Tittle: Hydraulic performance Analysis of water supply distribution network using water GEM v8i

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Abstract

About concern to the growing population of the world, need water is increased gradually. On the other hand, the restrictions on freshwater resources, including surface and sub-surface water and their pollution by either point or non-point source pollutants have added the concerns over the health of drinking water. The study was evaluated the hydraulic analysis of the water distribution network using water GEMS v8i. which is used for modeling and Simulation of hydraulic parameters in the distribution networks. The hydraulic parameters analyzed by using this software were junction pressure, water velocity the distribution system, and nodal demands, and the overall result of water supply did not satisfy demand. The water distribution system has been analyzed for steady-state and extended period simulation for the present population scenario for intermittent water supply using water Gems v8i. About 14 percent of the total number of nodes analyzed had negative pressures while 68 percent of the nodes had pressures less than the adopted pressure for the analysis. These negative pressures indicate that there an inadequate head within the distribution network for water conveyance to all the sections. In the same manner, 85.6 percent of flow velocities in the pipes were within the adopted velocity while around 14.4 percent of the velocities exceeded the adopted velocity. The results in this study revealed that the performance of the water distribution system of undercurrent demand is inefficient.

Keywords: Hydraulic parameters, pressure, velocity, Water distribution network, Water GEMS v8i

1. INTRODUCTION

Water is an essential element required for the sustenance of life, which play important role in the socio-economic development of a country (Ms. P. S. Salunke, An Overview of water Distribution Network by Using Water GEMS Software, 2018; TINA MAV, 2019; Rameshwari D.

Bhoyar1, 2017). However, approximately two and a half billion people on earth do not have access to safe drinking water (Pravinkumar Shinde 1, 2018; Berihun, 2017; Salunke, 2018; Wonduante, 2013), due to this, an acute crisis of water is looming time to time in this world, which is important to optimize the supply and reduce losses. According to, (Desalegn, 2015; Damgir, 2017; Rossman, 2000; THOMAS J. KUEHN, 2018; Zewdu A., 2014), the adequate provision of water supply distribution networks efficiently can eradicate poverty and ultimately provide the environment for sustainable development. However, water supply utilities in developing countries are faced with challenges of low service coverage and high unaccounted losses of water. The accessibility of the water supply system in most Ethiopian towns is becoming the most challenging in terms of its quality and quantity to the water utilities. The estimated water supply service level of Ethiopia, interims of its coverage, quantity, quality, and reliability is very low (Desalegn, 2015; Damgir, 2017). Consequently, water demand is increasing drastically due to the population growth rate and per-urbanization of the town through this country. The hydraulic analysis of flows and pressures in a distribution system has been a standard form of engineering analysis since its development by Hardy Cross in 1936 (Affairs, 1936). The demand usually reaches a peak in the morning when people are at home and preparing their meal and its second peak in the evening maximum water use and minimum water use, usually related to average water use by multiplication of peaking factors (Maina, 2015). The prime purpose of water supply distribution networking was for delivering access water supply for the required station with efficient pressure and velocity after the treatment plant (Rameshwari D. Bhoyar1, 2017). This distribution network is an essential hydraulic infrastructure that is a part of the water supply system composed of a different set of pipes, hydraulic devices, and storage reservoirs (Pravinkumar Shinde 1, 2018). The distribution system of a waterworks consists of the pipes, valves, hydrants, and appurtenances used for distributing the water, the elevated tank and reservoir used for fire protection and for equalizing pressures and pump discharges and meters (Izinyon and B. U., 2010; Ms. P. S. Salunke, An Overview: Water Distribution Network by Using Water GEMS Software, 2018). Water GEMS track flow of water in each pipe, the pressure at each junction, the height of water in each tank, and the concentration of water throughout the network during a simulation period.

2. Methods and materials

2.1. Study Area Description

The study was conducted in Oromia Regional State of Alibo town, East Wellega Ethiopia which is located 365 km from Addis Ababa which is located at an altitude of 2410m above sea level in the geographical coordinate system of 9º 32‟N and 37º 04‟ E as indicated in Figure 1. According to the Ethiopian metrological agency of the Alibo branch, the climatic condition of the district was divided into three seasons, those are, Summer season on which the average max and min temperature is 27.63 º C and 8.73 º C respectively, were as in the Autumn season; the max and min temperature 28.7 º C and 11.5 º C, and, for the Winter season the max and min temperature is 27.13 º C and 11.2 º C.

