Design Optimization of Water Distribution Suburban Area in Mranggen, Semarang, Indonesia

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Abstract. Water losses in water distribution systems are one of the problems that occur in water distribution systems. Water losses can be caused by physical losses or leakage. Leakages can be caused by technical and non-technical factors. The existing condition of the water distribution network in subdistrict capital Mranggen, Demak Regency has not been able to drain water continuously for twenty-four hours in Batursari and Kebonbatur Sub-Districts. The optimization of the drinking water distribution network is carried out by evaluating the network system using Epanet software and then doing the rehabilitation design and network development according to future developments. The results of the analysis of the epanet model show that the use of deep well pump systems directly distributed to customers results in inefficiencies from pressure. Access to the safe drinking water needs to be prepared first from the availability of raw water, treatment units to the distribution network. The construction of clean water transmission pipeline system is prepared to go into different zoning from the initial network. Zoning pumping network systems will increase pressure significantly and reduce leakage through control.

1. Introduction

The availability of clean water is an essential factor in human life. In the last decades, water resources availability has been a significant issue on international agenda [1]. Globally, water losses from water distribution systems are reaching alarming levels. They are made up of various causes, including physical losses or leakage that commonly caused by the failures of pipe breakages. Leakage made up a large part, some cases more than 70% of the total water losses [2]. In addition, according to World Bank data, 45 million m³ of water is lost each day only in developing countries due to the water distribution system failures3. Leakage can be caused by technical and non-technical factors. Water can be lost through burst leakages with a significant pressure loss or through background leakages.

The two main problems that are currently being faced by several Waterwork Company in Indonesia are low service levels and also high levels of water loss (non-residual water) or Non-Revenue Water (NRW). This problem is also now experienced by Demak Waterwork Company. Based on data found in the water distribution network, Implementation Development Agency in 2017, Demak Waterwork Company only serves 42.8% of the service area with a water loss rate of 36.31%. This percentage is
below the standard set in the Guidelines for the Preparation of Standards for Water Services in the Department of Settlement and Regional Infrastructure that the level of clean water services for small-town areas is 80% with water losses of 25%. In fact, the government has set a target for meeting access to drinking water for the community, as found in the long-term strategy 2015-2019, reaching 100 per cent in 2019. Demak Waterwork Company can use WaterCAD to control water losses. WaterCAD can help determine the operating conditions of the existing pumps and find out how long the pumps would need to fill up the new tank [4].

Conditions in the field show that the distribution of clean water in Demak Waterwork Company, especially in the water distribution network of Mranggen subdistrict has not been optimal. It happens because the supply of freshwater so far has not been able to reach several points in the Batursari and Kebonbatur villages continuously for twenty-four hours due to the minimal residual pressure, the level of water loss very high on the distribution unit, and suboptimal use of capacity and pump head. A high level of water loss can be caused by pipe leakage due to ageing of the pipe and decreasing quality. Whereas, water supply system efficiency is of primary importance in designing either new water distribution networks or expanding existing ones [5].

The limited supply of clean water from the Demak Waterwork Company resulted in the people of Mranggen Subdistrict preferring to use groundwater wells. However, the use of groundwater wells can result in a decrease in land surface height. The use of groundwater will also cause intrusion of seawater to land, thereby causing a reduction in the quality of groundwater. The existing Demak Regency on the coast will also be more susceptible to tidal flooding due to land subsidence.

There has been a lot of researches on optimizing water distribution systems by replacing pipes. Pipe replacement can reduce the level of leakage and increase pressure so the clean water can be distributed to the point that having low pressure [6]. But there is just a little research on replacing the system from using deep well water to groundwater.

The technical planning is supported through modelling EPANET 2.0 software as control and analyzed based on Minister of Public Works Regulation No. 18 of 2007 concerning the Implementation of Drinking Water Supply System Development, Government Regulation No. 122 of 2015 concerning Drinking Water Supply Systems, as well as other relevant references. The primary aim of the study is to identify the various elements that a rehabilitation decision model should encompass.

