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RESEARCH PAPER

The optimization of water network model in the central of Demak District

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Abstract. Demak Waterwork Company (DWC) has served 21,178 customers with the capacity flow of 159.33 l/s. The capacity was predicted to reach 300 l/s or double in in 2027. The Water Distribution Networks (WDN) was developed in a large zonation, but the water supply to the customer was not well managed. Low pressure especially at peak hours, the level of leakage, and the difficulty to detect leakage are water supply problems should be solved by WDN. The objectives of this study are forecasting the demand for drinking water in the 2036 and designing a zoning system to meet future needs of drinking water. This study applied Epanet Modelling to simulate the water network system in existing and predicted condition. The result show that the characteristics of pipes, pipe materials and pipe size based on the load of drinking water should be considered for pipe replacement. Some developmental strategies e.g. improving the capacity, establishing zones, and resizing the pump capacity improve the reliability and efficiency of the water distribution network. The pressure model resulted in sufficient value to supply the whole area of more than 0.5 bar in service pipe.

Keywords: Epanet modelling; optimal design; Water Distribution Networks (WDN)

1. Introduction

Water supply systems are characterised by a large variety and complexity providing an opportunity to improve the system to reduce cost and produce more reliable supply (Coelho and Andrade-Campos, 2014). Demak is a region in Central Java Province. The development of this region was mainly supported by the industrial sector and population settlement. It has an area of 89,753 ha consisting of 14 districts and 243 villages.

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The increasing number of residents leads waterwork company to develop its system continuously. The development of the system is directed to expand the coverage of drinking water services. Currently, the waterwork company in Demak has served 21,178 customers with a flow of 159.33 l/s which is expected to reach 300 l/s or double in the next 10 years. Indonesian government's program in Sustainable Development Goals (SDG) in Water Supply and Sanitation aims to achieve universal and feasible drinking water that is safe and affordable for everyone or 100% population can be served with clean water.

Urban area service of Demak water work company has not been optimal. Many factors affect the flow of water in when distributed through pipelines including pressure, pipe diameter, pipe type, and pipe age, pumps etc. In the distribution system, there are still areas with less pressure and it even flows the water at certain hours only. Water leakage in high pipelines also greatly affects the pressure drop and flowing discharge. However, it is difficult to detect because the pipes are mostly buried (Angulo et al., 2017). The leakage of the pipe is due to its age that is older than 30 years and many of them are asbestos. The addition of the network cannot be conducted anymore since the size of the pipe is too small to accommodate the flowing discharge. Hence the high of headloss causes the pump's pressure becomes larger.

The lack of water supply to customers due to the low pressure especially at peak hours, the level of leakage, and the difficulty to detect leakage because of the zone division that has not been optimal is a problem experienced by various cities in Indonesia such as in Waterwork Company of Gorontalo (Rivai et al., 2004). The distribution system was developed in a large zonation that resulted in the flow of water to be not properly managed. Many random pipe connections and unbalanced pump systems cause high energy demand. While Waterwork Company of Ternate still experiences the problem with the distribution system that is not smooth due to the service that is not 24 hours and the raw water discharge which is not maximal. An analysis on the distribution system is needed to acknowledge the flow, water pressure, and the continuity of water distribution system in Ternate City Waterwork Company (Ardiansyah et al., 2012).

Many studies on cases related to the optimization of the network distribution system have been done in developed countries. A case study from the regional water supply system of Apulia, Southern Italy used AQUATOR software package was conducted by Arena et al. (2015). Initially, Epanet software was built according to the condition of the water distribution system located in Chojnice (Poland) (Duzinkiewicz and Ciminski, 2004). Water distribution systems in Indonesia did not maximally utilize the available technologies. An appropriate optimization model for the pipeline has not been widely applied in Indonesia. Therefore, this research is important to be conducted. An approach based on regional characteristic is required in this research.

To overcome this problem, it is necessary to redesign the pipeline's system in Demak Waterwork Company. The increases in the number of people, as well as the need of drinking water, require a zoning strategy in phasing out pipe replacement that contemplates the complexity of the system. The objectives of this study include projecting of demand for drinking water in the 2036 and creating a system to redesign the zoning system to meet future needs of drinking water. A projection on the clean water requirement is very important to get the pattern on the water usage to assist us in creating hydraulic modelling for developing the design, analysis, and the operating system of the clean water (Do et al., 2017). The spatial distribution of the population growth is analysed using Spatial Detail Plan. While the preparation of zonation system used hydraulics modelling Epanet 2.0 software.