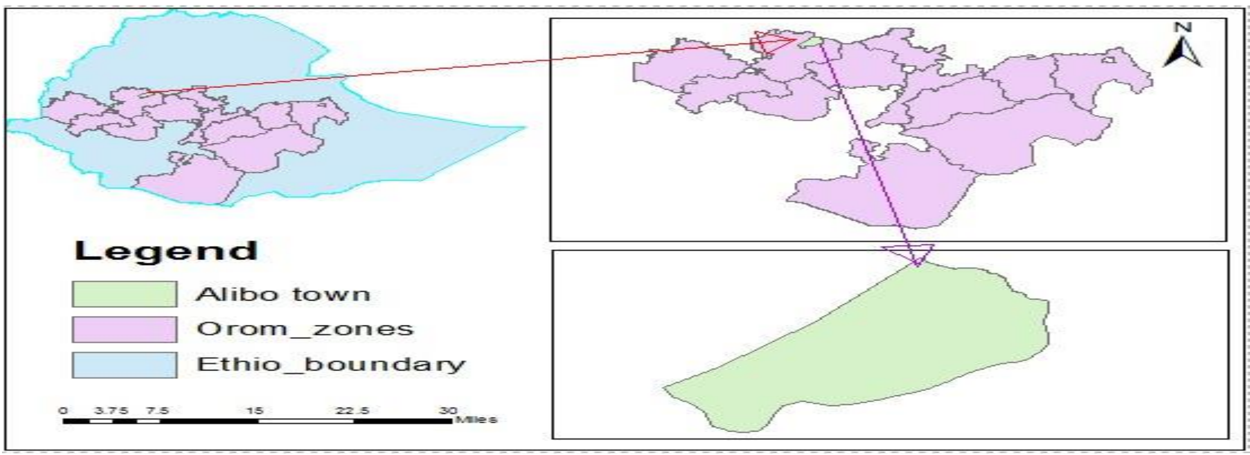

Figure 1: Map of study area

2.2 Study design flowchart for a methodology

Research design is referred to as a master plan, blueprint, and even a sequence of research tasks. Hence, this study is exploratory, descriptive, and applied study.

