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Spring Water Catchment Building and Water Distribution System for Domestic Needs

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ABSTRACT

The population growth implies that the population's need for clean water tend to increase. Clean water availability is not optimal due to geographical factors and discharge reductions during dry season. This research was conducted to design spring water catchment building and water distribution system at Kalikajar Village, Wonosobo. The population data, water demand, and spring discharge were utilized in this research. The population growth was calculated with arithmetic, geometric, exponential, and logistic method. Then water demand was calculated based on SNI 19-6728.1-2002. The population growth which predictably reaches 5328 people in 2050 will result in increasing clean water demand by 9.68% with domestic water demand of 4.63 L/s. The spring discharge measured at the research location showed an average of 10.80 L/s. Therefore, the spring discharge is able to meet the population needs in the projected year. The spring catchment building was designed with Type B, while three reservoir were designed with the capacity of 7 m^3 each. The water distribution is designed with gravity system because the elevation difference between the spring and the village is more than 10 m. The PVC pipeline used diameter of 100 – 150 mm, with total length of 11843 m. The design meets the calculated requirement and could be implemented.

1. INTRODUCTION

The population tendencies to grow have always been depended on the place where it lives. As food is necessary for human to live, population can never actually increase beyond the lowest nourishment capable of supporting it (Stimson *et al*., 2018). There are implications regarding to population grow such as, urban land use increase (Weber & Sciuba, 2019), climate change (Okello *et al*., 2015), and water scarcity (Kummu *et al*., 2016).

The problems to provide clean water have been quite challenging, especially in the place where the infrastructures were not well developed. Based on Pabilang *et al*. (2023) one of the problem of water supply such in the hilly-village area is that it could not be utilized to all area due to lack of infrastructure. Furthermore, according to Omarova *et al*. (2019) problem concerned the water consumption includes inconvenience of the sources resulting in poor estimation regarding quality of the water from wells, open sources, and tanked water.

Regardless to the challenges, such hilly area has potentials to provide clean water source. Based on Khadka & Rijal (2020) clean water source like spring become the major source as the groundwater in the hills and mountains is manifested as springs. Water springs were often to be the main of water security system in the mountainous area (Masitoh & Rusydi, 2019).

Providing clean water is one of the essential factor for achieving the sustainable development goals (SDGs). In an effort to utilize springs optimally and sustainably, appropriate steps are needed, including the formulation of strategies and preparations regarding to spring management program as well as adequate institutional support (Prastowo, 2008). Based on Lufira *et al*. (2012) the development planning for a clean water distribution needs to consider optimization from technical perspective.

In order to utilize spring water as a source of clean water, there are two major problem that should be considered at Kalikajar Village ; the protection of the spring and the infrastructures to distribute the water to the community. Therefore, this research aimed to design water distribution infrastructure by considering the spring water sustainability.

2. MATERIALS AND METHODS

2.1. Place and Time

This research was conducted in Kalikajar Village (Figure 1) in 2022. The trend of population growth in Kalikajar Village shows that the water demand will increase. Based on the data from the Wonosobo Central Bureau of Statistics (BPS, 2022), since 2010 to 2020 the population in Kalikajar Village increased from 4690 people to 4824 people. In general, clean water supply in Kalikajar Village is carried out with water sources from the river. However, the distribution was not optimal due to geographical conditions and water discharge reductions during dry season. One of the potential source of clean water source in Kalikajar Village is springs. This water source has not been utilized by local people, hence in the future it needs a sustainable development.

