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Domestic Water Distribution Planning from Springs in Jatimulyo Village, Girimulyo District, Kulon Progo

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Abstract During the dry season, most of the springs in Jatimulyo Village deliver less water. This condition causes difficulties for people in the area. Only two springs supply sufficient water for distribution. Therefore, it is necessary to optimize the water distribution from the two springs, Mudal and Sumitro. This study aims to provide an alternative technical plan for the distribution of domestic water and to provide recommendations in the distribution and regulation of the use of water from the Mudal and Sumitro springs to the local authority and community in Jatimulyo Village. The distribution system relies on gravity so that it does not require any pump. This study has conducted using the hydraulic equation for water flow through a pipe to analyze the design water discharge required for each reservoir. For water distribution planning, counting the number of houses that will be served was conducted using Google Earth imagery. The results of this study indicate that from the Mudal spring, water distribution pipelines can cover 282 houses, with a total required water discharge of 1,632 liters/second. For the Sumitro spring, the first alternative scheme can serve 161 houses and requires 0.932 liters/second water discharge. As for the second alternative, it is estimated to be able to serve 138 houses with a total required water discharge of 0.799 liters/second. It is necessary to measure all spring discharge every month. It will help determining the fluctuation of the discharge of each spring.

1. INTRODUCTION

Jatimulyo Village is administratively located in Girimulyo District, Kulon Progo Regency. Based on the Jatimulyo Village Medium-Term Development Plan (RPJMDes) 2019, during the rainy season, the flow of water from small springs around Jatimulyo village joins the flow from bigger springs, forming small rivers with clear water conditions. Between these streams, a large creek flows from the Mudal and Sumitro springs.

During the dry season, most of the springs in the village deliver less water or become dry. It caused difficulties for people who live in Jatimulyo Village to get water. Optimization of water distribution of the two large springs, namely Mudal and Sumitro springs, is needed. Currently, the utilization of these two springs is not optimal, so it is necessary to have a better understanding on how to estimate the existing amount of available water, how much the amount of water need, and how to distribute the water to reach a wide coverage area.

Currently, the springs are used for environmentally friendly tourism (ecotourism), and the water are used by the surrounding community by piping water from the springs. One of the ecotourism in Jatimulyo Village is the Mudal River Park. This ecotourism has been managed by the local community (Irsyad, 2020). The Mudal spring water is also used for irrigation of the rice fields around the Mudal River Park (Pratomo, 2019).

In the RPJMDes Jatimulyo 2019, it is written that the clean water facility development/rehabilitation is one of thirteen programs for the people of Jatimulyo Village. Meanwhile, this development plan does not cover any detailed development concept and design. Therefore, this study aims to provide an overview of development and

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alternative technical plan for the distribution of domestic water from the Mudal and Sumitro springs. This study provides recommendations to the Jatimulyo Village authority and the community in the distribution, and regulation of the utilization of water from the Mudal and Sumitro springs.

2. METHOD

The first step of this study is to design a domestic water supply system with a gravity distribution system (without a pump). This system is designed to reduce energy and costs needed to carry water from the springs to the residents' houses. The gravity distribution system can only serve settlements with a lower elevation of the Mudal and Sumitro springs.

2.1 Data Collection Technique

Aerial images taken from Google Earth satellite imageries are used to obtain the images and maps of the Jatimulyo Village parts. Figure 1 shows the aerial imagery of the Jatimulyo Village area. Based on the zoomed version Figure 1, the number of houses, primary pipelines, and the number of reservoirs of the water distribution network from the Mudal and Sumitro springs were identified.

