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The evaluation of water distribution network using Epanet 2.0 followed by the calculation of the population growth and water demands until 2030 (Case study: Comoro, Zone I, Timor-Leste)

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Abstract. In Timor-Leste, supplying clean water is the responsibility of Serviço de Água e Saneamento (SAS). The study area is in Zone I, locates in Comoro, Dili. The formulation of the problems are as follows: 1) what is the existing condition of water distribution network (WDN) in Zone I and does it meet the criteria from the Minister of Public Works No. 18 Year 2007 (No.18/PRT/M/2007)?; 2) how many additional active subscribers until 2030; 3) and how much water needs to be provided by SAS in 2030? **Objectives**: This study aims 1) to evaluate the existing condition of WDN in Zone I and refer it to the regulation of the No.18/PRT/M/2007 based on the pressure and velocity; 2) to calculate the projection population growth until 2030; 3) and to calculate the water needs for 2030. **Method and results**: The development of the WDN begins with projecting the population with 10-year planning using the Geometric, Arithmetic, and Exponential methods. The collection data is through observations in the study area as primary data. Secondary data is collecting SAS data such as: the map of water pipelines, data of piping, pump and reservoir, and consumers' numbers. **Conclusion**: The WDN in Zone I have met the pressure requirement from No.18/PRT/M/2007 with an average flow of 19.57 litres/second. However, the velocity did not meet the criteria; it suggests adding pump stations and reservoirs where the velocity did not meet the standard. The projection population in 2030 is 26,057, with an average flow of 48.46 litres/second.

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1 Introduction

Water is the most crucial element of human life in this world. According to World Health Organization (WHO), approximately 71% of the Earth's surface is water, and only around 3% of the existing reserves on our planet are freshwater [1]. Water is used for various purposes, especially in domestic needs, agriculture, industries, and environmental activities [2]. It is vital to provide clean water to meet the needs of the community to obtain a healthy and decent life, including basic needs for humans with all kinds of activities, among others, required for household needs, such as drinking, cooking, bathing, washing, and other activities [3,4]. Therefore, water must use as effectively as possible to be sufficient for humans' needs and all living things on Earth.

A water supply system that can provide enough clean water is essential for a large city. A water supply system consists of three main components: water sources, treatment, and distribution networks. Water sources can be reservoirs, rivers, or groundwater wells. Treatment facilities can be in the form of water disinfection, standard drinking water, water quality prior to reaching consumers. The distribution network is responsible for delivering water from a source or treatment facility to consumers at sufficient pressure and mainly consists of pipes, pumps, nodes (inlets), valves, and storage tanks. [5,6].

In Timor-Leste, clean water infrastructure and facilities are organized by Serviço de Água e Saneamento (SAS). SAS is a water supply and sanitation company that is responsible for serving and providing clean water needs for all communities in Timor-Leste, which is authorized by the government [7]. To meet the demand for clean water, SAS continues to make service improvements by increasing the equality of water delivered, increasing the amount of production capacity as well as making improvements to the distribution network system. SAS serves all water supplies in every district in Timor-Leste, including Dili the capital of Timor-Leste. In Dili, there are 10 zones of water distribution networks [7]. This research study is done in Zone I, which is located in Comoro. With the increasing need for clean water to customers, it is necessary to conduct an assessment and recalculation of clean water needs in Zone I and the future, so that the public's desire to obtain clean water distribution services from SAS can be maximally fulfilled.

The formulations of the problem in this research are: 1) What is the existing condition of WDN in Zone I and does it meet the criteria from No.18/PRT/M/2007? 2) How many additional active subscribers in Zone I until 2030 and 3) How much water needs to be provided by SAS in 2030 based on the current projections?

The purposes of this study are: 1) To evaluate the existing condition of WDN in Zone I and refer it to the Regulation of the Minister of Public Works No. 18 Year 2007 (No.18/PRT/M/2007) based on the pressure and velocity 2) To calculate the projection population growth until 2030 and 3) and To calculate the water needs for 2030.