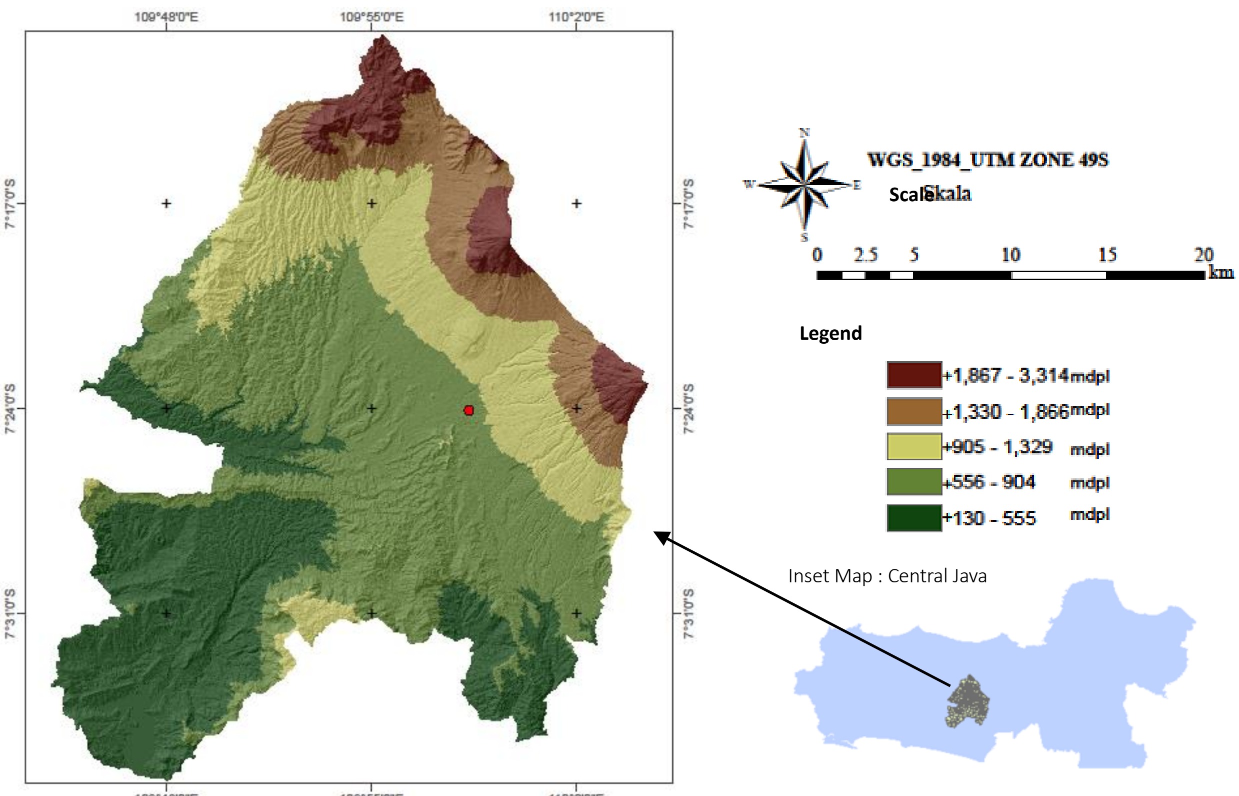

Figure 1 Research location (red point)

2.2. Material

Materials in this research include software such as AutoCAD, ArcGIS, and EPANET 2.0. The AutoCAD software was used to design technical drawing for the design and ArcGIS software was used to make map such as research location map and contour map. The software EPANET 2.0 was used to perform hydraulic pipeline analysis. Primary data was obtained by measuring the spring discharge while secondary data about population was collected from Central Agency of Statistics (BPS).

2.3. Required Data

The population projection was conducted based on arithmetic, geometric, exponential, and logistic method. The result of the population projection analysis was selected based on the highest correlation coefficient. The next analysis was conducted by calculating the need for clean water based on BSN (2002). The maximum daily discharge and peak hour discharge requirements then were plotted through water demand graphic. The water utilization in the year of 2023 and 2050 were plotted to predict the changes of water needs.

The hydrogeological map from Directorate of Geology and Environmental Management (Direktorat Geologi dan Tata Lingkungan, 1985) was used to specify the spring type and class based on its classification. The results were used to analyze feasibility of the spring water for domestic needs. Field observations were conducted to determine the type of spring at the location. Measurements of spring water discharge was carried out directly using the volumetric method. The results of the analysis would determine whether the discharge is able to fulfil the water needs.

2.4 Structural Design

The research flowchart was shown in Figure 2. Piping analysis was carried out to determine the appropriate sizes of the distributing pipes of the clean water. Further calculations were carried out to determine the head loss in the pipe, including minor head losses. The node and water conduit were designed based on the contour map. The flow simulation was tested using EPANET 2.0 software. Hydraulic pipe analysis was then examined based on the regulation from Ministry of Public Works.