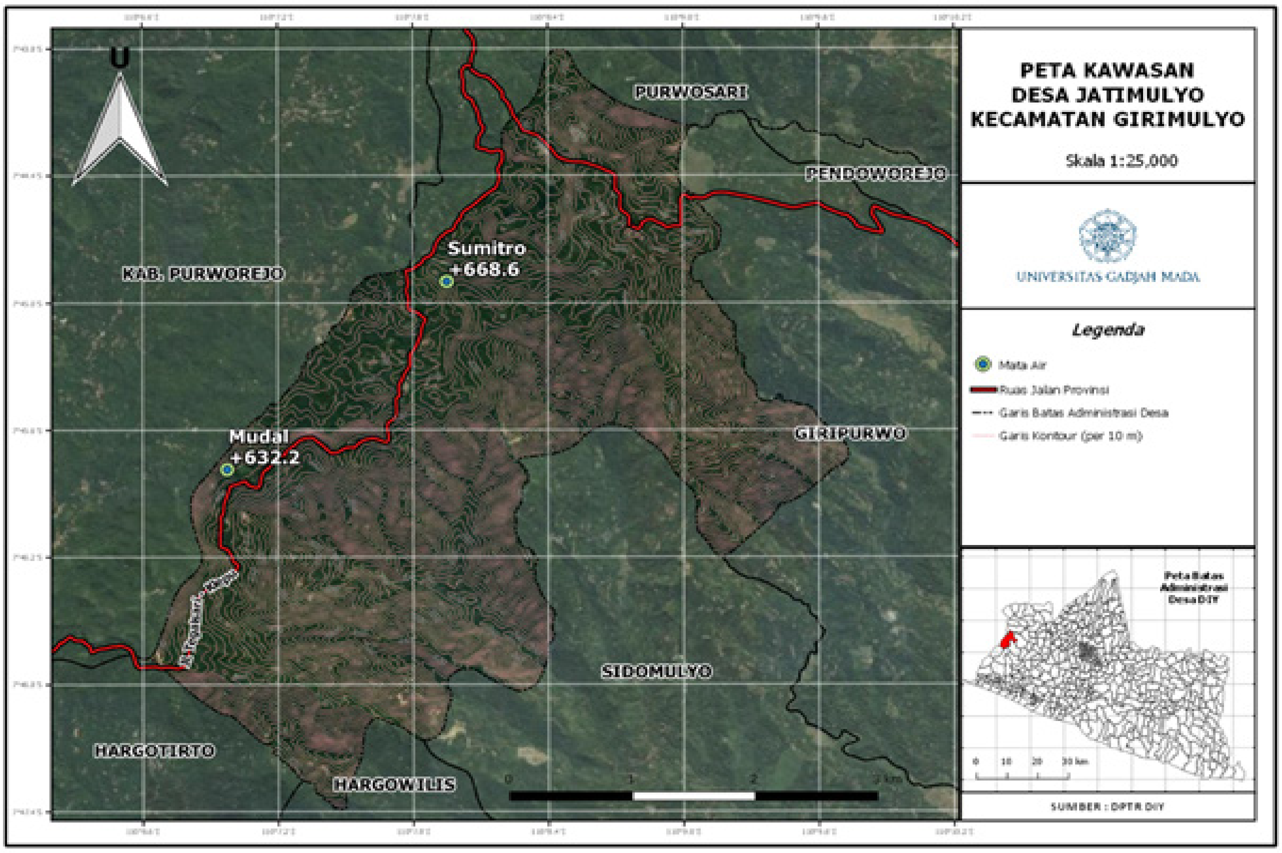


Figure 1. Map and satellite imagery of Jatimulyo Village Area, Girimulyo District, Kulon Prog

2.2 Data Analysis Technique

The method used in conducting the analysis consists of several stages namely (a) the preparation stage for conducting a literature study to search relevant references and secondary data, (b) the research phase for developing a map for the new domestic water distribution network, for calculating the water demand (basic demand) and (c) for analyzing the parameters of water pressure and water velocity on the new domestic water distribution network pipes.

The analysis begins with identifying the location and number of houses or families (KK) to be served. Ideally, this analysis was conducted using a direct survey in the field. However, since there was a Covid-19 pandemic, the houses were identified using Google Earth aerial images. A GIS processing program was used for making the Jatimulyo Village map and for analyzing the pipe network and for estimating the coverage area. Pipe network hydraulic analysis was conducted using MS Excel. The criteria for analysis was based on the Regulation of the Minister of Public Works of the Republic of Indonesia Number 18 of 2007. The number of home residents below the springs was analyzed from the aerial imageries. After the identification of the location and number of residential homes, this study estimated the domestic water needs.

Based on the national standard code SNI-19-6728.1-2002 entitled Preparation of Water Resources Balance, the standard requirement for domestic water for rural areas is of 100 liter/person/day. This number is equivalent to 0.0016 liter/person/second. Ideally, the number of family members in each residence house was observed by a direct survey in the field, however, since the survey could not be conducted, the number was assumed to be five people in each residence house. Therefore, the water requirement per house is 0.0058 liter/family/second. This number was used to estimate the amount of water that must be delivered by the springs.

