2016 untuk tekanan (5–80 m), kecepatan aliran (0,30–4,50 m/s), dan head loss (≤ 10 m/km). Rencana pengembangan mencakup penambahan 777 sambungan rumah, 2 DMA dan 7 sub-DMA, reservoir baru berkapasitas 117 m³, dan sistem distribusi gravitasi, dengan total CAPEX sebesar Rp 2.804.871.171 (Rp 3.612.157 per sambungan). Analisis hidraulis mengonfirmasi bahwa seluruh node yang direncanakan memenuhi persyaratan tekanan, sementara verifikasi kecepatan secara manual mengonfirmasi kepatuhan untuk semua pipa pengembangan. Hasil ini membuktikan bahwa kelayakan teknis ekspansi berbasis DMA merupakan strategi praktis untuk mengurangi NRW dan meningkatkan akses air minum yang aman di wilayah ibukota kecamatan perdesaan.

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ABSTRACT

Non-revenue water (NRW) due to leakage remains a critical challenge in Indonesia's drinking water distribution systems, with the national NRW rate reaching 33.51% in 2024, well above the 25% target set by the RPJMN. In Gedong Tataan Subdistrict, Pesawaran Regency, Lampung Province, piped water service coverage is only 6.95%, one of the lowest rates in the province. This study proposes a district metered area (DMA) based distribution network development plan for 2024–2027, with the novelty of integrating DMA zoning design with EPANET 2.2 hydraulic modeling in the rural administrative center, an approach not previously applied in Pesawaran Regency. Population projection used the least-squares method (selected based on the minimum standard deviation of 1,050), and hydraulic performance was evaluated against the Regulation of the Minister of Public Works and Public Housing No. 27 of 2016 for pressure (5–80 m), flow velocity (0.30–4.50 m/s), and head loss (≤ 10 m/km). The development plan covers 777 new house connections, 2 DMAs and 7 sub-DMAs, a new 117 m³ reservoir, and a gravity-based distribution system, with a total Capital Expenditure (CAPEX) of IDR 2,804,871,171 (IDR 3,612,157 per connection). Hydraulic analysis confirms that all planned nodes meet pressure requirements, and manual velocity verification confirms compliance for all development pipes. These results demonstrate the technical feasibility of DMA-based expansion as a practical strategy for reducing NRW and improving safe drinking water access in rural regency settings.

1. INTRODUCTION

1.1 Background

According to the Ministry of Health (2023), in line with international agreements on the Sustainable Development Goals (SDGs), Indonesia is committed to meeting SDG targets, particularly Goal 6 concerning universal access to drinking water. Universal access to drinking water is divided into two categories: improved drinking water and safe drinking water. Based on data, the achievement of improved drinking water access in Indonesia reached 92.64 % in 2024 (Central Bureau of Statistics, 2024). However, access to safe drinking water still lags significantly behind improved water access, hence requiring special strategies for its development.

Safe drinking water can be achieved through both piped and non-piped water supply systems. However, according to the data, non-piped water supply systems cannot meet the 4K principles (quality, quantity, continuity, and affordability) (Government of the Republic of Indonesia, 2015). Furthermore, Saputra & Juwana (2023) state that non-piped water supply systems still have risks because not all water sources are protected, so the water quality is not always safe for consumption. Therefore, the piped water supply system serves as the ideal solution to fulfil the 4K principles. Consequently, the development of a piped water distribution system is necessary.

The distribution system is one of the four main components of a water supply system (SPAM). A typical technical problem in distribution systems is non-revenue water (NRW). According to the Ministry of Public Works (2024), NRW levels in Indonesia remain above the set target. Based on RPJMN 2024, the target NRW level is 25%, but as of 2024, the national NRW rate is still 33.51%. This indicates the need for more intensive efforts to reduce water losses. One practical approach is implementing district metered area (DMA) technology.

DMA is a distribution network management strategy that divides or isolates the overall distribution system into several zones equipped with water meters, allowing the inflow of water within each service area to be monitored and controlled (Mustafidah, 2019; Spedaleeti et al., 2022). According to Al-Hanif & Rezagama (2016), implementing DMA enables operators to detect and repair leaks more quickly, thereby minimising water losses. The successful application of the DMA concept can be observed at PDAM Tirta Kahuripan, where the non-revenue water (NRW) level was successfully reduced from 42.74% to 11.30% (Widyanto et al., 2021)

Considering these conditions, this study focuses on developing a piped distribution system in Lampung Province, which has one of the lowest “BUMD” managed piped water coverage rates in Sumatra at only 11.45%, significantly below the national average of 26.77% (Ministry of Public Works, 2024) and a significant disparity between urban and rural areas. For instance, PERUMDAM Way Rilau Bandar Lampung City has achieved 14.71% coverage, whereas PERUMDA Air Minum Pesawaran Regency has only reached 7.26% (Ministry of Public Works, 2024). However, Pesawaran Regency has more potential raw water sources than Bandar Lampung (Lampung Province Environmental Service, 2022).