2. Methodology
This research was conducted in 2018. The research location was in Mranggen Subdistrict, Demak Regency. Sampling was carried out in January 2019. Equipment for sampling included manometers and stationery. The sampling method used in this research is the 24-hour pressure sampling in the piping network. Modelling clean water pipelines using EPANET 2.0 software [7]. This program can use various model parameters, such as pipe diameters, roughness coefficients, valve resistances, or nodal demands, which are required to be estimated [8]. The EPANET 2.0 modelling was developed by the USEPAs National Risk Management Research Laboratory’s Water Supply and Water Resources Division. EPANET 2.0 software can be used to illustrate hydraulic simulations and trends in the quality of water flowing in pipelines (Rossman, 2000). The piping calculation formula used is the Hazen-William formula as follows [9]:

\[ Q = 0.278 \times C \times d^{2.63} \times I^{0.54} \]  

(2.1)

Where:
- \( Q \) = Flow capacity, in \( (m^3/sec) \)
- \( d \) = Diameter of pipe, in \( (m) \)
- \( I \) = Hydraulic gradient, in \( (m/m) \)
- \( C \) = Coefficient of the pipe, depending on the roughness of the wall in the pipe
The existing piping network survey was conducted to find out information about the pipeline network such as service coverage, type of pipe used, pipe diameter, piping accessories used on the network. Data was collected by interviewing waterwork company sub-district capital Mranggen officials.

The water pressure survey in the pipe aims to find out the compressive height of water flowing in the piping network. The survey is conducted every hour for twenty-four hours using a pressure gauge, the Manometer. The pressure measurement survey was held at 6 points in the water distribution pipeline network of Mranggen. Here is a map that designates the pressure measurement points. This survey was conducted to determine the pattern of water usage so that it can also be known the peak hours of water use in the District of Mranggen. This survey was conducted by monitoring the reservoir outflow discharge for 2 x 24 hours. The measurement is done by looking at measuring instrument in the form of a manometer that has been installed at the sampling points.

Data on population is processed to be able to project the population of the next ten years so that the projected water needs can be determined. After obtaining population data for the past five years, the next step is to make population projections for the next twenty years — calculation of population projections using the arithmetic method.

\[
P_n = P_0 + r n
\]

Where:
- \( P_n \) = Total population in year \( n \)
- \( P_0 \) = total population at the beginning
- \( n \) = Calculation period
- \( r \) = Population growth rate / year

The formula above was changed in the form of regression to:

\[
P_n = P_0 + r n
\]

\[
Y = b + a x
\]

Where:
- \( P_n = y \) = Total population in year \( n \)
- \( P_0 = b \) = coefficient
- \( n = x \) = population years to be counted
- \( r = a \) = coefficient \( x \)

Water needs are determined based on the population served, water/capita/ person usage and non-domestic needs (commercial, industrial, social and others). The calculation of population projections is sourced from Central Bureau of Statistics statistical data Mranggen District from 2019-2028. In the estimation of the projected total water demand, the assumption of leakage used is 20% until the end of 2028, in accordance with the planned suppression of leakage figures in the 2014-2028 Water Distribution Network Master Plan. Whereas, the maximum daily factor and the peak hour factor refers to the provisions of Ministry of Public Works Regulation No. 18 of 2007 concerning Implementation of Water Distribution Network Development, which amounted to 1.175 and 1.75, respectively. The following is a graph explaining the results of the calculation of population growth projections and the projected regional water needs served by Demak Waterwork Company of Mranggen Subdistrict.

3. Result and Discussion

Demak Waterwork Company (DWC) has a responsibility to supply clean water demand that is needed by the community. Demak Waterwork Company currently serves a total of eight subdistricts which consist of Demak City, Bonang, Karanganyar, Mranggen, Mijen, Wedung, Wonomesalam, and Karangawen Districts. For Mranggen Subdistrict, Demak Waterwork Company has a Mranggen Subdistrict that serves seven villages including Waru, Ngemplak, Tamansari, Brumbung,
Bandungrejo, Mranggen, Batursari, and Kebonbatur with a total of 7,185 house connections and total water needs of 35.22 l/s. The raw water source in the Mranggen subdistrict distribution unit consists of two sources, namely surface water source and groundwater source. The surface water source comes from the Klambu Kudu Open Canal, which is then treated at the Water Treatment Plant in Waru Village. As for groundwater sources, seven pumping wells are located in Batursari and Kebonbatur Districts.

The water demand or water use system includes industrial water, agriculture water, household water and urban ecological water [10]. The existing water demand per person per litre per day of Water Distribution Network District Capital Mranggen is 106.69 litres/second. The next step is to compare water demand based on ideal theory. For this reason, a population projection will be carried out to determine the water demand per person per litre per day of the Mranggen Water Distribution Network District Capital for the next ten years.

Population development will lead to an increase in demand for clean water. The five variables are: commercial and industry billed consumption, public billed consumption, collective billed consumption, average daily summer temperature and region [11]. Below are the results of population growth projections and water demand projections in areas that are served by Demak Waterwork Company of Mranggen subdistrict.