2 Method

The location of the research was carried out in Zone 1 of Dili, sub-district of Comoro with a total area of 64,000 hectares (ha) which consists of thirteen blocks but only seven blocks are inhabitants with a total of 1,900 consumers; 1,833 domestics and 67 non-domestics (schools, factories, commercials and others) [7].

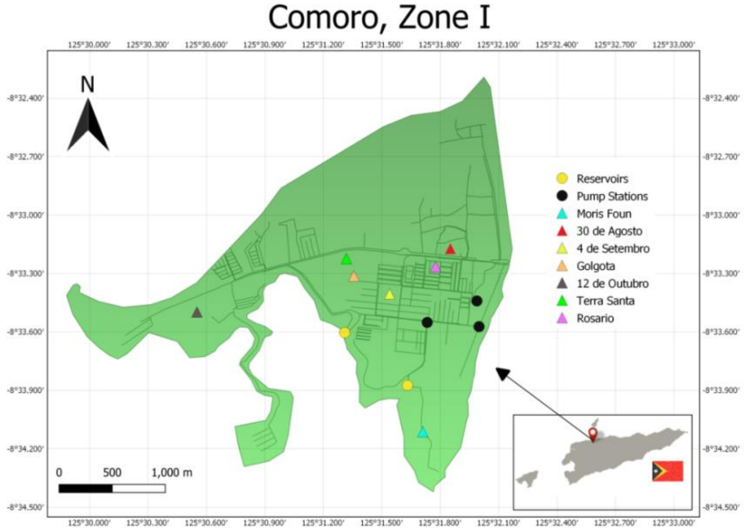

Fig. 1. Map of Comoro, Zone I

Table 1. Number of current consumers in Zone I (2020)

No.	Sub-district	Blocks	No. of Consumers		Total of consumers
			Domestics	Non-Domestics	
1	Comoro	Moris Foun	866	12	878
2		30 de Agosto	541	21	562
3		4 de Setembro	395	14	409
4		Golgota	15	2	17
5		12 de Outubro	12	6	18
6		Terra Santa	3	5	8
7		Rosario	1	7	8
Total			1,833	67	1,900

Source: SAS, 2020

2.1 The data collection techniques

There are two types of data collection techniques for this research: primary and secondary data. Primary data is the observation of the WDN in the service area followed by the contour lines file (kmz) from Google Earth to elevation file (gpx.) on GPS Visualizer then apply it to QGIS to see the elevation of the research site. Secondary data is the search activity through literature reviews, and collecting data directly from SAS such as the map of WDN in Zone I, piping data, pump data, reservoir data, and active consumers for the last 5 years, 2016 to 2020.

2.2 Data processing

After collecting the data and converting the contour lines to elevations, apply all into Epanet 2.0 software to simulate the existing WDN in Zone I then evaluate the distribution network based on No.18/PRT/M/2007.

Furthermore, to estimate the population growth in the future, three methods need to be used; arithmetic, geometric, and exponential. The three methods will then be tested for correlation to get the coefficient value close to number one.

The other step was taken in data analysis of WDN in Zone I, which calculates water demands, fluctuations in water requirements, water supply, and the reservoirs' cumulative contents from 2020 until 2030.

Afterwards, it evaluates the operation of the clean water distribution using Epanet 2.0 software based on the data obtained from SAS; network configuration and self-data; the elevation of the research site. With data input including, water sources, pipe network accessories. The data required in Epanet 2.0 are critical in analyzing, evaluating, and simulating the Epanet-based clean water network. The data inputs required are network map, nodes/junctions, elevations, lengths of distribution pipes, the pipe's diameter, type of pipe used, pump specifications, reservoir shape and size and water demand on each node [8]. After successfully inputting the required data, the program will automatically analyze some of the result data, and the outputs obtained: Hydraulic head for each point, pressure, velocity and headloss unit.

2.3 The projection of population growth

The calculation of population growth projection is a method to determine the estimated number of consumers in the coming years: three methods are used, including the Geometric Method, the Arithmetic Method, and the Exponential Regression Method.