Thus, this study focuses on Gedong Tataan Subdistrict in Pesawaran Regency. The selection is based on Regional Regulation No. 6 of 2019 on spatial planning, stating that Gedong Tataan serves as the regency’s administrative centre and hub for healthcare, trade, and services. This leads to higher population growth than in other subdistricts (BPS-Statistics of Pesawaran Regency, 2023). Earlier DMA research in Indonesia has mainly been used to assess the performance of existing DMA systems in urban areas or to evaluate the reduction of NRW in existing networks (Mustafidah, 2019; Widyanto et al., 2021). The novelty of this study is the design of a new DMA-based distribution network from scratch in a rural sub-district administrative centre with critically low coverage. The integration of population projections, DMA zoning, EPANET 2.2 hydraulic modelling, and CAPEX estimation into a single applied planning framework. The method has never been reported in Pesawaran Regency.

1.2 Research Objectives

The objectives of this research are to identify the existing distribution network of the Pesawaran Local Water Company, design a district metered area (DMA)-based distribution system development plan for the 2024–2027 period, and prepare the capital expenditure plan required for the distribution network development during the same period.

2. METHOD

2.1 Study Location

This research was conducted in Gedong Tataan Subdistrict, Pesawaran Regency, Lampung Province. There were a number of key reasons for choosing this subdistrict: (1) It is the administrative capital of Pesawaran Regency and a center for the development of an agropolitan area (Pesawaran Regency Government, 2019); (2) Gedong Tataan has a higher population growth rate compared to other subdistricts in Pesawaran Regency, which leads to an increasing demand for piped water services (BPS-Statistics of Pesawaran Regency, 2023); (3) The NRW rate of Perumda Pesawaran reached 24.71% in 2023, close to the national 25% threshold (Ministry of Public Works, 2024) and (4) the subdistrict has favorable topographic conditions suitable for gravity-based distribution without pumping. The subdistrict has a total area of 114,970.60 square kilometers. The study site is shown in Figure 1.

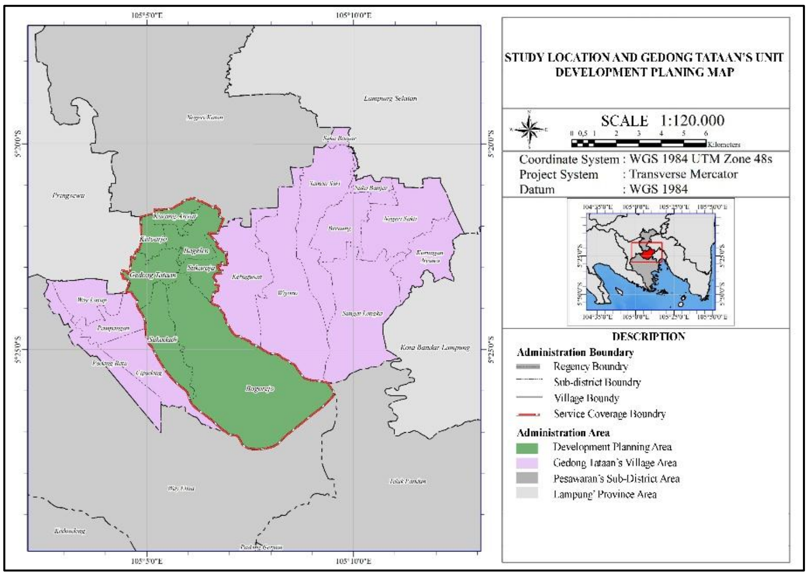


Figure 1. Study location and Gedong Tataan Unit development planning map

2.2 Data Collection

The data in this study were both primary and secondary. The primary data was collected through field observations and interviews with the local water company in Pesawaran regarding the existing conditions and development plans. Primary data collection was conducted in March–May 2024, in the form of field observations of the condition of the settlement and the existing reservoir, and semi-structured interviews with two technical staff members of Perumda Air Minum Pesawaran (the Director of Technical Affairs and a technical staff member), to obtain information related to the planned development of the distribution network. Secondary data are: (1) population data 2012–2023 from Pesawaran Central Bureau of Statistics (2023), (2) service coverage, customer data, and NRW rates from Perumda Pesawaran monthly operational reports (2023), (3) as-built pipe network drawing and customer location data from Perumda Pesawaran, and (4) topographic, geographic, and administrative boundary data from Inageoportal Indonesia. Cross-validation was performed by comparing field observations with as-built drawings to verify pipe routes, diameters, connection points, and the reservoir volume

2.2.1 Identifying the Existing Distribution Network

The identification process consists of 3 main points: assessment of the service coverage of the Gedong Tataan service unit, assessment of the current reservoir capacity, and modeling of the current distribution system using EPANET 2.2. The input of EPANET 2.2 used in this study is as follows: node elevation is based on topographic data, pipe length, and diameter are based on as-built drawings, the roughness coefficient of Hazen-Williams is 120 for U-PVC pipe, and the base demand is calculated based on four existing customer groups owned by Perumda based on actual consumption data. We consider two simulation scenarios based on the hourly loading factors reported by Rohmaningsih et al. (2017), i.e., the peak hour (08:00, LF=1.56) and the minimum hour (24:00, LF=0.25). The hydraulic performance was evaluated using 3 indicators, in accordance with population projection used the least-squares method (selected based on the minimum standard deviation of 1,050), and hydraulic performance was evaluated against Regulation of the Minister of Public Works and Public Housing No. 27 of 2016, namely pipe pressure (5–80 m), flow velocity (0.30–4.50 m/s), and unit head loss (≤ 10 m/km). The model results were checked for consistency with velocities calculated manually from the continuity equation system using EPANET 2.2.