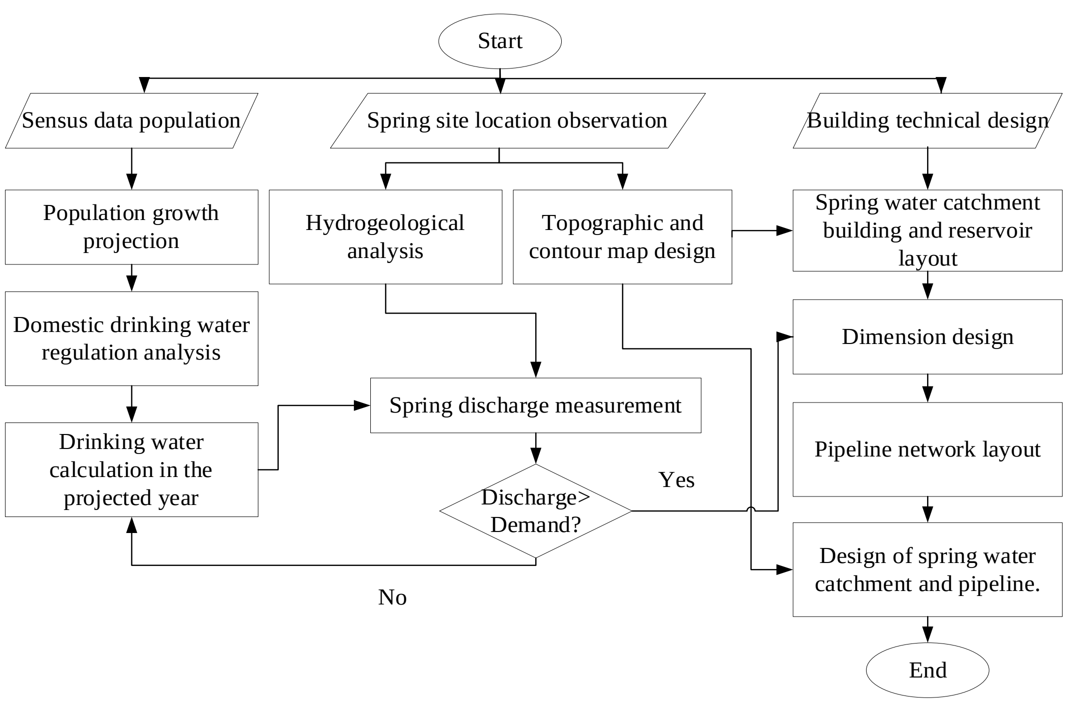

Figure 2. Research flowchart

Further design was carried out to develop the dimensions of the spring catchment building and reservoir. The design of spring catchment building refers to the regulation by the Ministry of Public Works and Housing. The reservoir was designed with the mass curve method. The effective volume of the reservoir was then determined. The reservoir placement was divided into several locations closest to the community houses.

3. 3. RESULTS AND DISCUSSION

3.1 Population Growth Projection

The population growth is a scientific calculation to predict the number of people that could live in the future with the assumption that there is no death, birth, and migration (Widayani, 2016). The population projection using arithmetic, geometric, exponential, and logistic showed that the number of people in 2050 were 5226, 5629, 5328, and 5199 respectively. The coefficients of determination calculated, using the population data from 2010 to 2020, were 0.55, 0.55, 0.58, and 0.56 for arithmetic, geometric, exponential, and logistic method respectively. The population growth projection graph can be seen in Figure 3. A high coefficient of determination indicates the suitability of the projection model that can describe population growth close to the original data (Sugiyono, 2016). In this case, population projection using the exponential method had the highest coefficient of determination, so this method was used for the population projection in 2050.

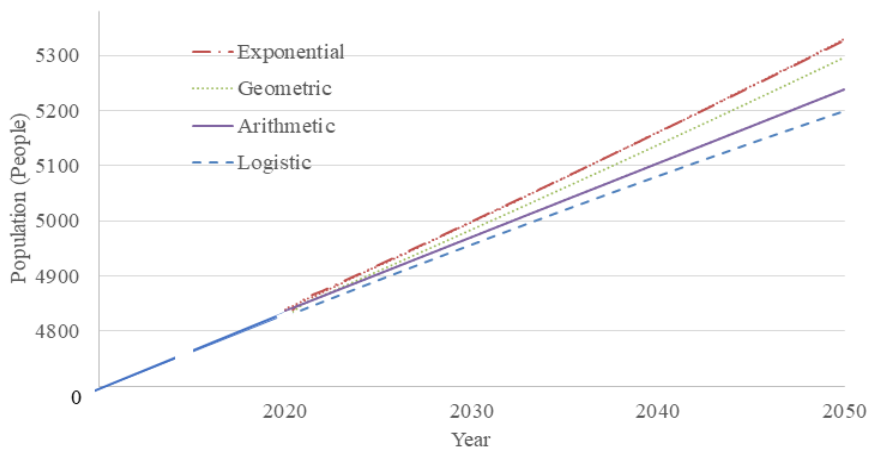

Figure 3. Population growth projection of Kalikajar Village

3.2 Domestic Water Demand

Water distribution in pipeline network could be designed by calculating water demand and peak hour discharges (Nggadas, 2014). Based on BSN (2002) daily water consumption for rural area is 60 L/person. The maximum daily discharge and peak hour discharge coefficient based on the Directorate General of Public Works (1986) is 1.25 and 2 respectively. Preliminary domestic water demand calculation depicted in Table 1 showed that the total domestic water demand will increase about 0.8 L/s or 9.5% during the period from 2022 to 2050. This tendency of growing domestic water demand are shown in Figure 4. From the calculation results, in projected year of 2050, a peak hour discharge of 9.26 L/s and total domestic demand of 4.63 L/s was obtained. The result of this subtraction was used to calculate reservoir capacity.

3.3. Reservoir

Reservoir is used to stabilize the out flow, pressure, and for emergency needs (Sofia *et al*., 2018). Based on the subtraction result between peak hour discharge and water supply, reservoir has to keep 4.63 L/s discharge. In order to find the specific time when people use water mostly throughout the day, the graph of actual water usage was observed. The recorded daily water used is plotted in Figure 5.

