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Evaluation of pipe network distribution system using EPANET 2.0 (a case study of the city of Jember)

Wiwik Yunarni Widiarti[1], Sri Wahyuni[2], Retno Utami Agung Wiyono[1], Entin Hidayah[1], Gusfan Halik[1], Dian Sisinggih[2]

[1] Department of Civil Engineering, Faculty of Engineering, University of Jember, Jember Indonesia
[2] Water Resources Engineering Departmenet, Faculty of Engineering, Universitas Brawijaya, Malang Indonesia

E-mail: wiwik.teknik@unej.ac.id

Abstract. Fulfilment of drinking water needs is one of the government programs to support the achievement of the target of Sustainable Development Goals (SDGs). One of the important parameters in the fulfilment of drinking water needs is a good distribution system. The aims of this research are to create a design to analyse the hydraulic model of drinking water distribution. The utilized model involved the EPANET 2.0 software. The utilized data included land elevation, pipe distribution base map, population, and discharge. The results indicated that the existing design has not fulfilled the standards of availability, hydraulics analysis, and calibration. Therefore, there needs to be a redesign that fulfils all parameters. The results of the new design requires a two-stage development process for the new water distribution system, with the first stage to be executed in 2015-2020 and the second stage to be executed in 2020-2025. Hydraulic analysis shows that additional discharge is needed to increase pressure and velocity. Model calibration was performed by comparing simulated data with field data; the result of pressure calibration is 0.928 and the result of discharge calibration is 0.894. These two results indicated that the results of the simulation are highly correlated with the field conditions.

Keywords: clean water, EPANET, hydraulics analysis, distribution model.

1. Introduction

The development of the economy and the growth of the population demand the provision of various services, including the supply of clean water in sufficient quantities and with a good quality. Therefore, it is not an overstatement to say that the development and management of water resources can be called the foundation of human life. Meanwhile, clean water needs continue to increase along with the increase in the population and in economic activities.

The availability and potential of raw water resources that exist at present and in the future are degrading in terms of quantity and quality. Water crisis is also predicted to become a serious problem in the upcoming decade. The sector of water resources becomes an important priority, given that the role that water plays is quite significant for various aspects of life. Economic development and population growth demand that the services to be provided, for example a supply of clean water, be sufficient in quantity and be of a good quality.

The provision of drinking water supplies in the Jember area becomes the responsibility of the PDAM (*Perusahaan Daerah Air Minum*, Regional Drinking Water Company) of Jember Regency, the

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Government of Jember Regency, and the people. The treated water to be supplied to consumers must meet the quality standards for drinking water that are stipulated by Minister of Health Notice No. 492/MENKES/PER/IV/2010 on the quality requirements of drinking water [1].. At present, only 61% of people in the Capital Sub-District region of Jember Regency have been supplied drinking water through the PDAM network [2]. Based on the data for drinking water provision in Jember, the needs of customers vary according to their level of income. People with higher income will also have high drinking water needs, because this is related to lifestyle.

A Drinking Water Supply System Master Plan Composition (RISPAM) is very much required for Jember Regency in order to find out the amount of potential that exists and can be utilized for specific activities that will later on provide added value for the prosperity and increased standard of living of the people in the community. The concept of supply being greater than demand provides a strategic step to prepare a foundation and scenario for sustainable water resource development and management in order to fulfil the various drinking water needs in the future.

This research is part of the creation of the RISPAM for the City of Jember, wherein the analysis of pipe networks for the distribution of raw water becomes a very important matter to be studied as one of the determinants for the achievement of the target for creating the RISPAM. Many previous researchers have conducted similar research on the same topic, including [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13]. All of the researchers obtained good results in their application of the EPANET 2.0 program as an assistive tool for the analysis of pipe network distribution systems. What differentiates this research from previous research, in addition to the study location, is that this research discusses in detail the existing conditions, projection of the needs for the population up to 2025, and the search for a new water spring location as the ways to resolve the problems of the research and achieve its objectives.

2. Material and Methods

2.1 Location of the Study

Figure 1. Location of the Study [14].

Jember Regency is divided into 31 sub-districts and 248 villages or hamlets, and includes approximately 76 islands of different sizes. Jember Regency has an area of 3,292 Km^2 or 329,333 hectares and is situated at elevations of 0-3,300 meters above sea level. Topographically, in Jember Regency, water sources or springs are located around or on the slopes of mountains, hills, and dunes. There are 1,670 dunes that have been accounted into the inventory and 285 that have not yet been accounted, spread among several sub-districts. The population in 2018 was 2,440,714 people [15].