2.3.1 The geometric method

This method predicts data or other events whose development or a fast growth for customer projection purposes. This method is used when the number of subscribers shows a rapid increase over time. This method is appropriate for high population growth and rapid urban development [9].

Formula:

$$P = P0\ (1+r)\ n \tag{1}$$

$$r = P0\,(1\ + n)^{1/n} \tag{2}$$

Where:

P0 = Total population in the nth year

P0 = Number of the current population

r = Population growth rate per year (%)

n = Number of projection years

2.3.2 The arithmetic method

This method is used when periodic data shows the number of increments (absolute number), which is relatively the same every year. This technique is used in cities with a relatively small area, economic growth rate, and low city development [9].

Formula:

$$P_{\boldsymbol{n}} = P(1 - rn) \tag{3}$$

Where:

Pn = Total population in the nth year

Po = Number of the current population

r = Population growth rate per year (%)

n = Number of projection years

2.3.3 The exponential regression method

This method is almost the same as the Geometric Method; the difference is that this method uses numbers [9].

Formula:

$$Pn = Po.e^{\,r.n} \tag{4}$$

Where:

Pn = Total population in the nth year

Po = Number of current population

r = Population growth rate per year (%)

n = Number of projection years

e = Natural logarithm number (2.7182818)

2.3.4. The Correlation Coefficient Test

The selection of the population growth projection method above is based on statistical testing methods based on the correlation coefficient values.

The correlation coefficient is as follows [9]:

$$r = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{\left(n\sum X^2 - (\sum X)^2\right)\left(n\sum Y^2 - (\sum Y)^2\right)}} \quad (5)$$

Where:

r = Correlation Coefficient

n = The amount of years

X = Total population of each year from the base year

Y = Total population per projected year

The value of r is a value close to +1. If r = 0 or close to 0, then the relationship between the two variables is very weak or there is no relationship. If r = 1 or close to 1, then the correlation between the two variables is positive and very strong [9].

2.4 Analysis of calculations with software tools

In the analysis of the Zone I clean water distribution system, calculations are needed. Microsoft Excel 2020 calculates the number of active customers, the average growth of the population, the projected population growth for 2030, average daily rates for debits, pressure, velocity and headloss, fluctuations in water requirements, water supply and the cumulative contents of the reservoir.

The use of Google Earth Pro Edition is to get the location of the area.

The software QGIS is needed to measure the water pipelines and obtain the research site's elevations.

This study's main software is Epanet 2.0, which is needed for pipeline network modelling to simulate water's hydraulic behaviour in a pipeline network. The following assumptions regarding of this study are: 1) the readers will comprehend how the existing condition of WDN works in Zone I; 2) the readers will understand the estimation growth of population in 2030; 3) and the readers will know the amount of water needs to be provided by SAS in 2030.

The scopes of this research are: 1) the evaluation of the clean water distribution system carried out in Zone I area; 2) and the calculation of the number of clean water demands which includes the projection of the addition of active subscribers, the fluctuation in water demands and the cumulative content of the reservoir.

The limitations of this study are: 1) the distribution system analysis only focuses on water continuity; 2) and due to lack of data it is not possible to do second simulation by the population projection.

3 Results and Discussion

The number of active customers from 2015 until 2020 is obtained from SAS. According to World Health Organization (WHO), the number of people per house is averaged 5 or 6 people. In this case, 6 people are used to determine the average number of people per house and the total population.