2.2.2 Planning for Distribution Network Development

The distribution network development planning in Gedong Tataan refers to the Business Plan of Perumda Air Minum Pesawaran Regency, which aims to increase service coverage. The projection of the served population was carried out for the period 2024–2027 using three methods (arithmetic, geometric, and least squares) (Ministry of Public Works, 2007; Putra & Diasa, 2018). Pipe network design was carried out using ArcMap 10.8 and the DMA approach. The method with the smallest standard deviation was selected as the basis for projection. The DMA zoning criteria applied in this study followed Farley et al. (n.d), considering: (1) number of house connections per zone (1,000–2,500 SR) and per sub zone (150–500 SR); (2) topographic conditions to ensure hydraulic self sufficiency within each zone; and (3) existing pipe network configuration to minimize required modifications. The hydraulic design stage involved: determining peak hourly demand per DMA zone; sizing pipe diameters using the continuity equation ($V= 4Q/\pi D^2$) to maintain velocity within 0.30–4.50 m/s; and verifying head loss against the 10 m/km limit. Following pipe sizing, the complete development network was modeled in EPANET 2.2 to verify system-wide hydraulic performance under both peak and minimum demand conditions, as well as the topography. In this study, the distribution lines were made from PVC pipes, chosen for their corrosion resistance, smooth internal surface, and hydraulic efficiency. In addition, PVC pipes are light and easy to install, making them especially suitable for rural areas where limited access and simple construction techniques are common. PVC pipes are easy to handle and joint, which facilitates the installation of pipelines and their burial (pipe laying) in rural areas. This simplifies construction and reduces implementation time (Miswaty & Widya, 2024).

2.2.3 Capital Expenditure (CAPEX)

The cost analysis for this study is based on capital expenditure (CAPEX), the initial investment required to construct the distribution system. The calculation of CAPEX is in Rupiah at the 2023 price level, in accordance with the population projection used the least-squares method (selected based on the minimum standard deviation of 1,050), and hydraulic performance was evaluated against Regulation of the Minister of Public Works and Public Housing No. 8 of 2023, with a cost reference based on the Lampung Province Regional Unit Price 2023. CAPEX scope includes procurement of PVC pipelines, pipeline laying works, accessories (gate valves, air release valves, tee connections), construction of thrust blocks, DMA meter setups, and development reservoir construction. CAPEX excludes land acquisition costs, operational and maintenance costs, and costs relating to the existing network. CAPEX is reflected in the bill of quantities (BOQ) prepared based on the technical drawings and adapted to the availability of local material. The total investment cost was then estimated based on a budget plan developed by BOQ and unit prices.

3. RESULTS AND DISCUSSION

3.1 Identification of Existing Distribution Network

The analysis of the existing distribution network was conducted to assess the condition of the established water distribution system and determine whether it still meets applicable technical standards and can be utilized in future development planning.

3.1.1 Service Coverage

Service coverage represents the proportion of the population receiving clean water services relative to the total population and serves as a key performance indicator for the local water company. In the Gedong Tataan Unit, there are two water treatment plants (WTPs/IPA) with a combined installed capacity of 30 L/s. However, the actual average discharge is only 10–11 L/s per plant. The water source for the WTPs is a natural spring called “Way Semah”. The spring emerges naturally and has been captured using a boron-capturing structure before being collected and conveyed to the WTPs. Of the 15 villages within the service area, only 6 are currently served, with a total of 1,454 house connections covering 5,816 residents. As a result, the service coverage reaches only 6.95% of the total population of 89,505 people, significantly below the Lampung Province average of 11.45% (Ministry of Public Works, 2024) , indicating that the Gedong Tataan Service Unit requires urgent and systematic network expansion to improve piped water access. The existing water distribution network is shown in Figure 2.

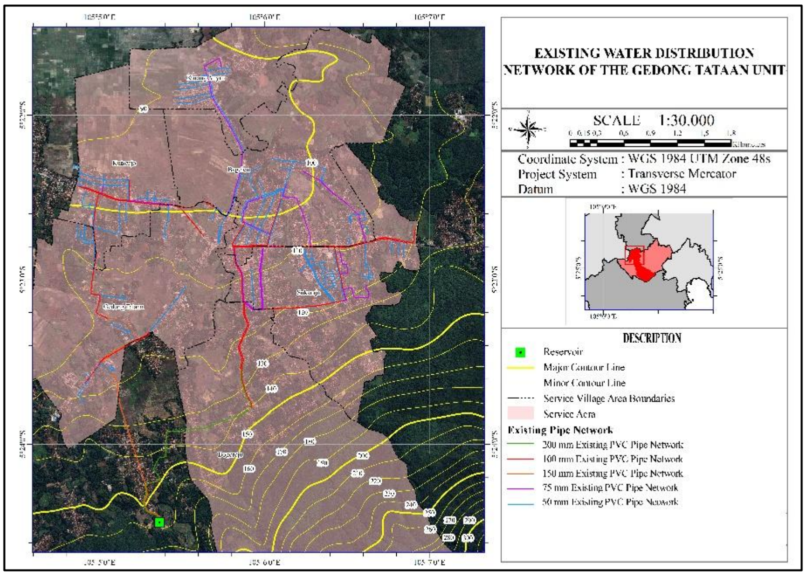


Figure 2. Existing water distribution network of The Gedong Tataan Unit

3.1.2 Existing Reservoir

The reservoir is a storage structure for treating water from the WTP. When planning the distribution system, it is necessary to compare the existing reservoir's capacity with the required storage volume for the planned development. Before making this comparison, the existing reservoir volume must be established from its dimensions (Table 1). The resulting existing reservoir volume is 182.60 m³.