2.2 Data Collection

For the purpose of this research, the data that were utilized for analysis and simulation are composed of two kinds of data, which are primary data and secondary data. Primary data are data that are obtained from direct measurements on the field, consisting of data on land surface elevation, pipe pressure, and discharge. Meanwhile, secondary data are obtained from several related institutions, and the data consist of the population, water needs and availability, and the pipe network distribution.

3. Result and Discussion

3.1. Existing PDAM condition

The water needs for public services are the water needs for various kinds of public services such as hospitals, schools, terminals, restaurants, and others. The amount of water needs for public services refers to the applicable stipulations, which amounts to 25% of domestic water needs. Jember Regency is composed of 31 sub-districts and 6 units of the Regional Drinking Water Company (PDAM). The pipe networks in the drinking water distribution system in Jember Regency cover PDAM channels, Association of Drinking Water Resident Users (HIPPAM), Water and Sanitation for Low Income Communities (WSLIC), and the National Program for People Empowerment (PNPM). The current rate of service still stands at 70%.

3.2. Projection of drinking water needs

The needs of clean water up to 2025 are calculated based on the projection of the number of population in the 31 sub-districts. The projection of clean water needs is calculated with consideration of the following various factors:

a. Rate of Service
   The rate of service is adjusted to the stages of the Drinking Water Supply System, for which at stage 1 (2015-2020) the rate of service is planned out to be 80% and at stage 2 (2020-2025) the rate of service is targeted to be 100%. Therefore, it is expected that in 2025 the water needs of all residents in the area of Jember Regency are fulfilled.
b. Rate of Consumption
   The rate of consumption is adjusted to various kinds of water needs:
   - Domestic water needs, where:
     - Ratio of household links (SR) to public hydrants (HU) = 80 : 20
     - Household links (SR) have water needs of 120 l/person/day [16]
     - Public hydrants (HU) have water needs of 60 l/person/day [17]
   - Non-domestic water needs are planned out to be 20% of domestic water needs [18]
c. Reduction of water loss due to leakage is planned to be 20% of the total of domestic and non-domestic water needs.
d. Fluctuation of water needs
   - Average daily water needs (Q average) are the sum of domestic water needs, non-domestic water needs, and water loss.
   - Maximum daily water needs are 1.2 times the Q average.
   - Water needs at peak hours are 1.5 times the Q average.
   - Water needs are reserved for emergencies such as in the case of fires.
   - Total water needs are the sum of water needs at peak hours and water needs for fires.

Table 1. Calculation of Water Needs up to 2025.

Population in 2014	Projected Number of Population		
	2015	2020	2025
2,375,288	2,419,994	2,531,759	2,563,424

Population in 2014	Water Needs (litres/day)		
	2015	2020	2025
2,375,288	314,599,220	329,128,670	343,658,120

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3.3. Raw Water Potential

3.3.1 Rivers

Regarding the potential of raw water in addition to springs and underground water, the City of Jember has 16 watersheds. Each watershed is composed of several rivers that flow through the surrounding agricultural fields. The largest river is the Bedadung River, which is located in the Bedadung Downstream watershed, passes through the regency capital with a length of 46,875 meters, and is able to irrigate agricultural fields of an area of 93,000 hectares. The longest river is the Mayang River, located in the Antirogo watershed, which has a length of 145,500 meters and irrigates 5,860 hectares of fields. The other rivers are Sanen River, Agung River, Krongkongan River, Besini River, Bondoyudo River, Tanggul River, Suko River, Watu Urip River, and Garanan River. This potential may be managed through efforts to dam up the river flow as an anticipative effort to increase discharge of raw water for the PDAM of the City of Jember in the future.

The potential of surface water that amounts to 7,153,660 m^3 may be utilized for domestic usage to an amount of 1,784,177 m^3 (25%) and agriculture to an amount of 1,463,539 m^3 (20%). The total usage for domestic and agriculture needs is 3,247,717 m^3 and the reserve surface water is 3,905,943 m^3 (55%).

The following are the development plans for the development of surface water in Jember Regency, as shown in Figure 2, which details the water resource network system plans for the regency.