2. Methodology

Model development

The hydraulic analysis was conducted using Epanet 2.0 software. It is a software which is released by US EPA and usually used to perform the analysis and planning of water distribution network. EPANET computed the nodal heads and link flows considering that the water demand is assumed to have values which are fixed, can be identified, and are assigned to the network nodes. The default unit used in Epanet 2.0 software was the unit litre per second (LPS), while the calculation of the high press used the Hazen-William formula. The data which was input was taken from the spatial piping system. The data on pipes, accessories, and pumps followed the existing conditions. The modelling used the extended period of 24 hours. The hydraulics analysis with the model was performed by comparing between the current and the projection condition of the next 20 years which had been redesigned.

The optimization of the pipelines used the concept of large branching reinforcement with a system which is divided into two major zones. The optimization of the distribution network model was designed through several stages including changing the pipe size, adjusting the pump size, and creating zonation. Some problems related to the optimisation technique will be solved using conventional trial and error methods. The zoning limit uses a centralized main pipe with the branch system. The minimum possible replacement in duplicates reduces costs of investment.

Area of study

This study examined the existing single network of water distribution in Demak with the service area of 74.438 Ha serving 21.178 household connections. This study was conducted from 2016 to 2017. The determination of water requirement quantity was based on the average daily water demand of Demak Water Work Company which is 130 l/s. The projected method of water demand was based on the projected population growth. The population projection formula used geometric, arithmetic, and exponential projection methods (Klosterman 1990). While the pattern of spatial growth of population was analyzed using the map of Spatial and Regional Plan of Demak. In developing the GIS Map, we used freeware Quantum GIS to identify the pipe locations.

Model validation

The hydraulic data of the water canal was obtained by measuring the pressure on the distribution pipelines at 8 points. This study used Bourdon Analog Manometer. The data on the pressure and discharge on the model will be compared with field measurement results to reach a different level of below 10%. Some assumptions are adjusted by modifying the pipe roughness, valve openings, and the condition of the existing pump.

Some critical points in the model were evaluated to compare the conditions before and after optimization.

3. Result and discussion

Prediction of water demand and review spatial planning

Based on the regulation number 32 of 2004 regarding the Regional Government Article 2 stating that "Local Government shall arrange and manage its own governmental affair according to the principle of autonomy and duty of assistance", and the Government Regulation Number 38 of 2007 concerning the Division of Government Affairs between Government, Provincial Government and District/City Government Article 7 Paragraph (1) explained that "the obligatory matters shall be government affairs which shall be administered by the provincial and district/municipal governments, in respect of basic services including drinking water services".

The first stage in rehabilitating or redesigning the system was to predict the number of population and water demands (see Figure 1). The assumption determination was important in just the amount of water demanded. The water usage in each region had different characteristics such as the pattern of the water use and the standard of the water which is required by one person per day. The projection does not simply refer to the demographic projection only, yet it refers to broader aspects. A planning would affect the reliability, the development tolerance, and the efficiency of the system.