The hydraulic analysis is conducted for each unit of the distribution pipe network, which can be seen in Equations (1) to (8). This analysis explains how to calculate flow velocity and head loss in each pipe segment. This analysis illustrates the ability of water to flow from an upstream (spring) to a downstream (water reservoir). The equation consists of the elevation difference and head loss between two supply pipe ends for a design discharge. The head loss must be less than the elevation difference for that design water discharge to flow. There is a condition that the head loss is greater than the elevation difference between two supply pipe ends. Therefore, head loss needs to be reduced. For example, selecting a bigger pipe diameter or finding a shorter pipe route can reduce the head loss.

For any type of supply pipe, there are maximum and minimum flow velocity requirements. The type of pipe material used is PVC. For PVC pipes, the highest water flow speed within a pipe to prevent scouring of the pipe walls is 3.0 m/s. The minimum velocity to prevent deposition of suspended solid particles in the pipe is 0.3 m/s.

Hydraulic analysis for the Mudal and Sumitro water distribution networks was calculated using Microsoft Excel worksheets. The analysis based on the maximum and minimum speed criteria, the head loss must be less than the elevation difference, and a residual pressure must be sufficient for water to flow out the downstream end of the supply pipe with an acceptable pressure. 2.2.1 Hydraulic Equations of Water Flowing Through Pipes

Fluid viscosity and wall roughness can cause flow energy loss due to friction. The energy loss can occur along the pipe. For long pipe flows, the frictional energy loss cannot be ignored. The relationship explaining this energy loss was proposed by Weisbach in 1855 and is known as the Darcy Weisbach equation as seen in Equation 1. Equation 1 relates head loss due to the friction coefficient and flows velocity and pipe dimensions:

$$h_f = f \frac{L}{D} \frac{V^2}{2g} \qquad (1)$$

hf is head loss friction inside the pipe, f is friction coefficient of the pipe, L is the length of the pipe, V is the velocity inside the pipe, D is the inner diameter of the pipe, and g is gravitational acceleration. By expressing velocity as a function of the flow pipe section area and discharge, Q (V = 4Q/πD2), the equation become as shown in Equation (2):

$$j = \frac{f}{12.1D^5} Q^2 \qquad (2)$$

j is unit of head loss per meter pipe length. The dimensional analysis of Darcy-Weisbach leads to Equation (3):

$$h_f = \frac{LV^2}{2Dg} \Phi \left[\frac{\varepsilon}{D}, Re\right] \qquad (3)$$

hf is head loss friction along the pipe, Re is the Reynold number, ε is the pipe roughness, and Φ is the function. Comparison of the Weisbach and Darcy-Weisbach equations shows that the friction coefficient f is a function of both relative roughness and Reynolds number. For turbulent flow and for Reynolds values less than 105 (H. Blasius, 1913) in the following Equation (4):

$$f = \frac{0.316}{Re^{0.25}} \qquad (4)$$

Most pipe flows correspond to a transition zone whose coefficient of friction depends on both the Reynolds number and the relative roughness. D. J Zigrang and N. D Sylvester (1982) derive complex relationships which have the advantage of being explicit and accurate for 4 × 103 ≤ R ≤108 and 0 ≤ ε / D ≤ 5 x 10-2, and R is the radius hydraulic in the Equation (5) as follows.

$$\frac{1}{\sqrt{f}} = -2log\left\{\frac{\varepsilon}{3.7D} - \frac{5.02}{R} log\left[\frac{\varepsilon}{3.7D} - \frac{5.02}{R} log\left(\frac{\varepsilon}{3.7D} + \frac{13}{R}\right)\right]\right\} \qquad (5)$$

Another empirical relationship based on polynomial representation developed by G.S Williams and A. Hazen (1933) is as follows in Equation (6):

$$j = \frac{10.68}{C_{HW}^{1.852} D^{4.87}} Q^{1.852} \qquad (6)$$

$C_{HW}$is the Hazen-Williams coefficient, another frequently used relationship is known as the Manning Equation which is expressed as follows in Equation (7):

$$j = \frac{10.29n^2}{D^{16/3}} Q^2 \qquad (7)$$

With n is the Manning roughness coefficient. Singularity head loss can be found at non-smooth pipe joint, discharge measurement devices etc. This head loss that occurs in long pipes is comparatively negligible because of head loss by friction along the pipe is large. The effect of singularity head loss becomes relatively large head loss in short pipes. Singularity head loss can be expressed based on the following Equation 8:

$$h_m = K_m \frac{V^2}{2g} = \frac{8K_m}{\pi^2 g D^4} Q^2 \qquad (8)$$

Where K_m is a constant of the singularity, and h_mis a singularity head loss.