Table 1. Summary of reservoir dimensions for Gedong Tataan Service Unit

Description	Reservoir				Baffle					Final Volume (m^3)
	Length (m)	Width (m)	Length (m)	Width (m)	Length (m)	Width (m)	Length (m)	Width (m)	Length (m)	
Value	9.96	9.96	1.96	194.40	7.77	0.26	1.96	3.00	11.88	182.60

3.1.3 Modeling of the Existing Distribution Network

The analysis of the existing distribution network was performed to verify compliance with the population projection using the least-squares method (selected based on the minimum standard deviation of 1,050), and hydraulic performance was evaluated against the Regulation of the Minister of Public Works and Public Housing No. 27 of 2016. Using EPANET 2.2, the analysis covered nodes (reservoirs and junctions) and links (pipes), yielding pressure, flow direction, velocity, and head loss (Table 2). Required inputs included elevation, pipe length and diameter, roughness coefficient, and base demand, which was calculated from Perumda Pesawaran's existing customers. To represent daily consumption variation, hourly loading factors (LF) were applied, showing a peak at 08:00 (LF = 1.56) and a minimum at 24:00 (LF = 0.25) as seen in Table 3 (Rohmaningsih et al., 2017).

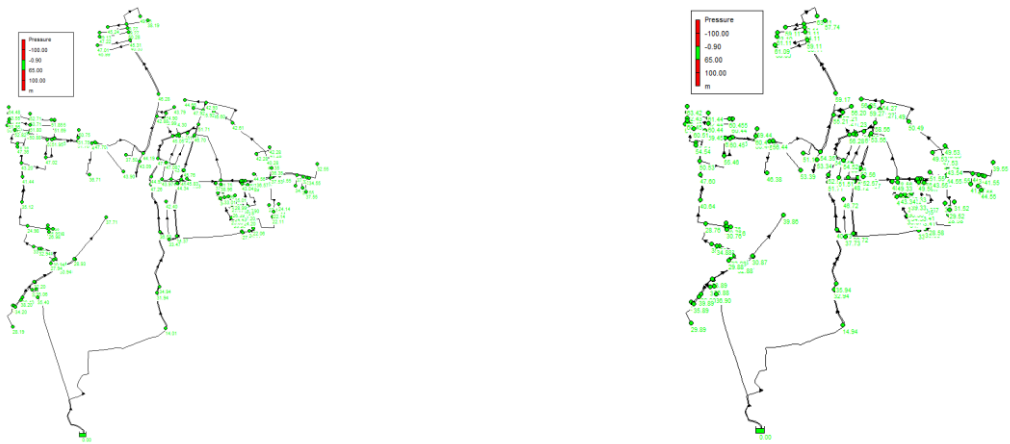
Table 2. Requirements for drinking water distribution systems

No	Parameters	Description
1	Pipe Pressure	5–80 m
2	Flow Velocity	0.30–4.50 m/s
3	Head loss	10 m/km

Table 3. Loading factor for water demand

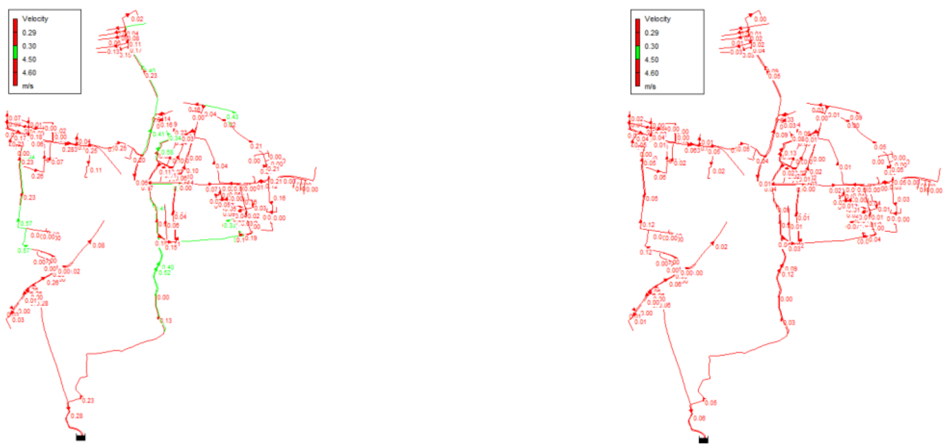
Hour	1	2	3	4	5	6	7	8	9	10	11	12
LF	0.31	0.37	0.45	0.64	1.15	1.40	1.53	1.56	1.41	1.38	1.27	1.20
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
LF	1.14	1.17	1.18	1.22	1.31	1.38	1.25	0.98	0.62	0.45	0.37	0.25

Pressure analysis at peak and minimum hours (Figure 3) shows that all nodes are within the required range. However, the flow velocity analysis (Figure 4) indicates that at the minimum hour, no pipe reaches the minimum velocity of 0.30 m/s. At the peak hour, only a small portion complies. This condition is primarily attributed to low distribution discharge and oversized pipe diameters relative to current demand, as indicated by the continuity equation ($V = 4Q/\pi D^2$): velocity decreases when discharge is low, and diameter is large (Mahardika, 2015).