![Population Projection & Water Demand Projection](image)

**Figure 1.** Population projection chart & water demand projection in Mranggen Subdistrict 2028

Each region has its unique problems of water quality and quantity depending on their climatic, geographic, geologic, social and economic conditions: surface water and groundwater are two primary sources of water [12]. Nowadays, the use of water from the Klambu Kudu SAB for the Mranggen Division of Demak Waterwork Company is 100 litres/second. This is due to technical improvements which are carried out by the Ministry of Public Works Regulation of in Bendung Klambu Kudu. For drinking water demand in Water Distribution Network of District Capital Mranggen in 2038 according to the projection of 139.21 litres/second, so that for the next ten years, the availability of raw water is still sufficient with the trend that can be seen in the graph as follows.
Based on figure 2, clean water delivery is a quite complex system. The pump must be started to ensure the flow of water is channelled to the farthest tick-point. Pump operation increases pressure on the pipe. If the pressure in the pipe is too low, water will not reach the highest point in the network. If the pressure is too high, leakage in the pipeline can occur [13]. The most significant peak factor at 07.00 WIB is 1.39. While the minimum / lowest factor value at 05.00 WIB is 0.71.

**Table 1.** Pressure measurement in primary pipe

| No. | Location | Time | Pressure (atm) |
|-----|----------|------|----------------|
| 1   | WTP Waru 50 l/s | 08.00 | 3.8 |
| 2   | T-junction Ngemplak Waru to Tamansari (bridge) | | 0.8 |
| 3   | Waru Street, crossroad Mranggen Market on the bridge | 08.00 | 1.2 |
| 4   | Batorsari Raya Street, T-junction on the bridge near SD Batorsari | | 0.8 |
| 5   | Kebonbatur residential, Distribution pipe Jayaraya (bridge) | | 0.7 |

**Table 2.** Pressure measurement in critical point

| No. | Sampling Location | Time | Pressure (atm) |
|-----|-------------------|------|----------------|
| 1   | Extention pipe in Pucang Karya Batorsari Village Extention pipe in | 08.00-10.00 | 0.35 |
| 2   | Pucang Indah Batorsari Village | | 0.62 |
| 3   | Extention pipe in Pucang Elok Batorsari Extention pipe in Kebonrejo near the market | | 0.4 |
| 4   | Krempyeng Kebonbatur Village Extention pipe in Jalan Kebonbatur Village | | 0.4 |
| 5   | Kebon Subur Kebonbatur Village | | 0.15 |
From table 1, it can be seen that the distribution network pipes in these locations. The distribution network pipe has a pressure less than one atm or does not meet the standards of the Minister of Public Works Regulation No. 18 of 2007 concerning Guidelines for Operating a Water Supply System that requires minimal pressure is equal to one atm [14]. From table 2, it can be seen that the five house connections at the critical point have a pressure of less than one atm. It means the condition is unsuitable according to the standards of the Minister of Public Works Regulation No. 18 of 2007 about Guidelines for Operating a Water Supply System that requires a minimum pressure on the customer of one atm [14]. This further strengthens that in the Batursari and Kebonbatur Sub-Districts, water does not flow continuously for twenty-four hours.

The WaterCAD v7.0i software is used as a modelling simulation, the remaining compressed data between modelling and measurements in the field can be compared to determine the suitability and find out the possibility of other problems on the network [1].

### Table 3. Comparison of pressure in the field and model in the existing condition

| Location                                                                 | Time  | Pressure (atm) | Model Pressure (atm) |
|--------------------------------------------------------------------------|-------|----------------|-----------------------|
| WTP Waru 50 lps                                                          | 3.8   | 3.69           |
| T-junction Ngemplak Waru to Tamansari (bridge)                           | 0.8   | 0.71           |
| Waru Street, crossroad Mranggen Market on the bridge                     | 08.00 | 1.2            | 1.22                  |
| Batusari Raya Street, T-junction on the bridge near SD Batusari           | 0.8   | 0.71           |
| Kebonbatur residential, Distribution pipe Jayaraya (bridge)              | 0.7   | 0.88           |

Problems that occur in the distribution unit based on the analysis of existing conditions are the amount of pressure in the distribution network at several measurement locations that have been determined shows a number of less than 1 atm. This also indicates that by using the existing pump head, the Waru WTP distribution pump has not been able to press the water up to the Batusarsi and Kebonbatur villages. Besides, there is a high level of water loss of 52.40 litres/second which cannot be accounted for. So, that the water supply from Waru WTP should be able to serve the Batusarsi and Kebonbatur Kelurahans that cannot serve the two villages.