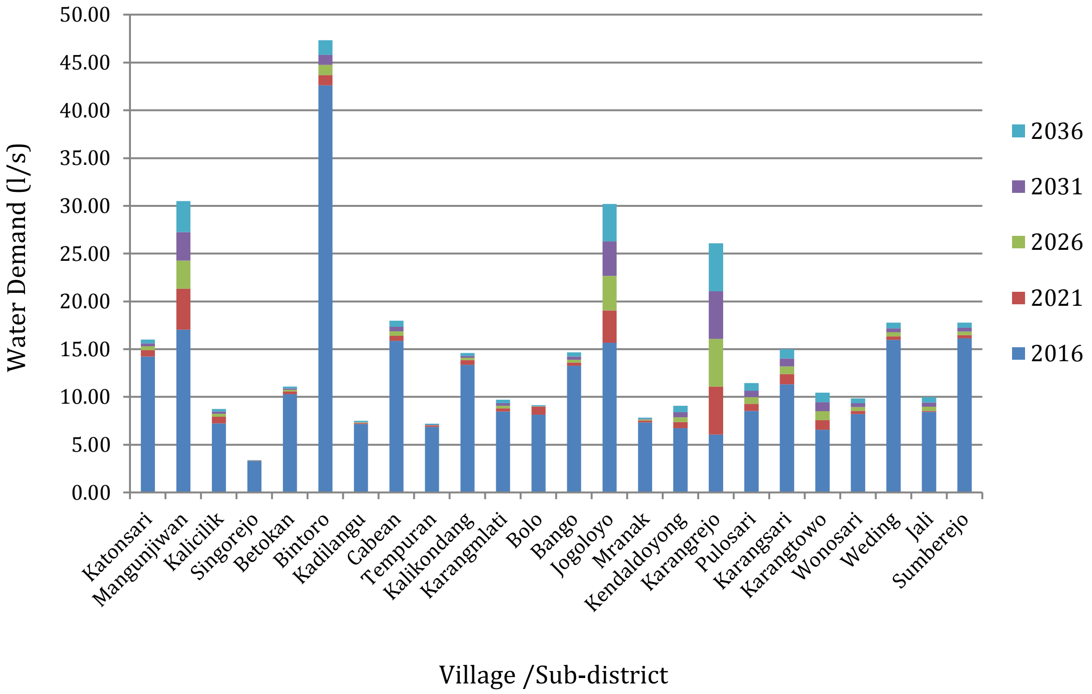


Figure 1. The Prediction of domestic clean water demand from 2016 to 2036

The network development was directed to expand the coverage of drinking water services. In 2017, Waterwork Company of Demak Regency has served 21,178 customers with the flow of 159.33 litres/second. It was expected to reach 300 l/s or double in 2036. The yellow bar shows the residential area while the green one indicates the agricultural region. Demak as the capital city in that Regency has a fast development. Bintoro, Mangunjiwan and Jogoloyo villages experienced the greatest increase in water demand in that region. The urban village of Bintaro, which now offers a new service level of 30%, was projected to reach 100% by 2025. Mangunjiwan and Jogoloyo are predicted to have a larger population growth due to the development of many new residential locations. While, the development of new pipeline systems will be in Sumberejo, Weding, Jali, and Jogoloyo.

The largest the developed areas in Demak are BWP I and BWP V (see Figure 2). BWP I consisted of Kalikondang Village, Kantonsari Village, Mangunjiwan Village with an area of approximately 1.068 Ha. Then BWP V consisted of Jogoloyo Village, Kendaldoyong Village, and Karangrejo Village with an area of approximately 775.5 Ha. The areas which are developed for residential were rice fields and no access road but the settlements are predicted to grow quickly especially in Mangunjiwan.