3. RESULT AND DISCUSSION

In this distribution pipe design, only the primary pipe networks (from springs to reservoirs) were designed. The community needs to design the pipeline networks from reservoirs to houses. This planning has produced three design schemes for the water distribution networks. There are two alternative designs for the water distribution networks from the Sumitro springs namely the Sumitro Alternative 1 and the Sumitro Alternative 2, and another design namely Mudal. The number of reservoirs, the number of houses served, and the total water demand discharge of the designed water distribution units are shown in Table 1.

In Figure 2 (a), the Mudal spring will flow through four main reservoirs, namely the main reservoirs A, B, C, and D. From each main reservoir, water will flow to the secondary reservoirs. The number of the secondary reservoirs for each main reservoir is determined based on the contours around the Mudal spring. The number of houses that will received water from each main reservoir or secondary reservoir varies. Main reservoir A will deliver water to 11 secondary reservoirs, main reservoir B will deliver to 4 secondary reservoirs, main reservoir C will deliver 10 secondary reservoirs, and main reservoir D will deliver to 3 secondary reservoirs. The detailed schematic of the pipeline network and reservoir can be seen in Figure 2 (b).

Table 2 provides information in form of number of families or number of houses that are planned to receive water from the Mudal spring. By determining the number of families or the number of houses to receive water, the water discharge demand of each reservoir can be calculated. To determine the number of houses to be served, the Google Earth aerial photo satellite is used.

Table 1. Water Distribution Pipeline Design

Design	Number of storages	Number of houses served*	Total water demand discharge (litre/ second)
Sumitro Alternative 1	4	161	0,932
Sumitro Alternative 2	4	138	0,799
Mudal	32	282	1,632