To overcome this problem, for the next ten years, Demak Waterwork Company plans to optimize the distribution network in Mranggen Subdistrict. Optimization objectives can encompass anything from minimal energy consumption to minimal build cost or minimum mean residence time. Energy consumption and residence time are parameters which can be computed by the hydraulic software for individual simulations or nodes in a simulation [15]. Therefore, technical planning is needed to optimize the water distribution network with the service area of the water distribution network of Mranggen Subdistrict, Demak Regency. One part of optimizing the drinking water distribution network in Mranggen Subdistrict is the rehabilitation and development of the network.

The water distribution system in the area of the Mranggen sub-district ministry uses a pumping system for the entire ministry's administration. Distribution zones in Mranggen Sub-district will be divided into 3 zones, namely Waru-Mranggen zone, Batusarsi Zone, and Kebonbatur Zone. The Waru-Mranggen zone consists of Waru, Ngemplak, Tamansari, Brumbung, Bandungrejo and Mranggen villages. While the Batusarsi Zone consists of the Batusarsi Village and the Kebonbatur Zone consists of the Kebonbatur Village.

The plan for optimizing subdistrict capital Mranggen's distribution network is increasing the capacity of Waru WTP, rehabilitating the distribution network of the Batusarsi and Kebonbatur
Distribution Zones, maximizing the discharge capacity carried by pipes in the Mranggen distribution network in the Waru-Mranggen Distribution Zone, and developing distribution networks to Tegalarum Village and Kembangarum Village. The strategy for optimizing subdistrict capital Mranggen's distribution network is appreting/building WTP with capacity adjusted to water demand projections. At present Waru WTP can only produce water an average of 34 litres/second. While the total water demand in 2028 is 139.21 litres/second. So that Demak Waterwork Company is obliged to carry out appreting and / or construction of a new WTP so that the water needs in 2028 can be met. Then, repairing existing pipes by replacing or adding pipes and completeness of the distribution network in the Batarsari and Kebonbatur Districts and repairing existing pipes by replacing or adding pipes and completeness of the distribution network in the Batarsari and Kebonbatur Districts. In the priority issue of pipe replacement, the need to consider four objectives: capital costs, risk of future pipe damage, pipe material, and system reliability [16]. The water supply from Waru WTP will be channelled to the Argo Reservoir in advance to be accommodated. It is intended that the distribution of water in the two villages can be optimized for 24 hours. For this reason, a new pipeline network from Waru WTP will be directly channelled to the reservoir with a pipe diameter of 300 mm. Optimizing the discharge capacity that can be carried by existing pipelines in areas that still have the potential to add to piped network customers. It is intended that the addition of these customers can improve the service of Demak Waterwork Company in these villages. The village that is the focus of the process is those that are in the Waru-Mranggen Distribution Zone. Network development is carried out by utilizing pipes that have been previously implanted in Tegalarum and Kembangarum Sub-Districts. For Tegalarum Kelurahan, a general distribution pipeline with a size of 100 mm has been embedded, while for Kembangarum Kelurahan, a general distribution pipeline with a size of 150 mm has been embedded.

During the network rehabilitation phase, there are two main activities will be carried out during five years of planning, that is upgrading the capacity of Waru WTP and the distribution network rehabilitation activities in the Batarsari and Kebonbatur Distribution Zones. It is expected that by the end of 2023, the existing problems in the form of the non-realization of the Batarsari and Kebonbatur villages continuously for 24 hours can be appropriately resolved.

Based on the results of discussions with the Head of the Planning and Network Development Section of the Demak Waterwork Company, an uprating activity at the Waru WTP has been installed which initially had an installed capacity of 50 liters/second and a production capacity of 34 liters/second to a production capacity of 70 liters/second. At present, the science uprating activity has been running 70% so that the production capacity of Natural Science has touched 56 litres/second. In addition, the plan will be to build a new WTP in the Waru WTP complex with a capacity of 50 litres/second, which can be done uprating to 100 litres/second. The plan is that the existing Waru WTP with a capacity of 70 litres/second will be used to serve the Waru-Mranggen Distribution Zone and will be added to the Kembangarum and Tegalarum Villages. Whereas the Waru WTP will be built with a capacity of 100 litres/second will be used to serve the Batarsari and Kebonbatur Distribution Zones. In 2028, Waru WTP will have WTP with a capacity that can be seen in the following table.

Distribution network problems resulting from the analysis of existing conditions are in the Batarsari and Kebonbatur Distribution Zones because, in this zone, water cannot flow continuously for 24 hours. Therefore, according to the aforementioned strategy, water supply from Waru WTP will be channelled to the Argo Reservoir in advance to be accommodated. It is intended that the distribution of water in the two villages can be optimized for 24 hours. For this reason, a new pipeline network from Waru WTP will be directly channelled to the reservoir with a pipe diameter of 300 mm so that it is necessary to increase the width of the pipe in this area. Some of the pipe addition and replacement locations for the rehabilitation phase are adding pipe on Raya Waru Street to Batarsari Raya Street.