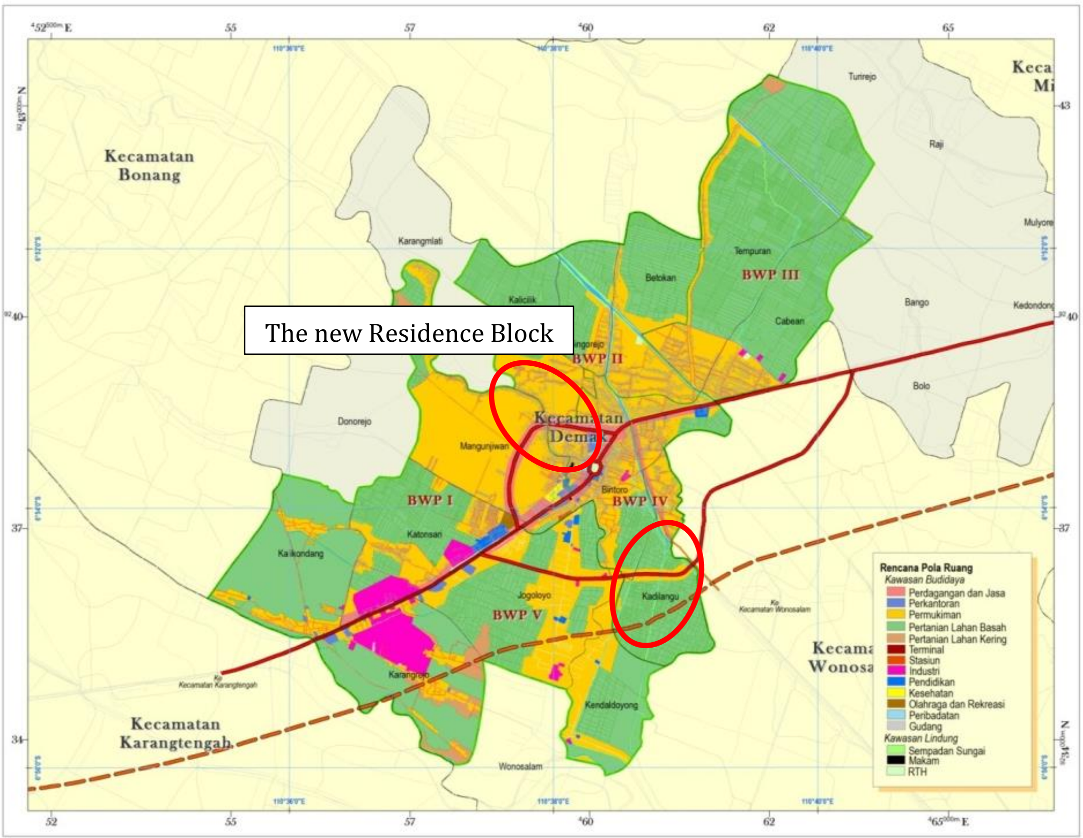


Figure 2. The New Mangunjiwan dan Jogoloyo Village Residence Block in spatial planning of Central Demak

Existing model network

At the certain age of the pipelines, the chemistry component in water can damage the pipe, pump, and valve. Especially in old pipes, corrosion is potentially subject to mineral clogging. This buildup can narrow and reduce the pressure of pipes, and worse the water quality. To overcome this ageing effect, stakeholders can select one of repairing options e.g. cleaning and relining the pipes, replacing new pipes (more likely) or installing other pipes in parallel. The rehabilitation of the system area might also provide sufficient fire suppression and solve the common problem at peak hour or in the distribution stage as described above.

The negative condition of existing water canals is a complicated and complex issue while the needs for clean water increases in line with urban development and population increase. Demak Waterwork Company was experiencing difficulties to supply new customers due to the poor condition of the system. The increasing number of customers will further exacerbate the areas of the water canals that are not treated well. Such condition also happened in the Meulaboh Waterwork Company. It had not been able to meet the need for clean water as the increasing number of new customers (Syahputra, 2005). The high demand of water supply was due to water-prone service areas in the dry season. Groundwater service areas could not be used for domestic needs due to its poor quality.

The current condition of the water usage pattern in the Waterwork Company was influenced by the pump operating hours. The biggest peak factor value was at 08.00 - 09.00 WIB (1.38) (see Figure 3). While the lowest peak factor value was at 04.00 - 05.00 WIB (0.32). This water use pattern showed the less ideal condition as it appeared too flat indicating that there might be a shortage of water supply at certain locations. In Cartenega, Colombia, in the places with the similar elevation, the distribution system could flow well by using pump. This condition is similar with the one in Waterwork Company of Demak Regency (Angulo et al., 2017).

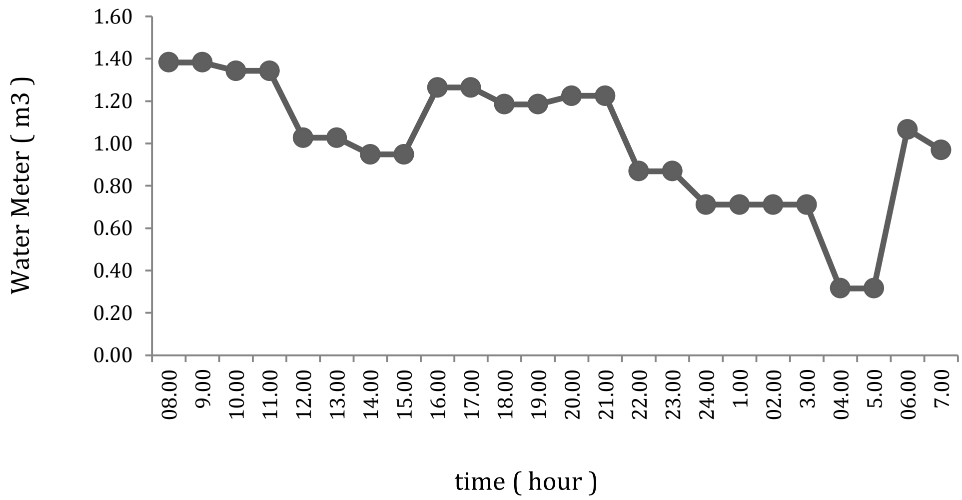


Figure 3. The water distribution pattern in Demak's Central Network System

Measuring the water level in the reservoir aimed to determine the fluctuation of storage in the reservoir. The water which has been processed was put in the reservoir to be pumped by citizens. The pattern of the water usage in this graph was more influenced by the operation of the pump. At peak hour, which started in the morning, the operation of 12 units of pumps resulted in the decrease of water in the reservoir storage. While at night, the consumption was relatively small. Therefore, the water in the reservoir increased. The Waterwork Company system that could not be served shows flat movement. The pattern of water usage from the pump operation more reliably represented the real condition of the field. The need for clean water and the schedule of pump usage greatly affected the pump performance. Appropriate scheduling of pump usage could reduce the excessive use of energy thus it can increase the energy efficiency (Menke et al., 2016).