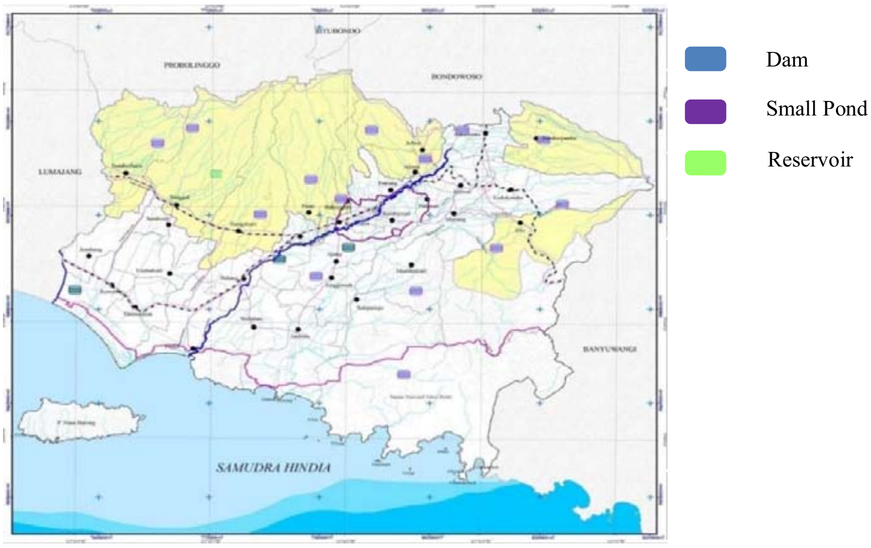

Figure 2. Development Planning Map for the Water Resource Network System for Jember Regency.

3.3.2 Spring Water Potential

Water sources or springs are in general located around or on the slopes of mountains, hills, and dunes. The number of dunes in Jember Regency that have been accounted into inventory is 1,670, while 285 have not yet been accounted; these are found in several sub-districts, including Arjasa, Sumbersari, Jelbuk, Sukowono, Kalisat, Pakusari, Ledokombo, and Sumberjambe. In the northern part of Jember Regency, the people in general utilize existing water springs in order to fulfil their clean water needs, as the PDAM pipe networks have not reached their location. Figure 3 shows the potential for spring water, from both springs that can be made to flow with gravity and groundwater that requires pumps for extraction.

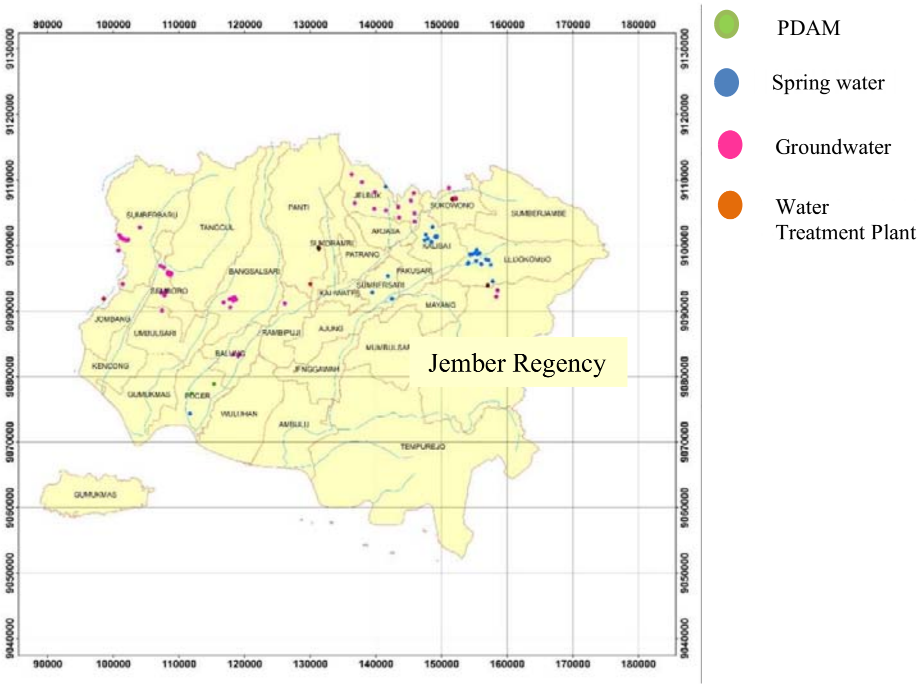

Figure 3. Map of Distribution of Spring Water in Jember Regency.

3.4. Development Plans for the Drinking Water Supply System

Each of the sub-districts located in the region of Jember Regency possess different raw water potential and contour characteristics, and therefore the service system for raw water to be applied in each sub-district is to be adjusted to the conditions of each individual region. In the 10 years from 2015–2025, the development plans for the Capital Sub-Districts are prioritized for sub-district regions that have the potential to be serviced as PDAM consumers and are regions with water issues. Table 2 below presents the plans for service systems and the targeted sub-districts for the creation of Capital Sub-Districts.