*estimated based on aerial photography using Google Earth

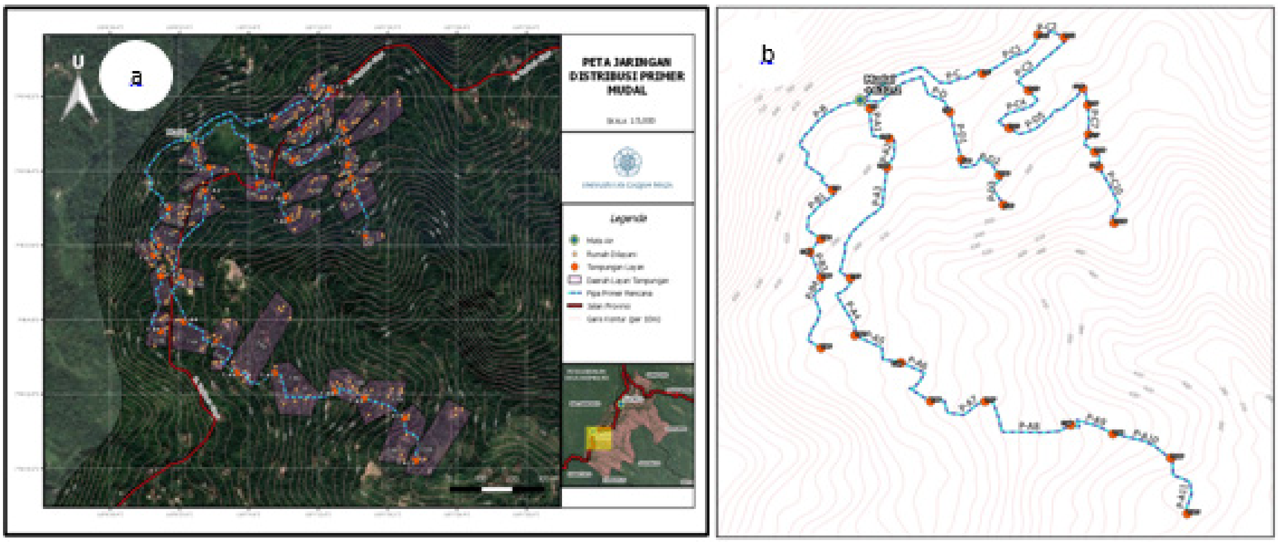
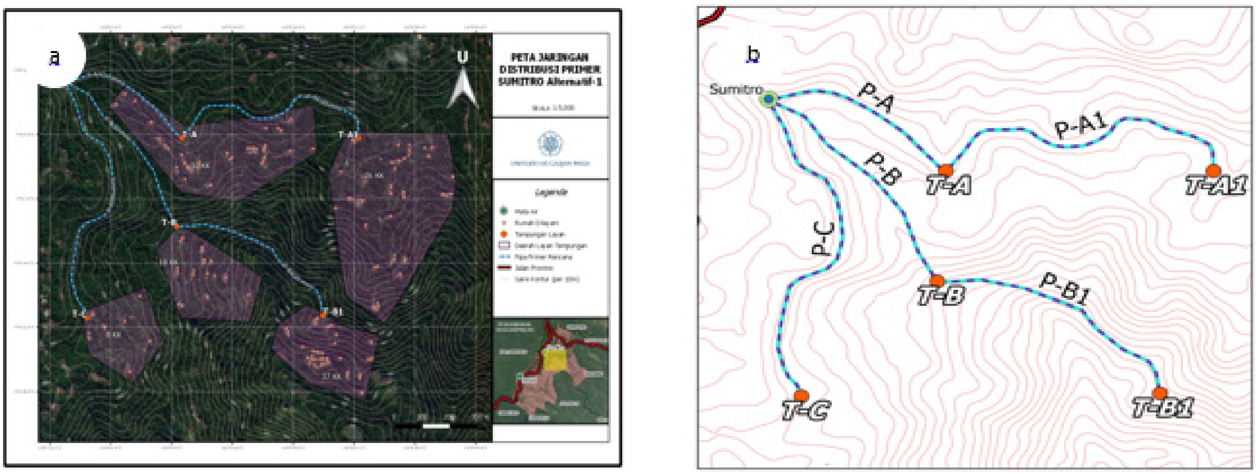


Figure 2. (a), the Mudal spring will flow through four main reservoirs; (b). The detailed schematic of the pipeline network and reservoir

The information about the length of the pipe, either from the spring or the length of the pipe between the reservoirs is shown in Table 3. All pipe segments in the Mudal water distribution satisfy the minimum and maximum velocity criteria where the P-A3 pipe segment has the highest flow velocity of 0.557 m/s (less than the maximum velocity of 3 m/s). The design of the Sumitro primary pipeline resulted in 2 alternative designs.

The Sumitro Alternative 1 design uses less storage than the Mudal design. However, each reservoir serves more houses with a relatively long distance pipes. Figure 3 (a) shows the Alternative 1 of the primary pipe design scheme of the Sumitro spring. Figure 3 (b) describes the design of 5 reservoirs, namely T-A, T-A1, T-B, T-B1, and T-C. There are 2 consecutive pairs of reservoirs, namely T-A with T-A1 and T-B with T-B1.



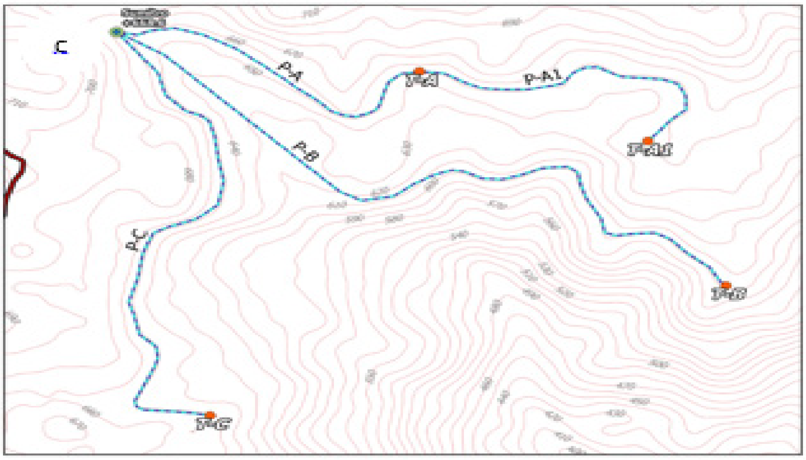


Figure 3. Distribution network map of alternative Sumitro, (b) Distribution network design of Sumitro Alternative 1, (c) Distribution network design of Sumitro Alternative 2