The optimization of network design

The distribution zone was divided based on the pumping system and mine pipe. This division was set through a discussion with the Waterwork Company representative for system and planning. Zone set would assist the analysis of the water supply and demand level thus it will be easier than the analysis of the existing distribution network system. The zone segregation was conducted used an administrative boundary approach. Some villages outside Demak such as Karangtengah, Bonang and Wonosalam were also accommodated in the distribution system. Also, some areas namely Jogoloyo Village, Weding, Jali and Sumberejo are included in the development system.

In the redesigning system, large reinforcement or branched network systems with a single water source were used. The diameter of the pipe was selected based on the hydraulic calculation by Epanet software. The purpose of the distribution system modelling is to optimize the design, maintenance and operation and the studies were presented in simple system (Gama et al., 2015). Replacing pipes with the ones with a bigger diameter could become the solution to reduce the pressure and valves to isolate planned or unplanned systems (Jose and SumamL, 2016). With a pipe with the bigger diameter, the service (pressure) will be better, but the capital cost would also be higher. In general, each link (connection between two nodes) in the system could consist of several segments of pipe with different diameters. The use of different diameters was intended to solve the constraints of heuristic-optimization problems (Hooda and Damani, 2017). In selecting the pipe for future development, we should consider the characteristics, the material and the size of the pipe because the drinking water load which is carried would affect the condition of the pipe. The effect of load would reduce the quality of the pipe and might affect pipe development (Rezaei et al., 2015).

Zoning method has been made by considering the zone division from the main pipe and the pump location. In this case, the area is divided into two zones which are the west zone and east zone (see Figure 5). The west zone is the districts which are passed by the main pipe with westward direction and pump division. The areas which are included in the west zone are Mangunjiwan, Karangmlati, Jogoloyo, Kendaldoyong, Wonosalam, Karangrejo, Katonsari, Kalikondang, Pulosari, Karangsari, Karangtowo, and Sumberejo. Then, the East Zone is merged from East Zone and South Zone. This emergence is based on the division of the pump, yet they have the different pipes. One of them is to the eastward direction while another is to the southward direction. Although they have different directions, they have the same pump outlet. Therefore, they are put into one zone. The districts which are covered by the east zone include Wonosari, Betokan, Tempuran, Cabean, Bango, Mranak, Bolo, Botorejo, Sidomulyo, and Kadilangu.