Table 2. Population of Zone I from 2015-2020

No.	Year of Service	Number of Active Consumers (Houses)	Total Population
1	2015	1,141	6,846
2	2016	1,346	8,076
3	2017	1,457	8,742
4	2018	1,482	8,892
5	2019	1,660	9,960
6	2020	1,900	11,400

3.1 Average Population Growth Rate

The population growth rate is used to assess an area's population growth, which will be used for planning water demand. The population growth rate of Zone I is based on the existing population from 2016 - 2020. An example of calculating the population growth rate is as follows:

The total population in 2015 = 6,846 inhabitants

The total population in 2016 = 8,076 inhabitants

Number of year (n) = 1 year

The population growth rate (r) can be calculated using a formula, for example, the Geometry formula:

$$P_n = P_0(1+r)^n \tag{6}$$

Where:

$$r = \left[\frac{\ln(P_n/P_0)}{1}\right] \times 100\% = \left[\frac{\ln(8076\,)/6846\,)}{1}\right] \times 100\% =$$

So from the calculation obtained the population growth rate (r) = 16.5%

The following are the results of the calculation of the Zone I population growth rate:

Table 3. Average population growth rate of Zone I

Year	Total Population	Differences	Growth rate	Methods		
				Geometric	Exponential	Arithmetic
2016	8,076	0		7,436	7,462	7,436
2017	8,742	666	0.0792	8,077	14,924	8,026
2018	8,892	150	0.0170	8,773	22,386	8,616
2019	9,960	1,068	0.1134	9,529	29,849	9,206
2020	11,400	1,440	0.1350	10,350	37,311	9,796
Total				44,178	111,965	43,092
	Average Growth Rate			0.0862		

3.2 Population Projection of Service Area

In planning the population's clean water needs for the next 10 years, population data is required. Below is the population growth estimation results based on the three methods: geometric, arithmetic, and exponential [9].

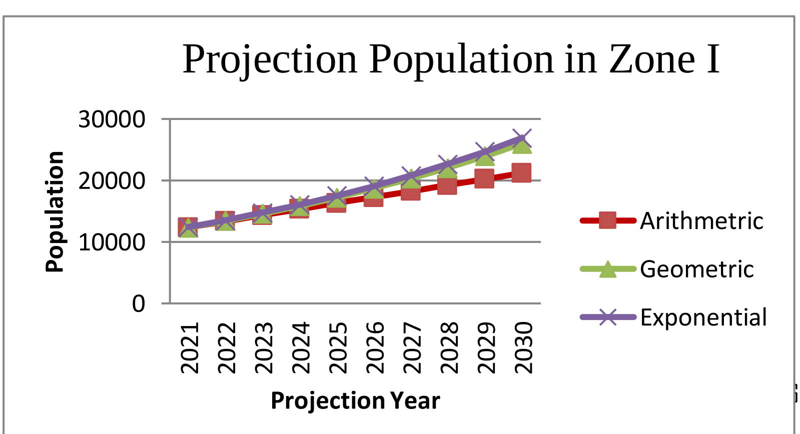

Fig. 4. Population projection graph of Zone I

3.2.1 Correlation coefficient

Figure 4 depicts exponential has the highest population and arithmetic has the lowest result. To determine which method is suitable to use in the following years, the correlation coefficient calculation is carried out. The formula is obtained from equation (6). One of the calculations is shown below:

Table 4. Regression determination data using geometric method

No	Year	n	Total Population (X)	Y	XY	X^2	Y^2
1	2016	5	8,076	7,436	60,052,995	65,221,776	55,307,898
2	2017		8,742	8,077	70,607,467	76,422,564	65,229,914
3	2018		8,892	8,773	78,008,289	79,067,664	76,931,899
4	2019		9,960	9,529	94,907,843	99,201,600	90,733,174
5	2020		11,400	10,350	117,991,055	129,960,000	107,010,343
	Total		47,070	44,165	421,567,649	449,873,604	395,416,141
Correlation Coefficient (r)					0.9683		

Table 5. Conformity Test of the Population Projection

No	Conformity Test	Methods		
		Geometric	Arithmetic	Exponential
1	Correlation Coefficient (r)	0.9683	0.95695	0.95695

From the calculations above, the result shows that the Geometric method has the largest correlation coefficient (r = 0.968324) that is more close to +1, which means that the two variables have the strongest linear relationship [10]. Whereas for the Arithmetic and Exponential method both correlation coefficient is r= 0.95695. Thus Geometric method was chosen for the projection of water demand in Zone I until 2030.