Table 2. Mudal Design Water Demand Analysis

Reservoir code	Reservoir coordinate position			Number of houses served	Requirement discharge for each reservoir
	Latitude	Longitude	Elevation		litre/sec
T-A	-7° 45’47.82”	110° 6’59.16”	622.78	93	0.5382
T-A1	-7° 45'50.10"	110° 7'0.559"	614.67	85	0.4919
T-A2	-7° 45'52.29"	110° 7'0.396"	600.54	77	0.4456
T-A3	-7° 46'0.652"	110° 6'57.71"	578.53	68	0.3935
T-A4	-7° 46'4.986"	110° 6'58.03"	567.24	60	0.3472
T-A5	-7° 46'7.057"	110° 7'1.371"	555.69	53	0.3067
T-A6	-7° 46'9.983"	110° 7'3.499"	539.34	44	0.2546
T-A7	-7° 46'10.00"	110° 7'7.464"	517.33	35	0.2025
T-A8	-7° 46'11.78"	110° 7'13.66"	472.00	28	0.1620
T-A9	-7° 46'12.48"	110° 7'16.72"	456.14	21	0.1215
T-A10	-7° 46'14.30"	110° 7'20.90"	424.48	13	0.0752
T-A11	-7° 46'18.51"	110° 7'22.07"	397.99	7	0.0405
T-B	-7° 45'53.97"	110° 6'56.42"	604.47	42	0.2431
T-B1	-7° 45'57.69"	110° 6'55.60"	596.20	32	0.1852
T-B2	-7° 45'58.66"	110° 6'54.77"	599.45	23	0.1331
T-B3	-7° 46'0.595"	110° 6'55.63"	590.27	12	0.0694
T-B4	-7° 46'5.937"	110° 6'55.59"	572.38	6	0.0347
T-C	-7° 45'45.22"	110° 7'7.347"	611.89	114	0.6597
T-C1	-7° 45'42.26"	110° 7'11.35"	615.38	103	0.5961
T-C2	-7° 45'42.46"	110° 7'13.24"	600.90	93	0.5382
T-C3	-7° 45'46.49"	110° 7'10.65"	595.19	83	0.4803
T-C4	-7° 45'49.32"	110° 7'9.236"	590.41	68	0.3935
T-C5	-7° 45'46.32"	110° 7'14.56"	570.80	57	0.3299
T-C6	-7° 45'47.60"	110° 7'14.94"	563.51	46	02662
T-C7	-7° 45'49.80"	110° 7'14.99"	554.65	35	0.2025
T-C8	-7° 45'51.14"	110° 7'15.45"	544.23	25	0.1447
T-C9	-7° 45'52.29"	110° 7'15.74"	538.80	13	0.0752
T-C10	-7° 45'56.53"	110° 7'16.83"	505.74	5	0.0289
T-D	-7° 45'48.09"	110° 7'4.939"	609.15	33	0.1910
T-D1	-7° 45'51.69"	110° 7'5.785"	597.16	24	0.1389
T-D2	-7° 45'52.88"	110° 7'8.513"	576.21	17	0.0984
T-D3	-7° 45’55.13”	110° 7’8.816”	557.01	9	0.0521