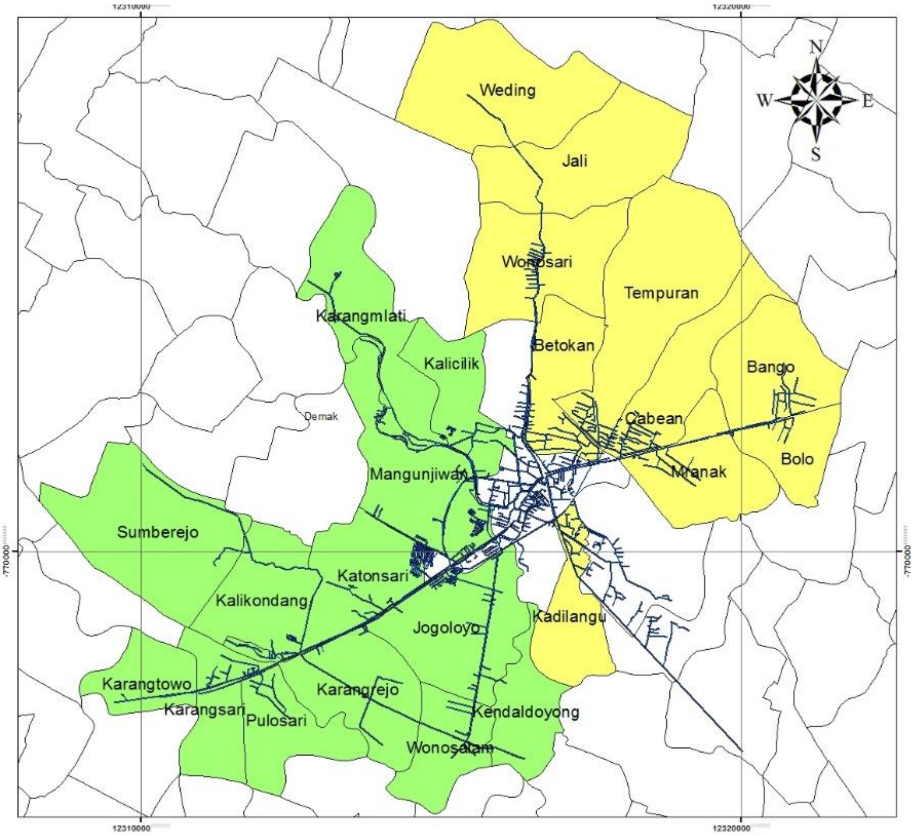
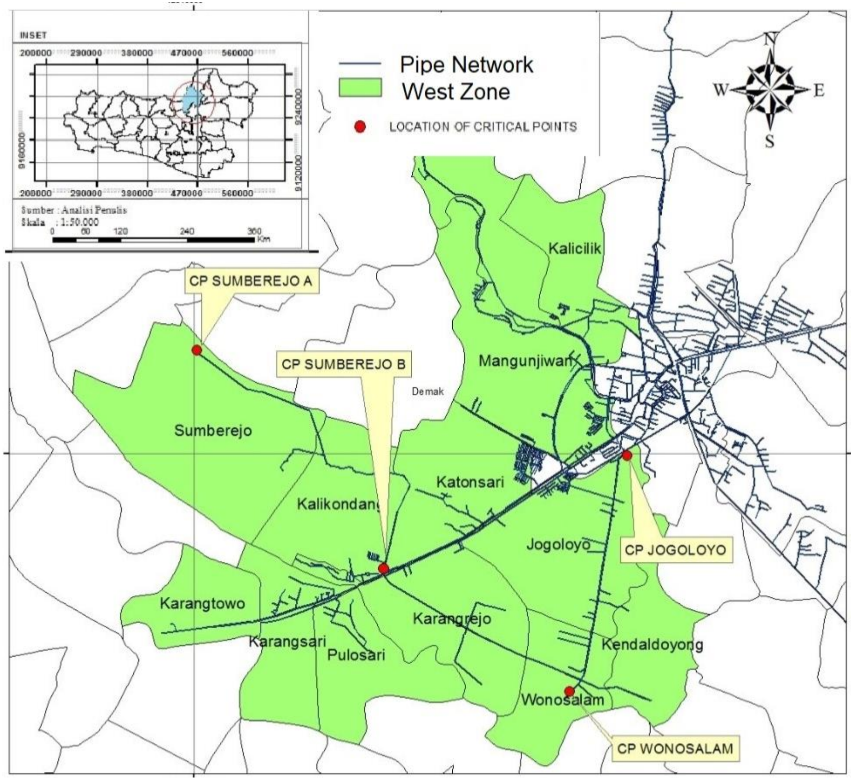
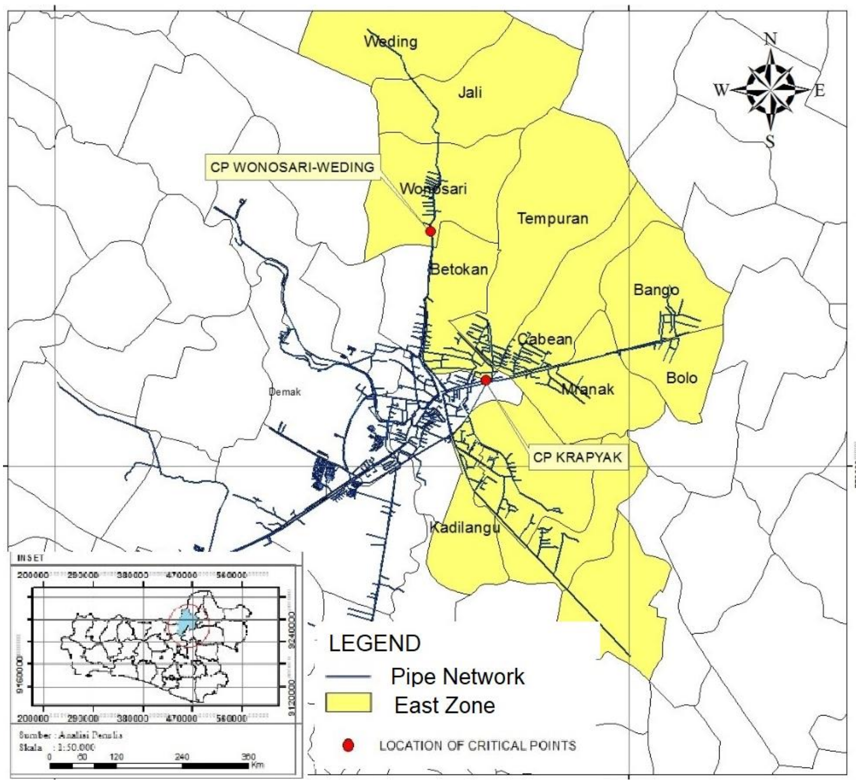