Table 1. Domestic water demand and peak hour discharge in 2050

No	Description	Value
1	Populations	5328 people
2	Service	100 %
3	Consumer	5328 people
4	Domestic water consumption	60 L/d/person
5	Domestic water demand	319701 L/d
6	Average demand	3.70 L/s
7	Head loss (25 %)	0.93 L/s
8	Total domestic water demand	4.63 L/s
9	Maximum daily discharge	5.78 L/s
10	Peak hour discharge	9.25 L/s

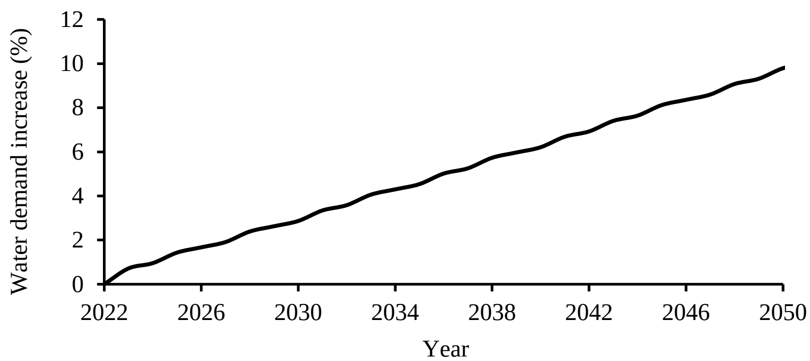

Figure 4. Domestic water demand increase

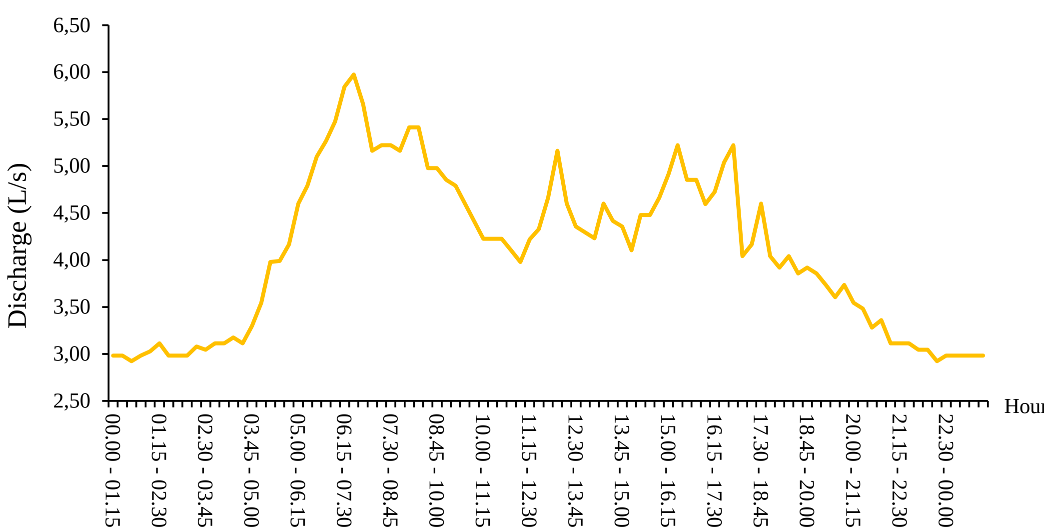

Figure 5. The daily demand pattern

The water consumption was started at 03:45 in the morning, and increased until it reached the peak at 07.30, due to the morning domestic activities, such as laundry, cooking, and bathing. The duration of this busiest time is 75 minutes, and mostly happened from 06.15 to 07:30. Regarding to the design in 2050 the reservoir capacity has to be designed based on the predicted water pattern at that year. The predicted water pattern at that year are shown in Figure 6.

The effective storage capacity has to keep 4.63 L/s for 75 minutes. Therefore, the reservoir volume capacity is designed of 20.79 m^3. Based on Pandjaitan *et al*. (2022) designing the location of the reservoir has to take topographical conditions into account. Regarding to topographical condition and resident housing, the reservoir should be placed in three location where it could hold water in accessible place. The reservoir is planned to be built at three locations and each reservoir has a volume capacity of 7 m^3. The reservoir design is seen in Figure 7.