Table 3. Hydraulic Design Analysis of Mudal Water Distribution

Pipe segment code	Length	Diameter	Discharge requirement	Flow velocity	Total head loss	Elevation difference from the reservoir	Residual pressure
-	m	mm	l/sec	m/s	m	m	m
P-A	24.48	39.7	0.538	0.435	0.160	17.00	16.840
P-A1	128.09	39.7	0.492	0.397	0.877	28.00	27.123
P-A2	191.32	397	0.446	0.360	1.778	41.00	39.222
P-A3	504.54	30	0.394	0.557	9.015	55.00	45.985
P-A4	655.34	30	0.347	0.491	16570	69.00	52.430
P-A5	791.65	30	0.307	0.434	23.923	81.00	57.077
P-A6	946.94	30	0.255	0.360	30.292	103.00	72.708
P-A7	1087.64	24.2	0.203	0.440	43.910	125.00	81.090
P-A8	1338.75	24.2	0.162	0.352	55.312	169.00	113.688
P-A9	1440.27	20.5	0.122	0.368	71.692	187.00	115.308
P-A10	1579.47	16	0.075	0.374	97.131	221.00	123.869
P-A11	1722.53	12	0.041	0.358	134.627	246.00	111.373
P-B	317.72	24.2	0.243	0.528	5.459	32.00	26.541
P-B1	471.78	24.2	0.185	0.403	10.518	40.00	29.482
P-B2	510.2	20.5	0.133	0.403	17.303	39.00	21.697
P-B3	571.74	16	0.069	0.345	25.336	46.00	20.664
P-B4	764.23	10	0.035	0.442	55.525	56.00	0.475
P-C	314.04	39.7	0.660	0.533	2.936	26.00	23064
P-C1	473.05	39.7	0.596	0.482	6.638	24.00	17.362
P-C2	538.25	39.7	0.538	0.435	10.161	37.00	26.839
P-C3	719.84	39.7	0.480	0.388	14.024	46.00	31.976
P-C4	879.17	39.7	0.394	0.318	17.359	49.00	31.641
P-C5	1084.01	30	0.330	0.467	28.787	69.00	40.213
P-C6	1120.93	30	0.266	0.377	36.930	75.00	38.070
P-C7	1188.02	24.2	0.203	0.440	51.805	83.00	31.195
P-C8	1243	24.2	0.145	0.315	60.516	93.00	32.484
P-C9	1283.2	16	0.075	0.374	81.184	102.00	20.816
P-C10	1431.39	10	0.029	0.368	120.933	128.00	7.067
P-D	245.4	24.2	0.191	0.415	2.775	30.00	27.225
P-D1	359.68	20.5	0.139	0.421	7.923	41.00	33.077
P-D2	490	16	0.098	0.489	20.423	62.00	41.577
P-D3	568	10	0.052	0.663	65.231	82.00	16.769

Each segment of the primary pipe is designed with a downward slope to avoid the pipe that goes up and down which is at risk of air trapping in the pipe. In the P-B and P-B1, the slope of the pipes is quite high due to the high difference in elevation to the springs. Table 4 shows the results of the analysis of the water demand for each reservoir in the Alternative 1 of the Sumitro water distribution pipeline network. Table 5 shows the results of the hydraulic analysis of each pipe in the Alternative 1 of the Sumitro water distribution pipeline network.

Table 4. Alternative 1 of Sumitro spring water demand analysis

Reservoir code	Reservoir coordinate position			Number of houses served	Requirement discharge for each reservoir
	Latitude	Longitude	Elevation		litre/sec
T-A	110° 8’10.81”	-7° 45’0.391”	659.33	83	0.480
T-A1	110° 8'31.70"	-7° 45'0.406"	650.21	41	0.237
T-B	110° 8'10.16"	-7° 45'10.24"	582.45	65	0.376
T-B1	110° 8'27.53"	-7° 45'20.23"	501.56	42	0.243
T-C	110° 7’59.54”	-7° 45’20.50”	648.93	13	0.075

Table 5. Hydraulics analysis of Alternative 1 of the Sumitro water distribution pipeline network

Pipe segment code	Length	Diameter	Discharge requirement	Flow velocity	Total head loss	Elevation difference from the reservoir	Residual pressure
-	m	mm	l/sec	m/s	m	m	m
P-A	508.06	42.7	0.481	0.336	1.93	6.88	4.948
P-A1	822.52	30	0.237	0.335	6.83	19.36	12.532
P-B	645.34	20	0.377	1.200	59.06	85.18	26.116
P-B1	677.24	20	0.243	0.773	87.85	166.53	78.681
P-C	953.36	16	0.075	0.373	15.36	20.23	4.872

In the Alternative 1 of the Sumitro design, all pipe segments satisfy the minimum and maximum velocity criteria where the P-B pipe segment has the highest flow velocity of 1.2 m/s (less than 3 m/s). The remaining pressure at the end of the pipe segment still meets the criteria. However, it is necessary to pay attention to the P-B1 segment where the residual pressure is quite high, namely 78.68 m. If the residual pressure needs to be reduced, pressure release can be carried out in the P-B1 pipe or in the T-B reservoir which is the P-B1 segment pipe.