(a) Peak (b) Minimum

Figure 3. Analysis results of pressure in existing distribution network



(a) Peak (b) Minimum

Figure 4. Analysis results of flow velocity in existing distribution network

Similar findings were reported by Meicahayanti et al. (2020) in the evaluation of the Loa Buah DMA network in Samarinda. Meanwhile, the head loss analysis (Figure 5) identifies four links exceeding the 10 m/km limit at peak hour; one example is L267 connected to pipe L4, which has significantly different diameters (100 mm to 50 mm). This excessive head loss is attributed to the abrupt diameter transition between pipes, as a greater difference in pipe diameters results in greater pressure loss at the connection point (Waspodo, 2017).

(a) Peak (b) Minimum

Figure 5. Analysis results of head loss in existing distribution network

3.2 Planning the Development of House Connections

This study develops a DMA-based water distribution network expansion for Gedong Tataan over a four-year period (2024–2027). The DMA approach was selected as proven effective in reducing non-revenue water (NRW) through zone-level inflow monitoring and leak detection (Al-Hanif & Rezagama, 2016; Widyanto et al., 2021). This planning is aligned with the Business Plan of Perumda Air Minum Pesawaran Regency, which targets a regency-wide coverage of 14.40% by 2027. However, since this research was limited to the service unit of Gedong Tataan and not the entire regency, the projected population served in 2027 was based on historical data from the last 11 years (2012–2023), rather than the coverage target for the entire regency. The development of the distribution network until 2027 is based on the business plan and is limited to the area where the main distribution pipe (JDU) has already been installed, to minimize development costs and maximize the efficiency of existing infrastructure investments. Currently, the Gedong Tataan Unit serves six villages. The development plan extends the service area to Sukadadi Village, bringing the total to seven villages. Sukadadi Village has a central distribution pipe in place but no active house connections, making it the least expensive to activate with minimal additional infrastructure. The planning area is shown in Figure 1.

3.2.1 Projection of Served Population and Facilities

Among the three methods, the least squares method had the smallest standard deviation at 1,050. The projection of the served population used the least squares method. Table 4 presents the projected number of residents served. Table 5 shows the projected number of public facilities.

Table 4. Projection of served population using selected method

Year	X	Projection of Served Population
2024	13	7,327
2025	15	7,625
2026	17	7,922
2027	19	8,220

Table 5. Projection of public facilities

Description	Facilities Quantity			
	2024	2025	2026	2027
Total	167	166	170	176
Water Usage per connection (L/s)	0.01	0.01	0.01	0.01
Non-domestic water needs (L/s)	1.68	1.67	1.71	1.77

Total water demand is expected to be 12.23 L/s in 2027. Domestic demand is 10.47 L/s for 2055 house connections. Non-domestic demand is 1.77 L/s for 176 public facilities. The water loss factor is included in pipeline planning to account for water loss during distribution. Thus, average demand rises to 14.92 L/s with 22% water loss (2.69 L/s). With correction factors, the maximum daily demand is 17.16 L/s and the peak hourly demand is 26.10 L/s. The projections are based on the business plan of the Pesawaran local water company, which forms the planning basis. Table 6 shows detailed information for 2024–2027.

Table 6. Summary of water demand calculation

No.	Description	Unit	2024	2025	2026	2027
A.	**Population**					
1.	Number of Served Population	Person	7,327	7,625	7,922	8,220
B.	**Domestic Water Demand**					
1.	Number of House Connections	Qty	1,832	1,906	1,981	2,055
2.	Domestic Demand	L/s	9.33	9.71	10.09	10.47
3.	Domestic Demand per House	L/s	0.005	0.005	0.005	0.005
D.	**Non-Domestic Water Demand**					
1.	Number Facilities	Qty	167	166	170	176
2.	Non-domestic Demand	L/s	1.68	1.67	1.71	1.77
E.	**Total Water Demand**					
1.	Domestic and non-domestic	L/s	11.00	11.37	11.79	12.23
F.	**Water Loss (Water Loss Percentage = 22%)**					
1.	Water Loss	L/s	2.42	2.50	2.59	2.69
G.	**Average Demand**					
1.	Average Demand	L/s	13.43	13.88	14.39	14.92
H.	**Maximum Daily Demand (Multiplier = 1.15)**					
1.	Maximum Daily Demand	L/s	15.44	15.96	16.54	17.16
I.	**Peak Hour Demand (Multiplier = 1.75)**					
1.	Peak Hour Demand	L/s	23.50	24.30	25.20	26.10

3.2.2 Development Reservoir

The reservoir serves as a storage facility for treating water before it is distributed. Due to increased demand between the base year and the planning year, the capacity of the existing reservoir (182.56 m³) was evaluated. Reservoir sizing was conducted using the daily consumption fluctuation method based on hourly loading factors. The analysis shows maximum and minimum volume fluctuations of +9.29% and -9.70%, respectively, relative to the maximum daily demand of 0.0171 m³/s. Based on these results, the required reservoir capacity is 282.00 m³. This indicates that the existing reservoir capacity is insufficient for the planning year, and a new reservoir is required. The proposed development reservoir has dimensions of 8 m × 8 m × 2.50 m, with a freeboard of 0.50 m and three baffles measuring 6 m × 0.30 m × 2 m, resulting in a final (net) volume of approximately 117 m³ (Table 7). Based on field observations, the proposed development reservoir can be constructed in front of the existing reservoir, as shown in Figure 6.