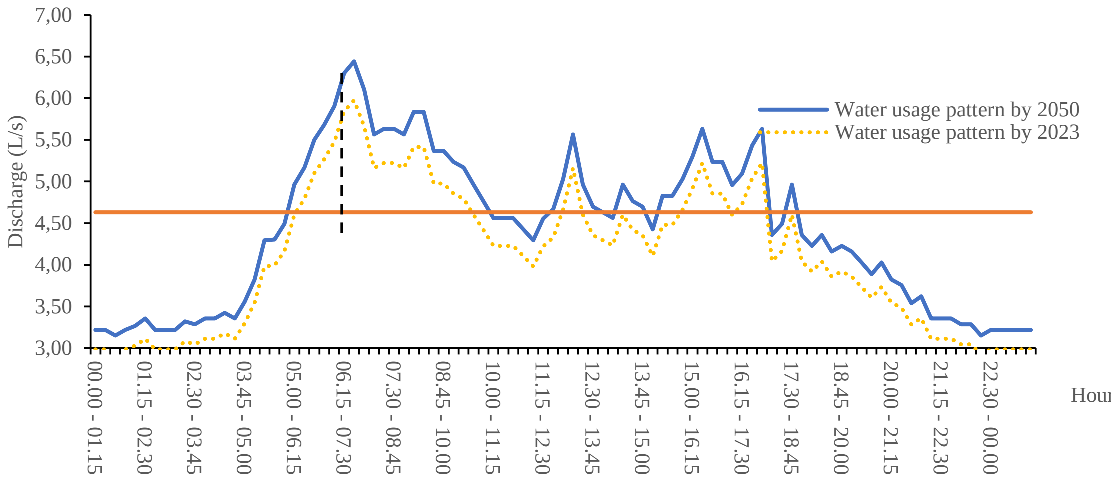

Figure 6. The daily water demand pattern by 2023 and 2050

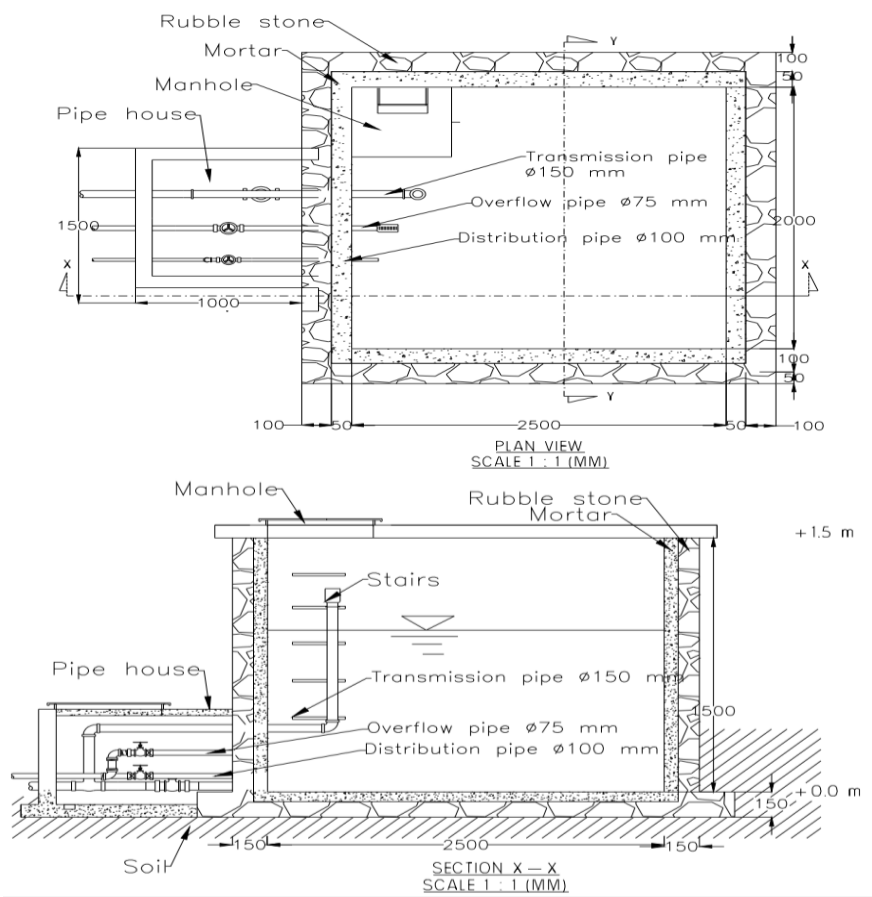

Figure 7. Reservoir design

3.4 Spring Catchment Building Design

Spring water could be produced from rainwater that is accumulated in recharge area (Jordan, 1984). According to Fensham *et al*. (2016), artesian springs can be identified by the presence of plants in the vicinity of the spring at a distance of up to 2 km. At the observed location, there were plants around the spring, particularly bamboo (*Bambusoideae*), banana (*Musaceae*) and coconut (*Arcaceae*). The classification of spring based on discharge was presented in Table 2. Based on Directorate of Geology and Environmental Management (Direktorat Geologi dan Tata Lingkungan, 1985), the type of spring found at the site is an artesian spring with class B. The hydrogeologic map of the location can be seen in the Figure 8. The discharge measurement was then carried out at the observation location. Based on Meuli & Wehrle (2001), spring discharge measurements can be carried out with volumetric method. The results of the spring discharge measurements at the location can be seen in Table 3.