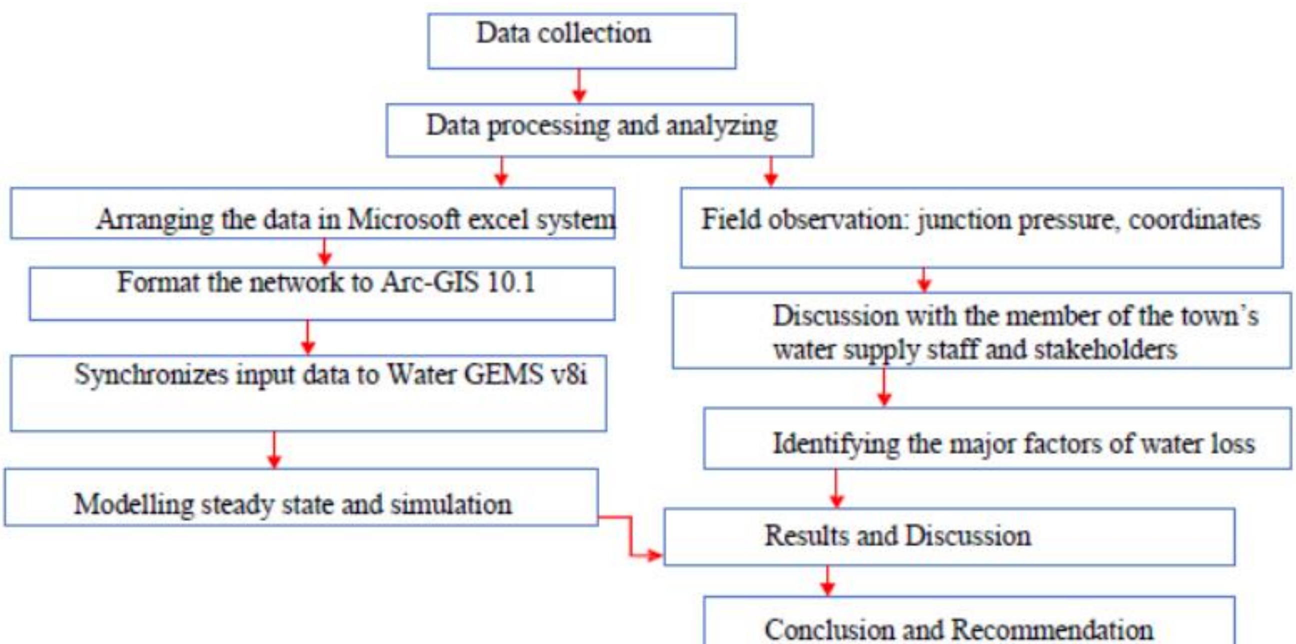

Figure 2: Study design flow diagram

2.3 Input Data Collection

The input data required for hydraulic network modeling were associated with the component of a distribution network for each link. This data can collect in each node of pipe link are, pipe label, pipe material, pipe length, pipe diameter, starting node, stopping node, and pipe roughness are some of the pipe input data requires for the modeling and simulation of water distribution network. The other input data associated are pressure junctions at node/link which includes junction label, junction elevation, and junction demand. Tank data requires are base elevation, minimum elevation, maximum elevation, initial elevation, and tank diameters. The pump input data collection is design flow, maximum operation flow, design head, maximum operating head, maximum operating head, shut-off design, and coordinate system.

2.4 Modeling Process for Water GEMS v8i

Hydraulic models are often used to validate the design of water distribution systems (Bentley, 2008) as indicated in Figure 3.

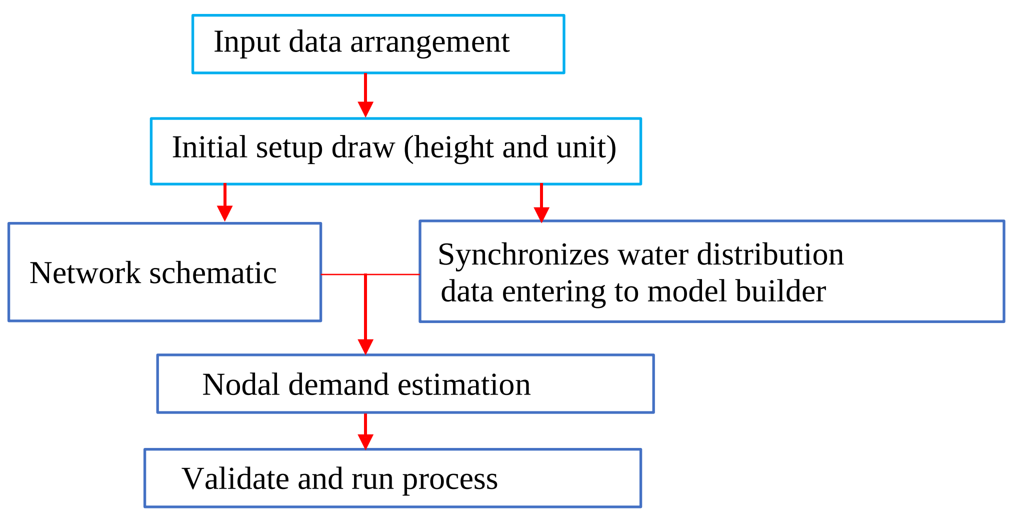

Figure 3: Modeling process for water GEMS v8i

2.5. Estimation of present and future water demand deficit

The design and execution of any water supply scheme require an estimate of the total amount of water required by the community. Designing the water supply scheme for a town is necessary to determine the total quantity of water required for various purposes for Alibo town has categories.

2.5.1 Domestic Water Demand

The water demand for actual household activity is known as domestic water demand. The demand was reliant on many factors, the most important of which are economic, social, and climatic factors. The water demand is calculated for the domestic water demand, per capita domestic water demand, non-domestic water demand, and institutional water demand, commercial water demand, industrial water demand.

2.5.2 Non-Domestic Water Demand

Accordingly, estimated domestic water demand is 10% for institutional and commercial demand, 10% for industrial water demand and 5% for firefighting water demand were added to get the average daily water demand.

2.6 Model Calibration and Validation

The study was measured the water pressure to evaluate the model performance. The method of pressure readings was done from Feb 24, 2020, to Mar 01, 2020, using pressure gauge meters were commonly taken both at the higher and lower zone of the selected points in distribution network; such as raw water pump stations, service reservoir, public fountains and different end-user taps. In this way, the perceived pressure data was taken a total of 10 samples for peak demand time analysis five samples were taken from the lower zone and five samples from the higher zone. From pressure junction and its coordinate system were collected for 10 nodes as a sample for validation of the study result (J-45, J-12, J-1, J-43, J-10, J-61, J-54, J-76, J-28, and J-87) measured near the corresponding location using a pressure gauge.