Table 7. Dimensions of the development reservoir

Description	Reservoir				Baffle					Final Volume (m³)
	Length (m)	Width (m)	Height (m)	Volume (m³)	Length (m)	Width (m)	Height (m)	Quantity	Volume (m³)	
Value	8.00	8.00	2.00	128.00	6.00	0.30	2.00	3.00	10.80	117.20

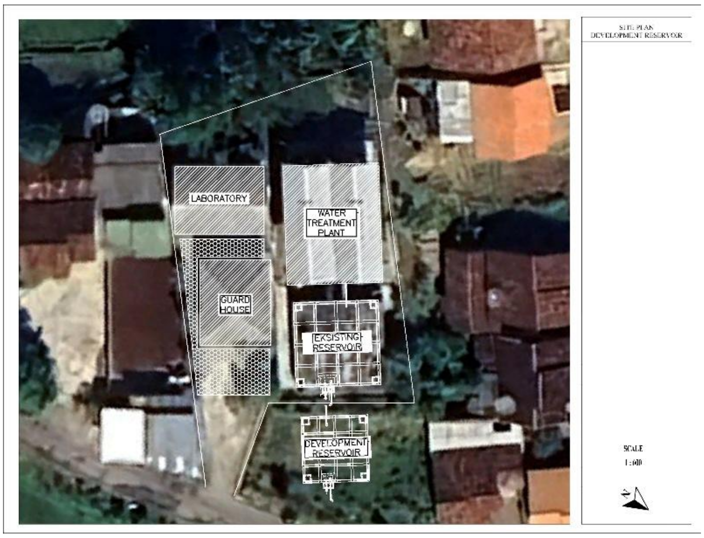


Figure 6. Site plan development reservoir

3.2.3 Development Plan and DMA Formation

In 2027, the served population in Gedong Tataan is projected to reach 8,220 people, of whom 2,404 are newly served. Assuming one service connection (SR) serves four people, 601 new service connections are required and will be allocated to villages proportionally to their populations. In addition to domestic service connections, non-domestic service connections were projected based on the number of public facilities to determine total demand and peak discharge, which were then used to size pipe diameters.

Before determining the development of pipeline routes, the service area was divided into two district metered areas (DMAs) based on topography and the existing network. Each DMA comprises several sub-districts metered areas (sub-DMAs) (DMA 1: four sub-DMAs; DMA 2: three sub-DMAs). Network adjustments, such as pipe closures and interconnections, were made to maintain efficiency and ensure distribution stability. The development planning in this study employs a gravity-based distribution system without pumps, relying on topographical conditions to ensure continuous water flow. The DMA and sub-DMA delineations are presented in Figure 7 and Figure 8.