Table 3. The spring classifications based on water discharge produced

No	Spring Classification	Discharge (L/s)
1	Class A	<10
2	Class B	10-50
3	Class C	50-100
4	Class D	100-500
5	Class E	>500

Source : Direktorat Geologi dan Tata Lingkungan (1985)

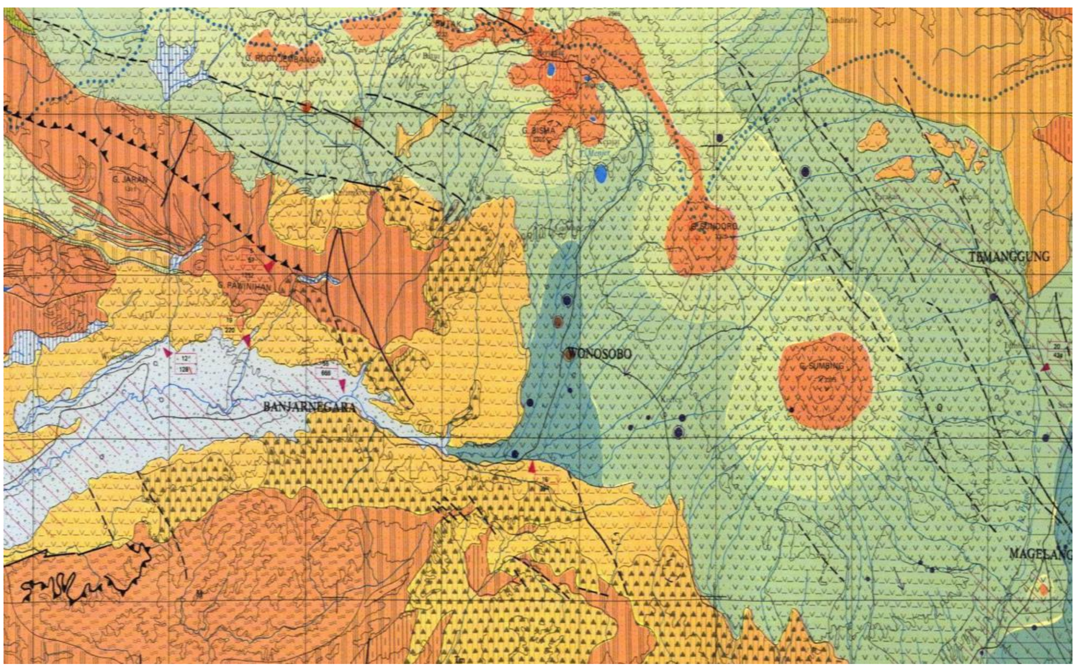

Figure 8. Hydrogeologic map around Kalikajar Village, Wonosobo Regency

Table 3 Spring discharge measurement

	Measurement	Volume (L)	Time (s)	Discharge (L/s)
March 22^{th} 2022	1	14.28	1.25	11.42
	2	14.28	0.98	14.57
	3	14.28	1.14	12.53
June 25^{th} 2023	1	21.00	2.32	9.05
	2	21.00	2.43	8.64
	3	21.00	2.45	8.57
		Average		10.80