2.7 Hydraulic Parameter Modeling

The design criteria used in the design of pressure zone boundaries, nodal pressure during the period of peak demand, and optimum velocities of the transfer and distribution mains are (pressure and velocity).

Pressure: The operating pressures in the distribution network according to the MoWR (2006) urban water supply design criterion shall be 15m to 80 ranges. Accordingly, MoWR reports that there are two main criteria to determine the pressure in the distribution networks whether it's in the ranges of scope.

Velocity: According to the MoWR urban water supply design criterion water velocities shall be maintained at less than 2 m/sec, except in short sections & for pumps. Velocities in small diameter pipes may need even lower limiting velocities. A minimum velocity of 0.3 m/sec can be taken, but for looped systems, there are also pipelines with sections having a velocity <0.1m/sec.This shows that a pipe designed to flow at a velocity between 0.6 and 2 m/sec, depending on diameter, is usually at optimum condition. The shortest sections, particularly at special cases, at inlet and outlet of pumps, may be designed for higher velocities.

3 RESULTS AND DISCUSSION

3.1 Population projection

Among different techniques of population projection methods, the study analyzed the minimum error and used the arithmetic method for estimation of population. Accordingly, the projected population at the end of the design period was 197000 of population, which implies that the current populations were increased by 47000 populations on water consumption. Therefore, Alibo town population projection from the year (2019-2035) was tabulated in the Figure 4.