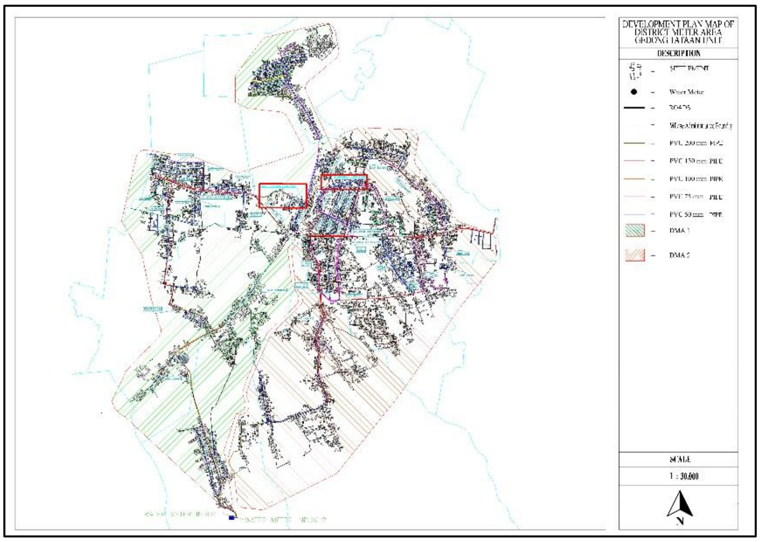


Figure 7. Map of planned district metered area division

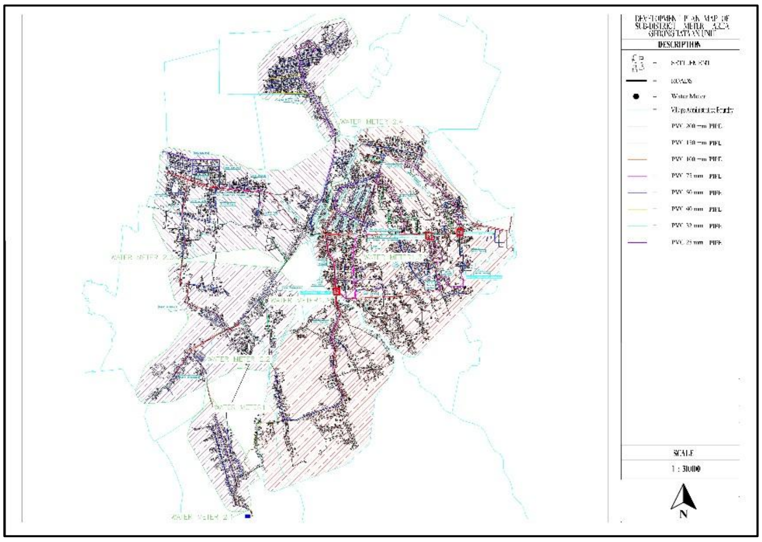


Figure 8. Map of planned development and sub-DMA division

3.2.4 EPANET 2.2 Hydraulic Analysis

A hydraulic analysis of the development network using EPANET was performed on the system after adding the new pipes and making network adjustments, focusing on pressure, flow velocity, and head loss. Pressure analysis at peak (08:00) and minimum (24:00) hours reveals that all nodes have stable pressures, with no negative or excessive values that could disrupt distribution (Figure 9). Flow velocity analysis (Figure 10) indicates that at the minimum hour, velocities are below the minimum standard. Although many pipes are below standard during peak hours, the development network performs better than the existing network. Following (Mahardika, 2015), a manual verification of velocity was conducted using the following equation:

$$V = \frac{4Q}{\pi D^2} \quad (1)$$

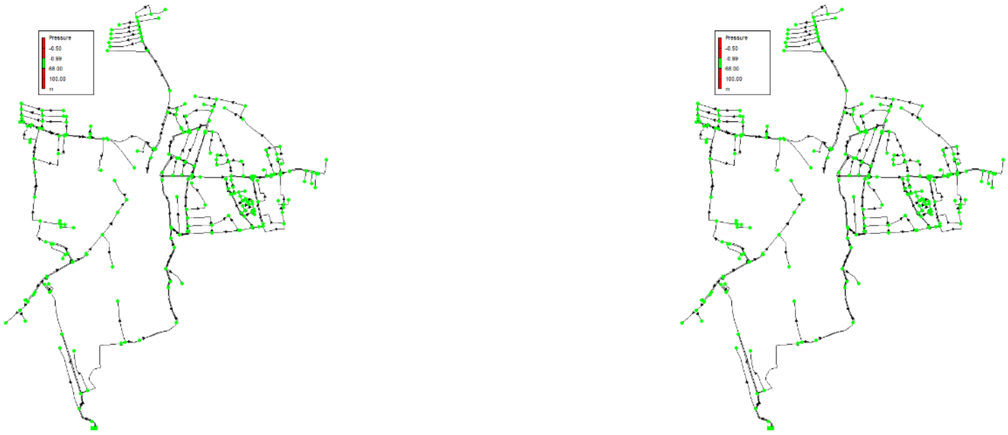
Description:

Q : flow rate

D : diameter

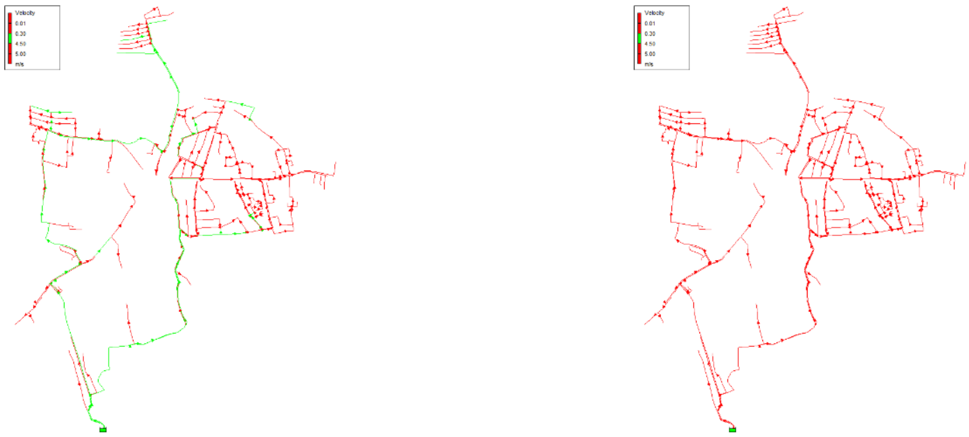
π : phi

The verification results indicate that all development pipes meet the velocity standard, as outlined in Table 8. Head loss analysis (Figure 11) indicates values within limits at the minimum hour; however, at peak hour, some development pipes experience excessive head loss, potentially due to diameter differences between new and existing pipes and the use of fittings. Nonetheless, the distribution system can still deliver water effectively throughout the network, as indicated by end-of-line pressures that remain within acceptable ranges.