Figure 4. Separated planning zone in network distribution system

The problem-solving strategy was made in two stages. The first one needed lower cost and simpler development but had a significant effect on reducing the burden. The second phase was a complete overhaul including the replacement of the main pipe so that the pressure problem could be resolved for up to 10 years. The strategies to optimize the system included several strategies to reduce the cost. First, the interconnection between adjacent pipes will be a simple solution to be applied in several districts that are nearby the main pipe. In some locations, the header pipe is quite small affecting the quantity and the pressure to be less so more tapping points are needed. Secondly, the pipe system is enlarged with skeleton concept. Every zone is facilitated with one main pipe to the pump system. The concept of the skeleton network adopts the fishbone flowing. This concept is better to control the pressure, detect the leakage and maintain the quality. The third, some areas need particular pipes installation for secondary distributions. Pipes in some locations bring excessive capacity to be distributed to the smaller pipes. Creating smaller zone leads to simplify the analysis. Fourthly, the improvement of the pressure reliability was conducted by installing more pumps to handle peak hours. Some pump had been too old to operate. Therefore, they need to be upgraded to distribute a bigger capacity for a better efficiency. Every zone will be installed with different pumps and pipes. The fifth, the operator needs to conduct research, repairment, and installation on the pressure gauge and water meter on sub-network system.



(a)



(b)

Figures 5. (a) West Zone, (b) East Zone shows that zoning division location, also the location of the critical point in the service area and the value of critical point

Changes in pipe diameter also solved the low pressure. The pipe optimization was conducted on the main pipe with a high head loss which is marked by the flow velocity exceeding 1.5 m/s at peak hour. A pipe which led to the northern area, especially those serving Wonosari Village, Jali Sub-district, and Welding Village were enlarged from the diameter of 6 inches to 8 inches and 10 inches. The pipes leading to the southern area, which served Kadilangu Village, Botorejo Village, Sidomulyo Village, and Pilangrejo Village were enlarged from the diameter of 4 inches to 6 inches and 8 inches. Pipes serving Bango and Bolo Sub-districts were also changed in their diameter which was from 4 inches to 6 inches, and from 6 inches to 8 inches.

In the West Zone, changes in the pipe diameter and pump capacity successfully served adequate drinking water. In Sumberejo Sub-district, the furthest point where the pressure was situated was at 14.9 m and at the end of Jogoloyo system (28.5 m). Other efforts were the addition of 6-inches pipe in Jogoloyo area, the installation of 6-inches pipe leading to Sumberejo Sub-district, and the installation of 4-inches pipe in Wonosalam Sub-district in Karangrejo Street.

Table 1. The critical point before and after optimization

Critical point Location	The pressure on critical points (m)	
	Before	After
Sumberejo A	0	4.9
Sumberejo B	4.4	25
Jogoloyo	24.7	41
Wonosalam	1.2	12
Wonosari-Weding	9.5	9.8
Krapyak	6.2	35

The validation of network

Most of the distribution pumps were in the negative section of the centrifugal pump that was located above the tank. If the water in the tank is shallow, the cavitation will increase and there will be more sediment deposition in the bottom of the tank. As the result, the water volume in the tank was not optimal in fulfilling the water demand. The test results between the pressure and the model show the result quite similar to the difference under one bar. The assumption of pipe roughness used includes 100 for pipes over 20 years and 110 for PVC pipes under the previous year.

The measurement which was conducted at the furthest point of Kalikondang-Sumberejo was to identify the pressure to be developed (see Figure 6). From the measurement, we identified that it was 0.44 bar. Since the pressure in the area was below 1 bar, it did not meet the minimum water pressure requirement (Pekuwali et al., 2005). The problem related to the low pressure also occurred in the distribution network of Waterwork Company Matawai Amahu of Wangipau. This condition has led some areas to be unably receiving water. The high frequency of leakages and the incompatibility of pipe diameter with the water needs were also the causes of the problem(Pekuwali et al. 2005). The use of old asbestos pipes at Waterwork Company of Demak Regency causing leakage resulted in the high loss of water. In Cluj-Napoca, Romania the replacement of asbestos pipe was highly prioritized on its developmental step (Aşchilean et al., 2017).