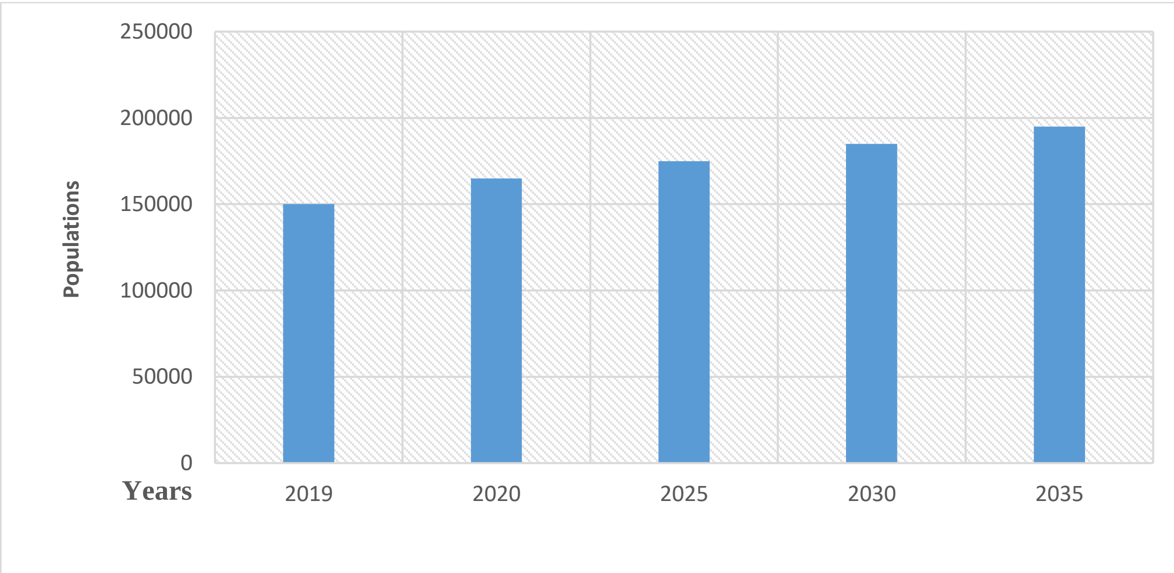

Figure 4: Alibo town population projected

3.2 Domestic Water Demand Analysis

For this projected population (Fig 4), based on the study area capacity, climates of the study area, socioeconomics and other limited resources, the average water demand varied from 20 L/c/d to 25 l/c/d at the end of the design period (2035) and the average daily water demand of Alibo town was 5,486.8 m^3/d. This result is greater the average daily water demand for Nava Shihora Zone (Vidhi N. Mehta, Geeta S. Joshi 2019) done, even if the projected population were different. Whereas the peak hour demand of the town was 8,778.8 m^3/d and peak hour demand is the highest demand of any one hour over the maximum day. Domestic water demand is the daily water requirement for use by human beings for different domestic purposes like drinking, cooking, bathing, gardening, etc. According to (MOIE, 2016) reports, the towns and cities of Ethiopia was categorized based on population number for effective design of water supply distribution system. For this study the projected populations of Alibo town were estimated to 197000 which have been used for water demand analysis for the study period. The variation of water demand was developed through each year consequently which have a great effort on the design of water supply for the study area. Hence the average daily demands of the study area for 2020, 2025, 2030, and 2035 were increased by 8.99 %, 50.97 %, 94.23 %, and 147.41 % respectively as compared to the 2019 average daily water demand. While maximum daily demand and peak hour demand were increased by 10.4%, 26.94%, 94.20% and 142.2% and 7.33%, 65.90%, 98.73% and 143.02%, respectively.

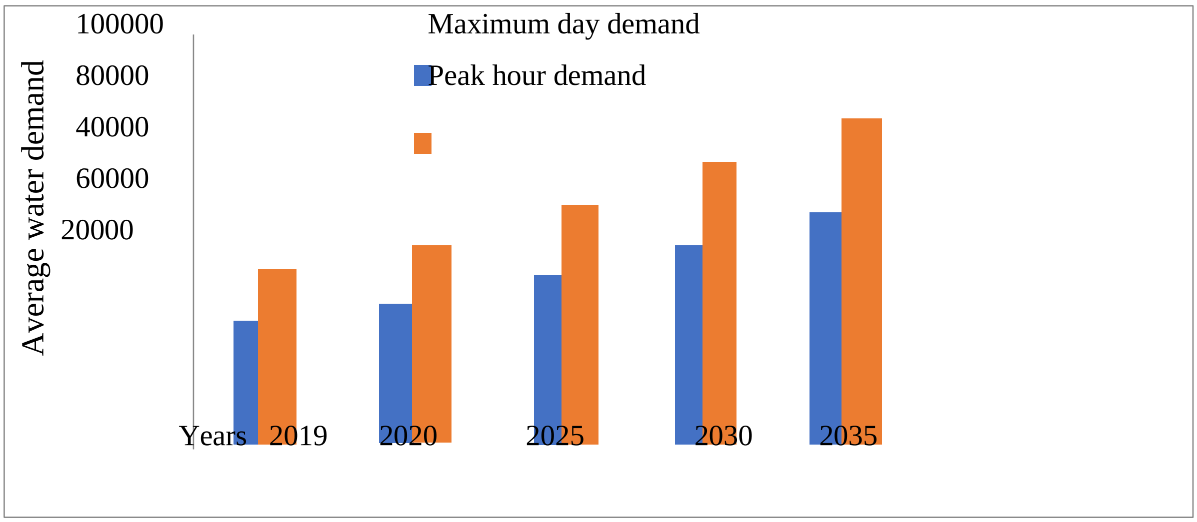

Figure 5: Maximum day demand and Peak hour water demand

3.3 Prediction of future water demand deficits

The estimated water demand deficits versus water supply production of the study area were plot in below Figure 6. Accordingly, the productions of water supply for were only meeting the water demand requirement for different consumption rates averagely up 2020 years. Beyond to this year water requirements of the town were less than year water production to the area due to limited supply and water demand was becomes day to day distressing.