3.3 Projection of clean water demands

The calculation for water demands is based on the population's projection in the planning year and categorized as urban with an average requirement of 100 liters/person/day with a population of less than 20,000 people. This value is taken from the Directorate General of Public Works, 2007 [11].

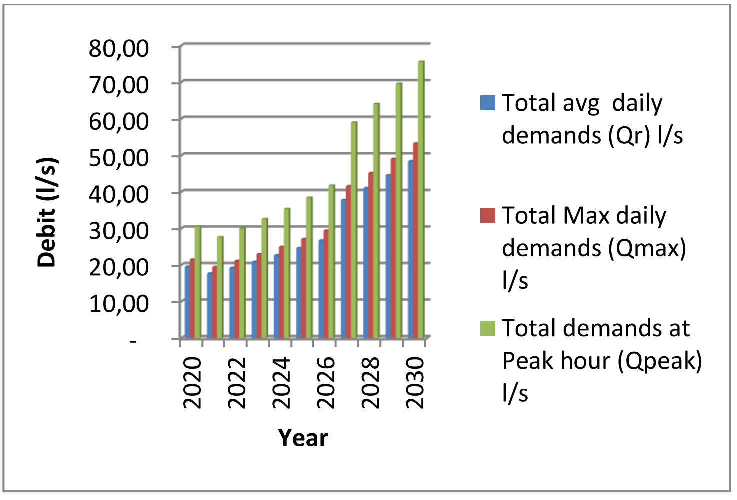

Fig. 5. Projection of clean water demand from 2020-2030

3.3.1 The calculation of fluctuation of water demands

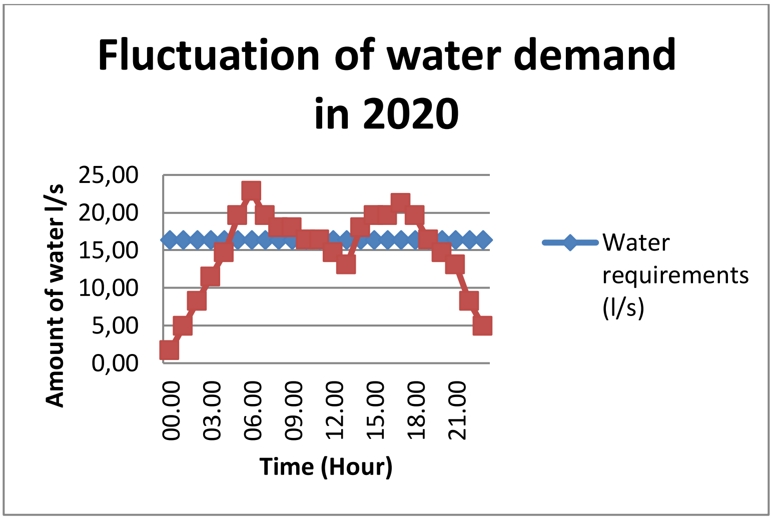

Fig.6 Fluctuation of water demand in 2020

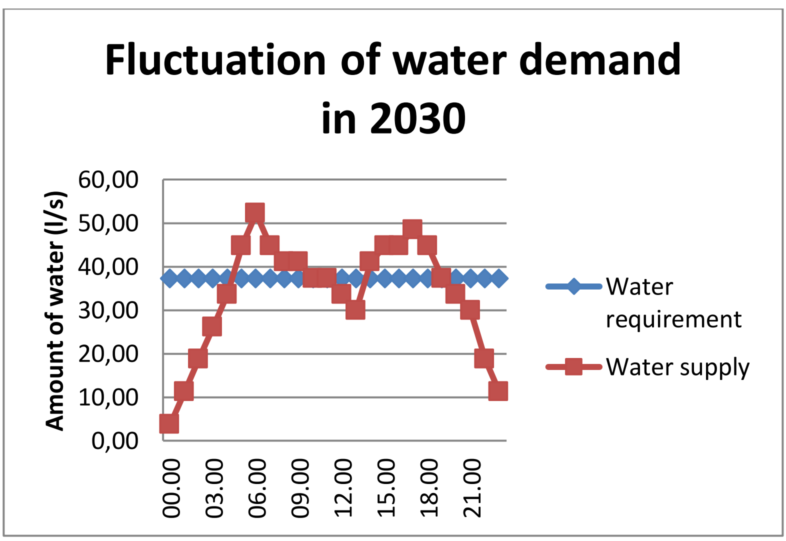

Fig. 7. Fluctuation of water demand in 2030

Multiplier factor is very influential on water needs hourly where it is based on the different water usage patterns of the population. The reservoir's capacity is based on fluctuations in the water needs of the existing service area—the greater the water consumption, the greater the capacity of the existing reservoir [12]. In the cumulative content of the reservoir, the highest figure in 2020 is 40.771 l/s and in 2030 is 100.950 l/s. From the reservoir results, it is necessary to build a reservoir to accommodate water to 8726.4 m3/d (101 l/s). The reservoirs are planned to be circular with a diameter of 53m and a height of 4m.

From Figure 6 and Figure 7, it can be stated the water demand increases from 01:00 to 6:00, the peak hour, which signifies the time when most people wake up in the morning and prepare for their daily activities such as taking a shower, cooking for breakfast, and other activities in preparation for work or school. From 7:00 to 13:00, the water demands