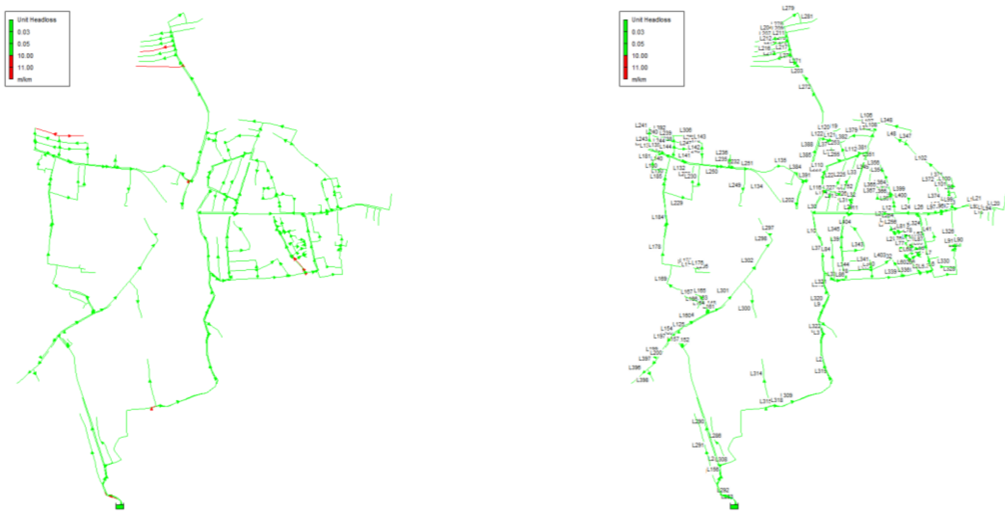
(a) Peak (b) Minimum

Figure 9. Analysis results of pressure in development distribution network



(a) Peak (b) Minimum

Figure 10. Analysis of flow velocity in development distribution network



(a) Peak (b) Minimum

Figure 11. Analysis results of head loss in development distribution network

Table 8. Flow velocity calculation in development pipes

Village	Pipe Material	Flow Rate (m³/second)	PVC OD Pipe (mm)	PVC ID Pipe (mm)	ID Pipe (m)	V check	Description
Sukadadi	PVC	0.0016	50	45.20	0.045	0.98	√
Gedong Tataan	PVC	0.0015	40	36.20	0.036	1.44	√
Bagelen	PVC	0.0020	40	36.20	0.036	1.99	√
Sukaraja	PVC	0.0022	50	45.20	0.045	1.36	√
Bogorejo	PVC	0.0013	50	45.20	0.045	0.84	√
Karang Anyar	PVC	0.0009	32	28.60	0.029	1.45	√
Kutoarjo	PVC	0.0008	25	22.60	0.022	1.86	√

3.3 Capital Expenditure (CAPEX)

The capital expenditure (CAPEX) for the four-year distribution network development was calculated at IDR 2,804,871,171 at 2023 price levels, using the Lampung Province Regional Unit Price, as per population projection used the least-squares method (selected based on the minimum standard deviation of 1,050), and hydraulic performance was evaluated against Regulation of the Minister of Public Works and Public Housing No. 8 of 2023. As shown in Table 9, the highest cost element of pipeline installation works was IDR 1,689,354,000 (60.20%), followed by reservoir construction at IDR 577,151,032 (20.60%) and the procurement of PVC pipeline at IDR 373,506,924 (13.30%).

Table 9. Summary of budget plan

No.	Activity Details	CAPEX (Rp)
1.	Procurement of PVC Pipelines	373,506,924
2.	Pipeline Installation Works	1,689,354,000
3.	Procurement of Accessories	150,779,700
4.	Construction of Thrust Blocks	10,424,515
5.	DMA Establishment	3,655,000
6.	Development Reservoir Construction	577,151,032
CAPEX Total		2,804,871,171

The unit cost per new house connection is around IDR 3,612,157 per SR. With respect to costs, pipeline installation is dominant because relatively long distribution routes must be developed to reach scattered rural settlements. The DMA establishment cost is IDR 3,655,000, representing only 0.13% of the total CAPEX, confirming the cost-effectiveness of using DMA technology for this purpose. The total budget was estimated based on the BOQ-based cost analysis, and the regional unit price was in accordance with the approach used in similar drinking water distribution planning studies in Indonesia (Cahyani et al., 2023) and was feasible for phased implementation within the framework of the Perumda Pesawaran Business Plan in the planning period 2024–2027. The detailed results are given in Table 9.

4. CONCLUSION

The conclusions obtained from this research are as follows:

1. The existing distribution system in Gedong Tataan Unit serves only 6.95% of the total population (5,816 from 89,505 residents), which is much lower than the Lampung Province average of 11.45%. The unit has two WTPs with a total installed capacity of 30 L/S, but the actual production is only 10–11 L/s per plant. This points to considerable underutilization of the existing infrastructure. The existing reservoir capacity of 182.60 m³ was found to be insufficient for the planning year, which requires a minimum storage volume of 282 m³. Hydraulic modeling further confirmed that while all nodes maintain acceptable pressure (5–80 m), the existing network exhibits widespread low flow velocities below the 0.30 m/s minimum standard and localized head loss violations exceeding 10 m/km in eight pipe segments attributed to oversized pipe diameters relative to current demand and abrupt diameter transitions between connected pipes.

2. The DMA-based development plan for 2024–2027 extends the service area from six to seven villages by adding Sukadadi Village, bringing 777 new house connections across two DMAs and seven sub-DMAs. EPANET 2.2 hydraulic analysis confirms that all planned nodes meet pressure requirements, and the development plan results in more pipes meeting the minimum velocity standard at peak hour than in the existing network. For development pipes that did not meet velocity criteria in EPANET simulation, manual verification using the continuity equation confirmed compliance with the 0.30–4.50 m/s standard. Some hydraulic parameters do not fully meet the required criteria, but the distribution system can efficiently deliver water throughout the network. This is confirmed by node pressures that are consistently within the 5–80 m range across all simulation scenarios. By removing the need for pumping infrastructure, the gravity-based distribution system reduces long-term operational costs.

3. The total CAPEX required for the four-year development is IDR 2,804,871,171 (IDR 3,612,157 per new connection), calculated at 2023 price levels using the Lampung Province Regional Unit Price. Pipeline installation accounts for the largest cost component at 60.20%, while DMA establishment represents only 0.13% of total CAPEX, confirming the cost-effectiveness of adopting DMA technology to improve distribution monitoring.

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