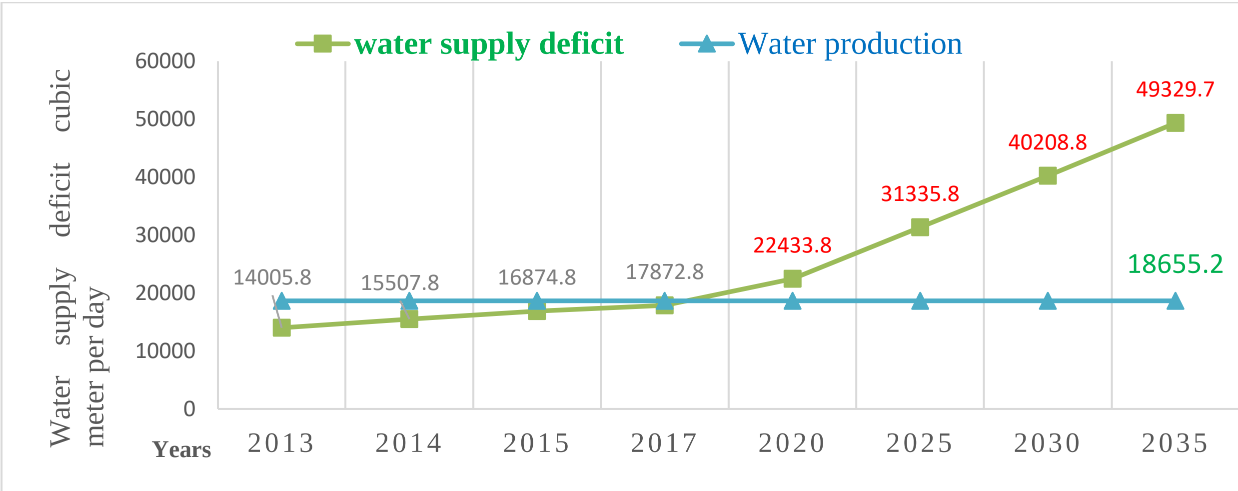

Figure 6: Alibo town water production and water demand deficit

3.4 Analysis of water demand variation in distribution networks

The consumption of water by urban population, based on different factors among those climate condition, socio-economic, topographic area and others determine the demand of urban area which is depend on distribution network performance of the systems. As far as distribution of water is concerned, the properties of hydraulic parameters in distribution network allowable limit were estimated and based on this issue the peak hour demand (187.5 l/s) of design period (2035) simulation of Water GEMS V8i. For this study the peak hour factor is greater for a smaller population and hence, this peak hour demand result did not match with that of the growing population of the town and this demand can vary from each distribution network as shown in Figure 7.

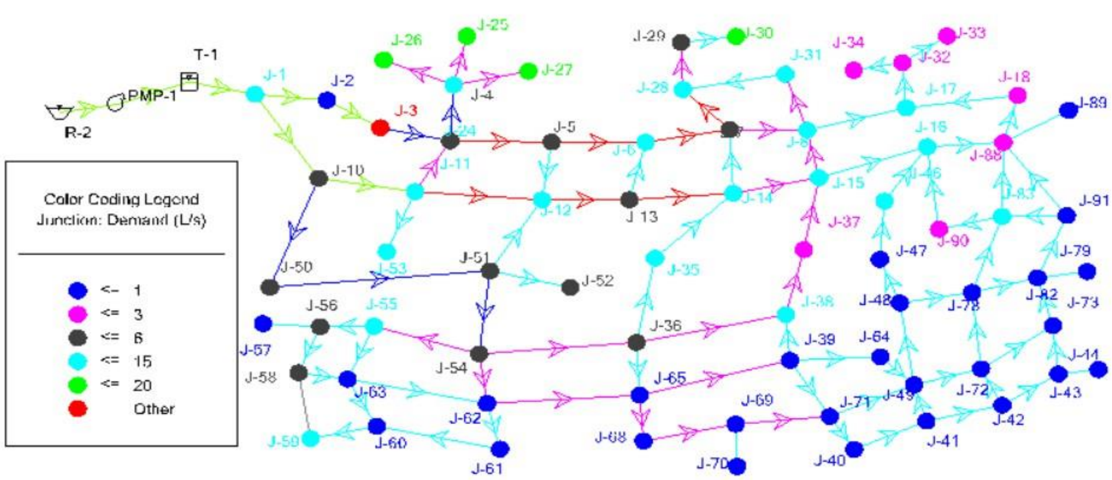

Figure 7: Variation of water demand in the distribution pipe networks

As described in the Figure 7 the blue, magenta and brown color were indicate the demand value have been less than or equal to 1 L/s, 3 L/s and 8 L/s, respectively. This indicated that, almost more than half of the study area nodal water demand was obtains greater than or equal to 8 L/s as justified in Fig 7.

3.5 Analysis of Pressure in the Networks

The water distribution network was designed based on pressure criteria and the existing criteria on the minimum and maximum pressure in the network. The operating pressures in the distribution network according to the Minister of water resources, urban water supply design criterion shall be 15m to 80m ranges. Accordingly, this study result of the pressures distribution networking is avail in within this ranges. However, as the researcher analyzed, negative pressure was observed/recorded in 8 junctions, which shows that no water flows/ currents reached this segment of the distribution network, which was no provisioning of water to the consumers. This negative pressure may occur due to the size of the pipe, and levels of water, avail in the distribution network which has a great impact on societies. It was attempted in the design to meet the optimal diameter and minimum pressure in the network as shown in Figure 8. Accordingly, the study considers low peaks through night hours the pressure in the system becomes high and the leakage loses expected to increase whereas at high peaks the pressure becomes small and the leakage losses expected to decrease. High value of pressures affects adversely the hydraulic performance of the distribution network at night time (4:00 AM) during low consumption period, the pressure in the system become high.