decreases, and then it increases again from 14:00 to 17:00. From 18:00 to 00:00, it decreases rapidly, which indicates the lowest water consumption, especially during midnight because this is when most people are not consuming a high level of water, which is probably due to people who are already asleep.

3.4 The existing conditions of the distribution system in Zone I

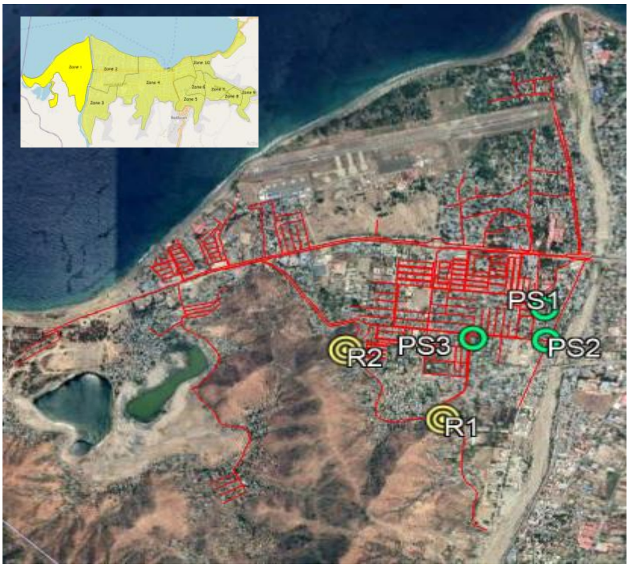

Fig. 8. Water distribution network in Zone I

Figure 8 displays a map of the studied area from QGIS. The red lines represent pipes for the distribution of clean water to the service area, the green circles signify as pump stations and the yellow dots are the reservoirs. In this study area, the community consumes water source from the groundwater.

Table 6. Data of pump station in Zone I

No. Node	Location	Power Speed (watts)	Flow Rate (L/sec)	Head (m)
PUMP 1	Comoro D	95	27	80
PUMP 2	Comoro E	77	17	80
PUMP 3	Comoro C	77	17	80

Source: SAS, 2020

Table 7. Data of the reservoirs in Zone I

No. Node	Location	Type	Height (m)	Water Volume ($\mathbf{m}^3$)	Elevation (m)
Reservoir 1 (R1)	Malinamuk	Rectangular	4	1000	55
Reservoir 2 (R2)	Golgota	Circular	4	600	60

Source: SAS, 2020

3.4.1 Pipe networks

There are four different types of pipes used in Zone I: polyvinyl chloride (PVC), Polyethylene (PE), galvanized steel (GS), and galvanized iron (GI). The pipes' diameter is 50 mm, 63 mm, 80 mm, 90 mm, 100mm, 110 mm, 150, 200 mm, 250 mm, and 300 mm. The length of the pipes varies from 1 m to 1000 m. The pipe diameter is secondary data, while the pipe length for each segment is measured using QGIS by adjusting the scale on the map.