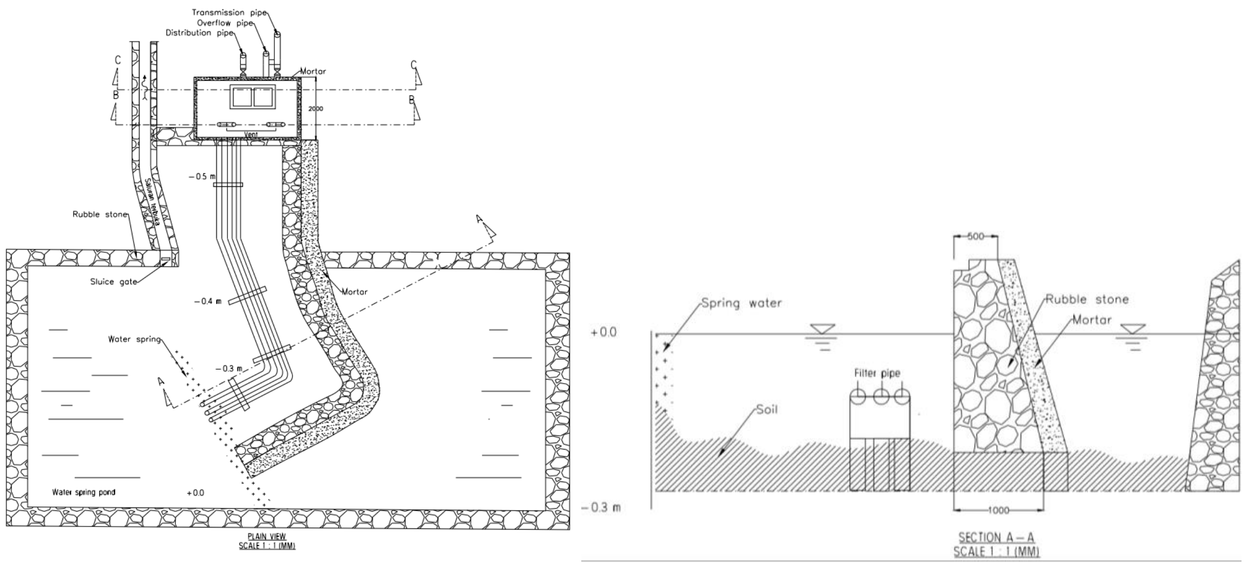

Figure 9. Spring water catchment building design

The measurement results at the site shows that the discharge yielded (10.80 L/s) is greater than the maximum daily water demand in the projection year (4.63 L/s). Based on these results, it can be concluded that the spring discharge is able to meet the needs of the community until the year of 2050. The gravity spring catchment building was designed using Type II B with consideration from the type of artesian springs with medium-high productivity. According to Ministry of Public Works (KemenPU, 2007), a Type B spring catchment building is designed with dimensions of 4 m long, 2 m wide and 1 m height. In this design, 0.5 m height is added as freeboard. The design can be seen in Figure 9.

3.5. Pipeline

Pipe diameter for clean water distribution is regulated by SNI 7511-2011. Based on the discharge that is less than 15 L/s, the appropriate diameter for this design would be 100 – 150 mm. According to this standard, the excavation width to plant the pipe would be designed for 450 mm to 800 mm depth. Based on Nugroho & Utomo (2018), there are three types of water flow inside a pipeline such as minimum, medium, and maximum with the velocity of 0.3 m/s, 1.3 m/s, and 3 m/s respectively. The hydraulics requirements for clean water pipelines regulated by the Ministry of Public Works (KemenPU, 2007) presented in Table 4.

Table 4 The hydraulic criteria of water distribution system

	Hydraulic Criteria	Transmission Pipe	Distribution Pipe
1	Water pressure (MPa)		
	Minimum	0.1	0.05
	Maximum		
	PVC Pipe	0.8	0.6
	DVIP Pipe	1.0	1.0
	PE 100 Pipe	1.2	1.2
	PE 80 Pipe	0.9	0.9
2	Water velocity (m/s)		
	Minimum	0.6	0.3
	Maximum		
	PVC Pipe	4.5	3.0
	DCIP Pipe	6.0	6.0

Source : KemenPU (2007)

Table 5. The discharge applied in the simulation

No	Node	Discharge Simulation (L/s)
1	4	1.00
2	7	1.00
3	14	1.00
4	17	1.00
5	21	1.00
6	26	1.00
7	31	1.00
8	38	1.00
9	50	1.00
Total		9.00

The discharges applied in the simulation are shown in Table 5. Discharge simulation is placed at the farthest node so that it can distribute water to the entire residential area. Pipe network is designed with branched system. Simulation of pipe network planning with EPANET 2.0 can be done based on pressure and velocity analysis. The simulation is done by entering data depending on the water structure and equipment. In the spring catchment building, data is entered in the form of total head pressure and elevation. Furthermore, the reservoir volume data is entered with a minimum requirement of 1 m water height and maximum water does not exceed the safe height. The data entered at the nodes are elevation and discharge. On the pipe, the data entered includes the length, pipe roughness, diameter, and flow direction. In this plan, two valves are installed on the pipe connecting nodes 22-23 and 27-28. Layout in EPANET 2.0 can be seen in Figure 10. Based on the results of this simulation, the total head of water pressure in the pipe is in the range between 50 - 75 m (0.5 - 0.75 MPa). In the simulation, the pipe section connecting nodes 22 - 23 and 27 - 28 is installed with valves so that the pressure generated can meet the minimum standard of 0.1 MPa. The maximum flow velocity in the pipe reached 1.97 m/s and the minimum flow velocity in the pipe was 0.05 m/s. The pressure and velocity can be different based on the fluctuation pattern of water usage. The EPANET 2.0 simulation results can be seen at Figure 11.