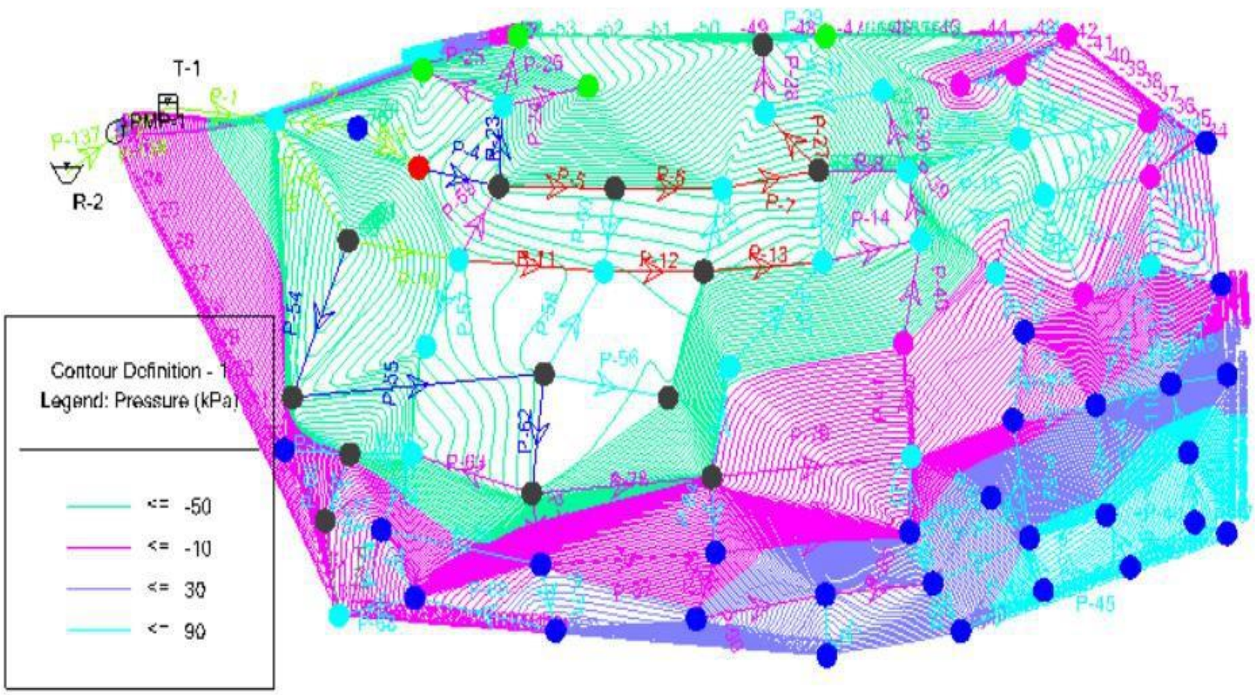

Figure 8: Pressure/contour map for the Alibo town water distribution networks

As described in the Figure 8 the magenta and green color have the pressure value less than or equal to 15 Kpa, whereas blue and green bricks pressure were between 60 - 80 Kpa respectively. As described in this Figure, Green color indicates areas around Sichale, Gaba kemisa, Alibo (high school, secondary and preparatory school) with pressure value between 15-60 mH_2O, which was with in permissible range. The areas which were below permissible range of pressure have been around Usho and Barji kebeles, because the areas were very far from Barbare water supply source and due to the high elevation levels. The pressure above permissible range indicated by Green color on Figure 8, was areas around Hospital and Mekan Yesus church, which based on the population served, types of dwellings and topography in the area. The pressure at node depends on the adopted minimum and maximum pressure within the network, topographic circumstances, source position, storage elevation and the size of the network as shown in Table 1.