PVC, PE, GS, and GI are used because they are resistant to corrosion, less friction, lightweight, low maintenance cost, and can easily be installed. GS and GI are durable, which can last to more than 25 years in urban areas, whereas in rural areas, they can continue to more than 50 years [13]. However, they can become rusty over some periods, and pipes may begin to erode, leading to a leak and corrosion materials entering the water supply. PVC and PE disadvantages are they are easily damaged and unresisting to high temperatures [13]. Therefore, these pipes need to be investigated at least once a year since Timor-Leste can be warm during the dry season.

3.5 Epanet simulation results

By using the Epanet 2.0 software, you can find out the situation at nodes and pipes for each hour [14]. The following is the result of WDN which indicates the different color of the components during peak hour by using the Epanet software:

3.5.1 The pressure

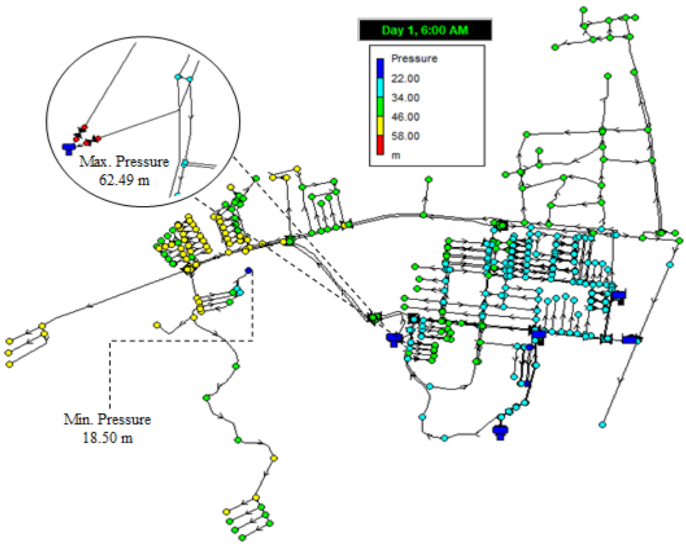

Fig. 9. The simulation results of the pressure on each node during peak hours

From Figure 9, the colors display the ranges of the pressure. The blue conveys the lowest to the highest pressure, which is the red color. Figure 9 illustrates that the highest pressure value during peak hours is at node 404 & 406. The pressures of these nodes are 64.49 m, caused by the location of the nodes which are close to the reservoir. The pressure received at point 53 is the smallest pressure when compared to other points on the network. The low pressure at this node is 18.50 m due to a high elevation of ± 34.89 m.