For the development of the new Capital Sub-Districts, the service systems for clean water are closed systems, which means the zone boundaries of the Capital Sub-Districts are clear; this was implemented to lower the figure of non-revenue water (NRW) and to ease control and service management for clean water. The target of service for Jember Regency up to 2025 is 100%, whether serviced by pipe networks or non-pipe networks, and whether serviced by the PDAM or the local Association of Managers and Users of Drinking Water.

Table 2. Planned Systems for Clean Water Services by the PDAM of Jember.

Sub-District	Planned System
Sumberjambe	Gravity from Spring
Sukowono	Deep Drilled Well
Wuluhan	Deep Drilled Well
Tempurejo	Deep Drilled Well
Panti	Water Treatment Plant
Mayang	Water Treatment Plant
Sukorambi	Water Treatment Plant
Silo	Gravity from Spring
Kalisat	Deep Drilled Well

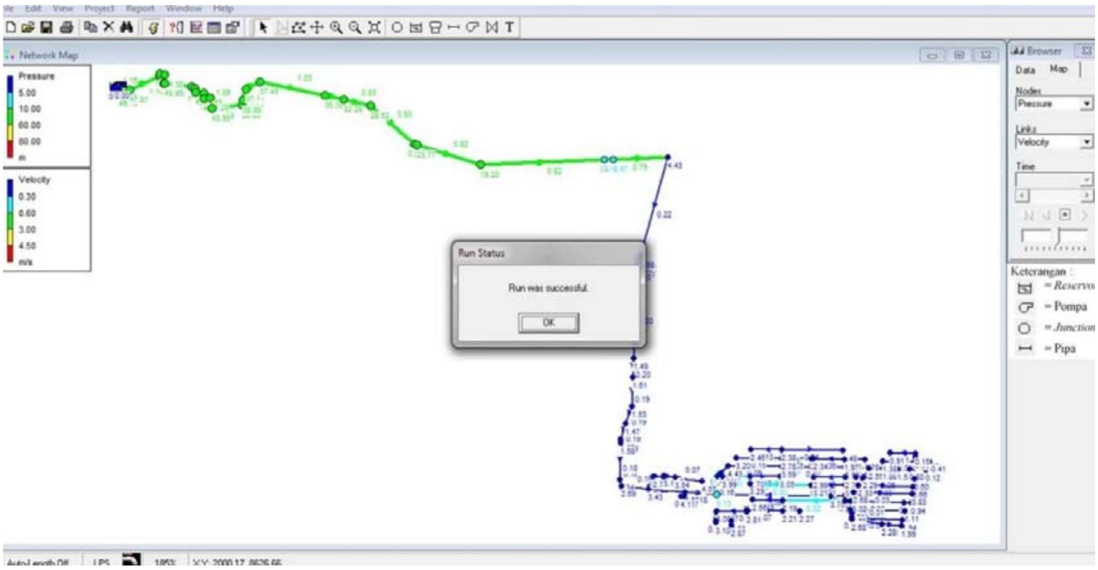

Figure 4. Results of Running the Existing Modelling for the Drinking Water Distribution Network For Kaliwates Sub-District.

Figure 4 is an example of running the modelling for the drinking water distribution network using the EPANET 2.0 software for Kaliwates Sub-District (one of the Sub-Districts of the City of Jember, which is also one of the three Capital Sub-Districts). Results of running the modelling showed that junctions that are coloured dark blue have pressures ranging from 0-5 m, light blue have pressures ranging from 5-10 m, and green have pressures ranging from 10-60 m. For pipes or links, those that are coloured dark blue have velocities ranging from 0-0.3 m/s), light blue have velocities ranging from 0.3-0.6 m/s, and green have velocities ranging from 0.6-3 m/s. According to results of running the model for existing conditions, it was found that the pressure values have not met the requirements of 5-80 m, and velocity values have not met the requirements of 0.3-4.5 m/s.

Table 3 shows the pressure calibration values from the results of the simulation in comparison to the pressure values from on-the-field measurements, and the correlation value is 0.928. Results of pressure calibration indicated that there is a strong relationship between the simulation and on-the-field data, which has a correlation value in the range of 0.8-1 [19].