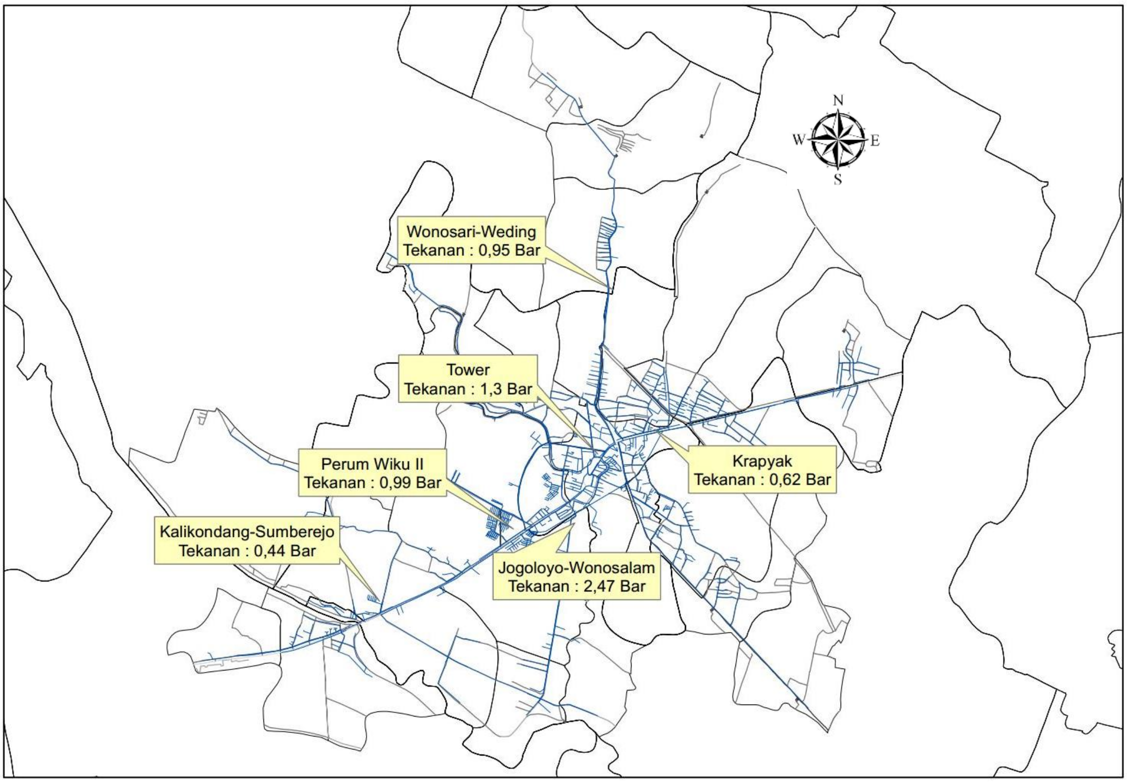


Figure 6. Observation pressure in network area existing to validate

4. Conclusion

The fastest growing happened on residence block in spatial planning like Mnagunjiwan and Jogoloyo Village. The chosen problem-solving strategy was the selection of simpler development with lower cost but could bring a significant effect. System optimization strategies included several ideas to rcost. Firstly, the interconnection among adjacent pipes will be the most simple solution in several districts that are nearby the main pipe. Secondly, pipes with high velocity are enlarged. In replacing the old pipe, the selection of the new ones should consider the characteristics, materials and size of pipes since the drinking water load to be carried is big. The network concept adopts a fishbone flow. Such a concept is better in controlling pressure, detecting leakage, and maintaining quality. The third, some areas need to be installed with additional pipes. The smaller the zone is, the better the analysis will be. The fourth, The reliability pressure can be improved by installing more pumps to handle peak hours. The fifth is separating the network system into four main zones. Every zone will be installed with a different pump and pipe. The sixth, the operator needs to conduct research, repairment, and installation on the pressure gauge and water meter on the sub-network system. The optimization of the pressure model showed that Jali-Weding village of 9,8 m and Sumberejo of 4.5m, and West Zone in Wonosalam Village of 12 m and in Jogoloyo Urban District of 41 m are at critical condition.

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