3.5.2 The velocity

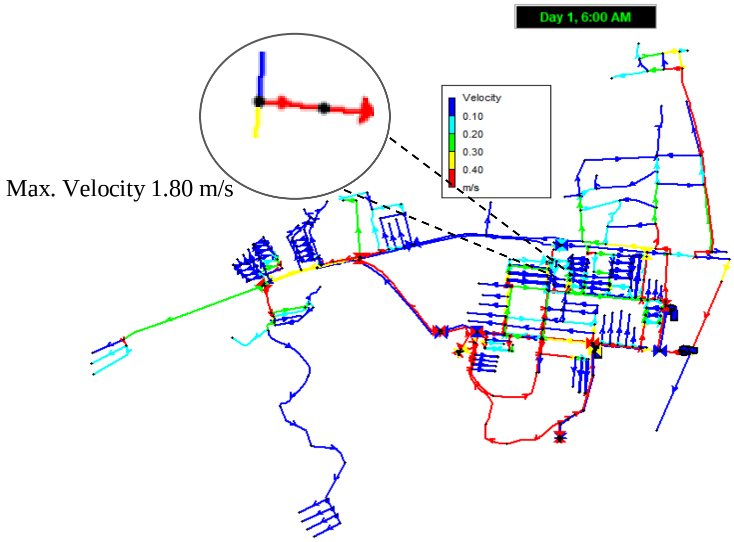

Fig. 10. The simulation results of velocity in each pipe during peak hours

Figure 10 shows that the red pipeline indicates the most significant flow velocity found in pipe 505 of 1.80 m/s with a flow rate of 3.53 l/s. The high velocity is due to the pipe being close to the reservoir (R2). Pipes that have high velocity; the headloss that rises is more significant. The cause is due to friction between the flow and pipe walls [15]. The blue pipelines illustrate as low velocity, which is under 0.20 m/s. The lowest velocity found in this WDN is 0.01 m/s, which is found in several pipes. This is because those pipes are on a flat topography.

3.6 The evaluation of the distribution network

The evaluation of the clean water distribution network is based on criteria designs in the Regulation of the Minister of Public Works no.18 years 2007 concerning implementing of a clean water supply system that covers.

Table 8. The criteria regarding the implementation of clean water supply system

No.	Description	Symbol	Criteria
1	Planning Debit	Q Peak	Peak hour water requirements Q peak = F peak x Q average
2	Peak Hour Factor	F Peak	1,15 – 3
3	Water velocity of the pipe a. Minimum pressure b. Maximum pressure PVC pipe or ACP steel pipe or DCIP pipe	V min V max	0,3 m/sec 6 m/sec 3,0 – 4,5 m/sec
4	Pressure in the pipe a. Minimum pressure b. Maximum pressure a. PVC/ACP pipe b. Steel pipe /CDIP c. PE pipe 100 d. PE pipe 80	h min h max	10 m 60 – 80 m 103 m 12.4 Mpa 9.0 Mpa

Source: Minister of Public Works, 2007

In general, the simulation results with Epanet 2.0 on the WDN ran well and successfully. According to water discharge, the water can flow to all junctions with positive pressure and flow rate. Based on the *Regulation of the Minister of Public Works No. 18 Year 2007* (No.18/PRT/M/2007), from Figure 9, the pressure is in the range of 18.50 m – 64.49 m, which indicates that the pressure at each node has met the design criteria from No.18/PRT/M/2007 which is between 10 – 80 m. However, one criterion still needs to be attained: velocity, as shown in Figure 9. Figure 10 shows that most of the pipes have water velocity below the minimum standard of 0, 3 m/s from the Regulation of No.18/PRT/M/2007, and only a few pipelines (yellow and red lines) have met the criteria (0.3m/s). This is because the pipe diameter size is larger than the flow rate in the pipe. If the velocity rate is below the standard, it needs to be adjusted; otherwise, it would not deliver adequate water to the consumers.

To accelerate the velocity, it needs to reduce the pipe's diameter and add more pump stations and reservoirs at the location where the velocity did not meet the criteria; thus, it can meet the standard and run optimally in Zone I.

SAS must obtain data of population on each block so that the water demand can be calculated accurately and other data such as water loss. Furthermore, the government of Timor-Leste must find other water sources and not highly dependent on groundwater because it does not last forever, which may leave the country in drought in the future or may increase the extent of seawater intrusion into aquifers.

4 Conclusions

Overall, the simulations show that water pressure has complied with No.18/PT/M/2007 regulation within the standards of 10-80 m. However, the water velocity still needs improvements since it did not encounter the criteria.

For the projected the year 2030, the results of the calculation of water requirements are: the average daily total requirement (Qr) is 48.46 l/sec, maximum daily demands (Qmax) is 53.30 l/sec, and total demands at peak hour (Qpeak) is 75.60 l/sec. With the population projection results based on the geometric method, it is predicted to supply enough water to approximately 26,057 people in the service area.

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