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Table 3. Pressure Calibration using the EPANET 2.0 Software for Existing Conditions

Calibration Report - Pressure

Statistics | Correlation Plot | Mean Comparisons

Calibration Statistics for Pressure

Location	Num Obs	Observed Mean	Computed Mean	Mean Error	RMS Error
56	1	10.54	12.55	2.015	2.015
59	1	10.19	11.83	1.636	1.636
61	1	8.43	11.17	2.739	2.739
63	1	10.19	11.54	1.347	1.347
77	1	11.25	13.53	2.285	2.285
107	1	7.73	9.00	1.266	1.266
Network	6	9.72	11.60	1.881	1.953

Correlation Between Means: 0.928

Table 4. Discharge Calibration using the EPANET 2.0 Software for Existing Conditions

Calibration Report - Flow

Statistics | Correlation Plot | Mean Comparisons

Calibration Statistics for Flow

Location	Num Obs	Observed Mean	Computed Mean	Mean Error	RMS Error
73	1	0.20	0.42	0.221	0.221
75	1	0.11	0.07	0.036	0.036
76	1	0.18	0.21	0.033	0.033
78	1	0.16	0.19	0.033	0.033
87	1	0.19	0.25	0.059	0.059
101	1	0.10	0.08	0.019	0.019
Network	6	0.16	0.20	0.067	0.097

Correlation Between Means: 0.894

Table 4 indicates the values of the simulation results for discharge calibration that is compared to the discharge values from on-the-field measurements, and the resulting correlation value is 0.894. Results of discharge calibration indicated a very strong relationship between simulation results and on-the-field data, which lies in the correlation range of 0.8-1 [19].

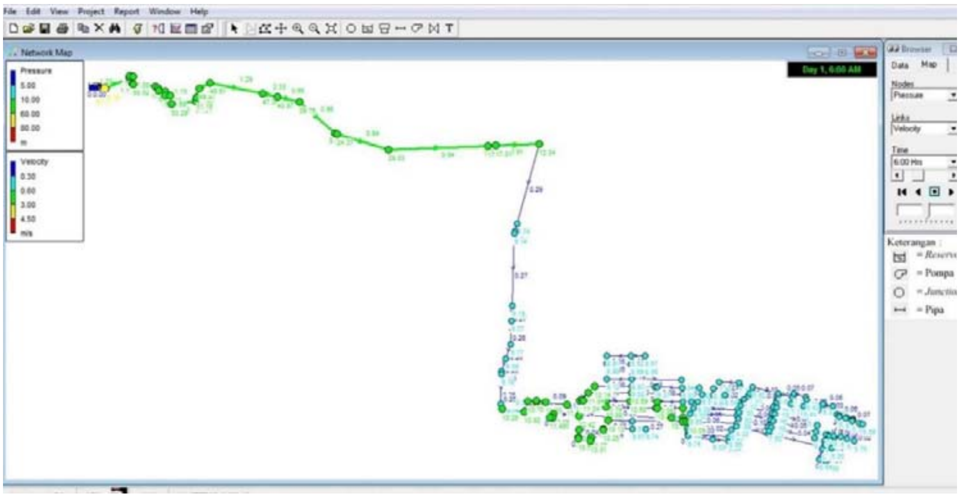

Figure 5. Results of Running the Final Stage Development Modelling for the Drinking Water Distribution Network for Kaliwates Sub-District.

Figure 5 is an example of running the development modelling at the final stage for the drinking water distribution network for the Kaliwates Sub-District. Results of running the modelling showed that junctions that are coloured light blue have pressures ranging from 5-10 m and green have pressures ranging from 10-60 m. Meanwhile, for pipes or links, those that are coloured light blue have velocities ranging from 0.3-0.6 m/s and green have velocities ranging from 0.6-3 m/s). According to results of running the model for the final development stage conditions, it was found that the pressure values have met the requirements of 5-80 m, and velocity values have met the requirements of 0.3-4.5 m/s. The running of the model for this condition involved the addition of a new spring to fulfil the required standards for pressure and velocity.

4. Conclusions

a. The water needs for development at stage 1 (2015-2020) is 329,128,670 litres/day, while for development at stage 2 (2020-2025) is 343,658,120 litres/day.

b. The level of service is adjusted to the stages of Drinking Water Supply System development, which for stage 1 (2015-2020) is planned to be 80% and for stage 2 (2020-2025) is planned to be 100 %.
c. The potential for raw water, in order to anticipate the fulfilment of additional discharge for the PDAM of the City of Jember in the future, includes 16 watersheds, 1,670 inventoried springs and 285 non-inventoried springs, and several scattered groundwater channels.
d. Hydraulic analysis using EPANET 2.0 software resulted in pressure values of 5-80 m and velocity values of 0.3-4.5 m/s, which have fulfilled the requirements.

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