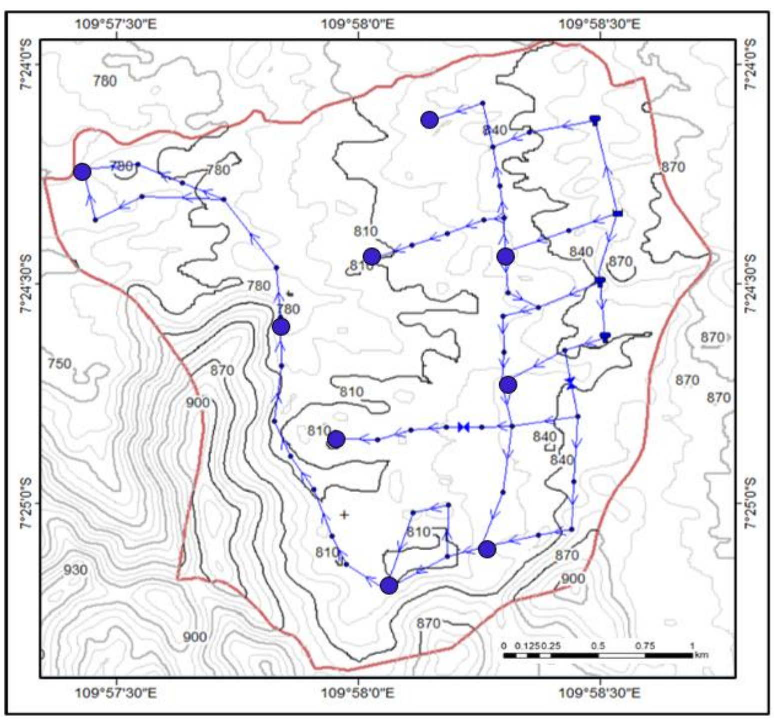

Figure 10. Pipeline design layout in EPANET 2.0

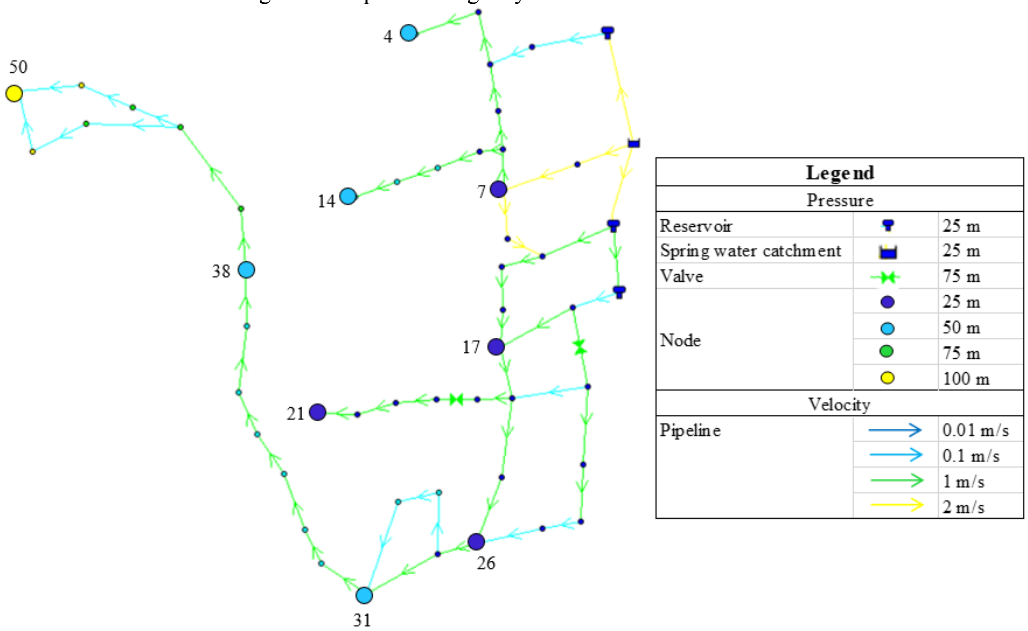

Figure 11. Pipeline network simulation in EPANET 2.0

Based on Karunia (2013) low velocity can be caused by flat topography factors. In order to prevent too low velocity, a pipe with a smaller diameter can be used. Differences in pipe diameter size and material type could affect water pressure and velocity. Total pipeline length for this design reached 11843 m. Based on the simulation using EPANET 2.0, the pressure and velocity showed that this design has meet the requirement, with pressure and velocity that are not fall behind or exceeding the regulation.

To develop water infrastructure in the village need an investment to be realized. As village has budget allocation from the government, the collaboration between people and government is needed. Based on Munawaroh *et al*. (2020) such program has shown successful implementation in developing clean water infrastructure and distribution in the village. The village budget from the government could be prioritized in the form of development rural infrastructure and various developments aimed at empowerment of village communities as they strengthen community welfare (Kusuma, 2017). Further implementation on this research needs several stakeholder such as government and community participation to make whole construction succeed.

4. CONCLUSIONS

The spring in Kalikajar Village produced water discharge with the capacity of 10.80 L/s. The catchment building needs to designed with Type B. The domestic water demand in 2050 is predicted to reach 4.63 L/s, therefore the water produced by spring could meets the demand. Water distribution infrastructure include three reservoirs of 7 m^3 capacity. PVC pipeline with 100-150 mm diameter with total length of 11843 m is required to distribute the water with gravity system. The hydraulic criteria of water distribution system include pressure and velocity that is kept at 0.05 – 0.6 MPa and 0.3 – 0.6 m/s respectively. The design has met the requirements so that the design could be implemented.

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