In the Sumitro Design Alternative 2, four main reservoirs will be used to distribute and serve the houses based on distance and elevation. The design scheme of the primary channel and the main reservoir of the Sumitro spring can be seen in Figure 3 (c). The design of the distribution network scheme of Alternative 2 the Sumitro water distribution is divided into 3 primary channel networks. The first primary channel network is the PA network which connects the Sumitro spring to the first reservoir, namely T-A. From the T-A reservoir, it is then reconnected to the P-A1 primary channel network to be connected to the T-A1 main reservoir. The second primary network is the P-B primary network which connects the Sumitro springs to the T-B main reservoir. The T-B main reservoir is the one that is farest from the Sumitro spring. The third section of the channel network is the primary channel P-C which connects the sumitro springs to the T-C reservoir on the south side of the Sumitro springs.

The results of the analysis of water requirements in each Sumitro Alternative 2 design reservoir are presented in Table 6. The demand discharge for each reservoir varies. It depends on the number of households that will be served and distributed through the pipeline network. The results of the hydrological analysis on the Sumitro Alternative 2 design pipeline are presented in Table 7.

Table 6. Sumitro Alternative 2 water demand analysis

Reservoir code	Reservoir coordinate position			Number of houses served	Requirement discharge for each reservoir
	Latitude	Longitude	Elevation		litre/sec
T-A	-7° 44'58.14"	110° 8'15.36"	651,80	48	0,278
T-A1	-7° 45'2.944"	110° 8'29.18"	647,06	24	0,139
T-B	-7° 45'15.72"	110° 8'33.35"	601,65	45	0,260
T-C	-7° 45'26.58"	110° 8'3.162"	651,84	45	0,260

Table 7. Hydraulic analysis of Sumitro Alternative 2 design

Pipe segment code	Length	Diameter	Discharge requirement	Flow velocity	Total head loss	Elevation difference from the reservoir	Residual pressure
-	m	mm	l/sec	m/s	m	m	m
P-A	685.81	39.7	0.481	0.389	3.77	15.89	12.12
P-A1	515.92	30	0.237	0.335	7.88	21.54	13.65
P-B	1524.90	39.7	0.452	0.365	7.27	67.44	60.16
P-C	1198.16	39.7	0.481	0.389	6.73	17.72	10.98

Based on the hydrological analysis of the primary pipeline network, the Sumitro Alternative 2 design has satisfied the criteria for the minimum and maximum water flow velocity limits for each segment of the primary channel to the reservoir. Each pipeline network shows a flow velocity of 0.335 m/s to 0.389 m/s with the largest residual pressure in the P-B channel is of 60.16 m.

The results of the analysis and report on water distribution planning from the Mudal and Sumitro Springs have been carried out and submitted to the Jatimulyo Village staffs on November 12, 2020. Figure 4 shows the submission of the report.

Figure 4. (a) Submission of analysis results and reports documents, (b) Jatimulyo village staffs, (c) listening feedback from the Jatimulyo village staffs, (d) discussion with the Jatimulyo village staffs

4. CONCLUSION

In order to fulfil the domestic water demand of Jatimulyo Village, based on the results of the pipeline network analysis of the Sumitro and Mudal Springs, the detailed design of the pipe networks was avaliable. To meet the domestic water demand of 138 to 161 houses, Sumitro Spring needs to provide water at least more than that estimated numbers, that is 0.932 liter/second.

The Mudal Spring is required to supply the demand of 282 houses, or about 1,632 litre/second. The results of the analysis and design of water distribution are expected to complement to the regional development plan in terms of meeting domestic water for the community in Jatimulyo Village.

It is necessary to measure the spring discharge every month. This will help to determine water discharge availability of each spring, not only for Mudal and Sumitro springs but also for all other springs. Therefore, the community of Jatimulyo Village is able predict the condition of the discharge and the amount of water that can be distributed to each house. The more data obtained, the easier it is to plan and manage the distribution network.

Reports on the results of analysis and distribution planning Mudal and Sumitro springs have been completed and submitted to the Jatimulyo Village staffs. The handover was carried out directly by implementing health protocols while the Covid-19 pandemic was still ongoing.

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