Besides the replacement of distribution pipe, distribution pump replacement is also needed so that the remaining pressure at all distribution zone service points is at least 1 atm. The recommended pumps instead of the existing pumps are as follows.
Table 4. New distribution pump recommendations

|                | Existing Pump | New Pump | Distribution Zone |
|----------------|---------------|----------|-------------------|
| Flow (l/s)     | Head (m)      | Flow (l/s)| Head (m)         |
| 50             | 40            | 50       | 60                |
| -              | -             | 50       | 60                |
| -              | -             | 50       | 60                |
| -              | -             | 50       | 60                |
| 25             | 20            | 100      | 30                |

WTP Waru

- Waru- Mranggen Zone
  Specifically to Argo Res.
  Baturu and Kebonbatur Zone

Comparison of the residual pressure on the pipe at the sampling point in the conditions before and after network rehabilitation in table 5.

Table 5 Comparison of pressure before and after rehabilitation

| Location                                           | hour | Pressure Before | Pressure After |
|----------------------------------------------------|------|-----------------|----------------|
| Waru WTP Pump 1 and 4 (50 l/s)                     |      | 3.8             | 6.11           |
| Ngemplak Waru T-junction to Tamansari (bridge)     |      | 0.8             | 5.35           |
| Waru Street, Cross-Road Mranggen Market on the bridge | 08.00 | 1.2             | 4.53           |
| Batursari Raya Street, T-junction on a bridge close to Elementary School Batursari |      | 0.8             | 2.84           |
| Kebonbatur Housing Complex, Jayaraya Distribution Pipe (bridge) | | 0.7             | 4.83           |

In accordance with the 2014-2028 Demak Water Supply System Main Plan, network development will be carried out in two sub-districts in Mranggen Subdistrict, Kembangarum and Tegalarum Subdistricts. Previously, the Mranggen Division PDAM had installed public distribution pipelines in the two villages. For Tegalarum Village, a public distribution network pipe with a size of 100 mm has been installed, while for Kembangarum Village, a distribution pipe network with a size of 150 mm has been embedded. So for the next ten years, the network development in the two villages will utilize existing pipes so that the costs needed can be made more effectively and efficiently. The locations for the addition of pipes for the development stage are Tegalarum Village, Kembangarum Village, Brumbung Village, Bandungrejo, and Permata Batusari Residential.

Comparison of the remaining pressure in the pipe at the sampling point and the point of distribution of the carrier network in the conditions before and after the increase in the existing pipe discharge capacity and network development can be seen on table 6.

Table 6. Comparison of pressure before and after development

| No. | Location                                           | hour | Pressure Before | Pressure After |
|-----|----------------------------------------------------|------|-----------------|----------------|
| 1   | Waru WTP Pump 50 l/s                              |      | -               | 6.65           |
| 2   | Ngemplak Waru T-junction to Tamansari (bridge)     |      | 0.8             | 5.35           |
| 3   | Waru Highway, Cross-Road Mranggen Market on the bridge |      | 1.2             | 4.53           |
| 4   | Batursari Highway, T-junction on the bridge close   |      | 0.8             | 2.84           |
| No. | Location                                                                 | hour | Pressure Before (atm) | Pressure After (atm) |
|-----|---------------------------------------------------------------------------|------|-----------------------|----------------------|
| 5   | Kebonbatur Housing Complex, Jayaraya Distribution Pipe (bridge)           | 0,7  | 4,83                  |
| 6   | Tegalarum Village                                                          | -    | 3,79                  |
| 7   | Kembangarum Village                                                        | -    | 4,03                  |
| 8   | Brumbung Village                                                           | -    | 4,31                  |
| 9   | Bandungrejo Village                                                        | -    | 4,62                  |
| 10  | Permata Batusari Residential                                               | -    | 5,52                  |

![Figure 3. Pressure monitoring location](image)

4. Conclusion

The existing condition of the water distribution network in subdistrict capital Mranggen, Demak Regency has not been able to drain water continuously for twenty-four hours in Batursari and Kebonbatur Sub-Districts. The use of deep wells must be changed to the use of surface water in order to meet the customer's demand continuously with a good distribution system. Optimization is needed to have a proper distribution system. Optimization of the water distribution network in subdistrict capital Mranggen, Demak Regency is carried out in the long term with two stages, namely the network rehabilitation stage and the network development stage.

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