Table 1: Simulated result of pressure at low water consumption hour (4:00 AM)

Pressure range value	≤ 15 mH2O	15 - 60 mH2O	≥60 mH2O
Number of nodes	190	34	7
Percentage	82.25	14.71	3.04

The result of simulation run was obtained after model constricted from the input of existing data a total node of 231 was reported from the project inventory dialog box software. Table 1 show that 14.71 % nodes have been observed with in recommended serviceable pressure (15 mH_2O to 60 mH_2O). According to Mesfine, (2017), existing Tulu- bolo town water supply distribution system from the total nodes 1.9 %, nodes have pressure below 15 mH_2O, 94.33 % have permissible pressures between 15 mH_2O and 60 mH_2O and 3.77 % of the node has above 60 mH_2O. This implies that the percentage of permissible pressure for Alibo town water supply distribution system was lower than Tulu bolo town. Due to source position and topographical circumstance of Alibo town water supply distribution network permissibility of pressure distribution was lower than Tulu bolo town.

3.6 Analysis of Network Profile

The software has the potential to give a variety of information, including hydraulic profile, velocity profile, and pressure gradient at any point in the network to the user. One of the town s mainline is shown in the figure with respectively.

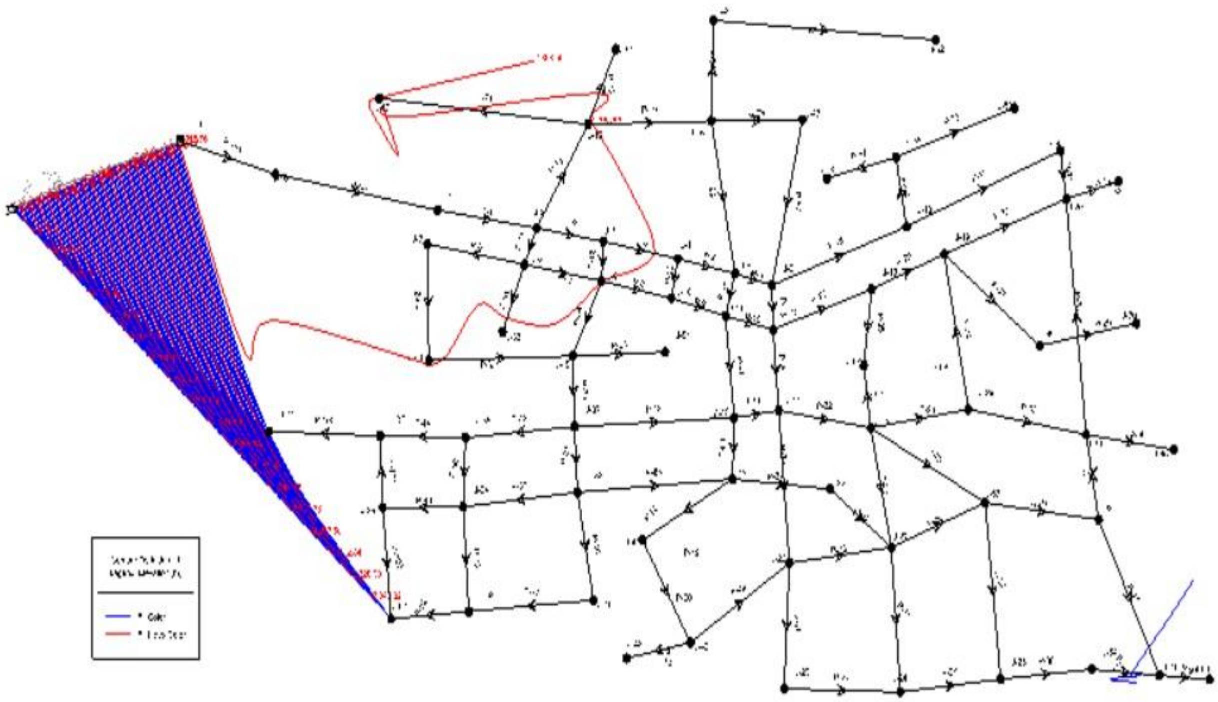

Figure 9. Elevation profile of the distribution from a reservoir to end customer pipes

In the distribution main lines of the study area, the locations of nodes in the water distribution line are near each other. The maximum and minimum water pressure in the distribution system was 98.45

and 8m from the reservoir head to the ends of the customer services pipe. According to the design criteria of the FDRE; a Minster of water, irrigation, and energy, the maximum and minimum water pressure in the distribution system is 80m and 15m, respectively. This water was delivered to the distribution main by gravity means, and the system was served beyond its design life. Nodes having low values of pressure, Steady-state Analysis ($5 \leq P \leq 10m$) and Nodes having high values of Pressure, Steady-state analysis ($80 \geq P \leq 98.45m$). The hydraulic grade line and base elevation starting from the Tank to the distribution system were plotted as shown in Figure 10.

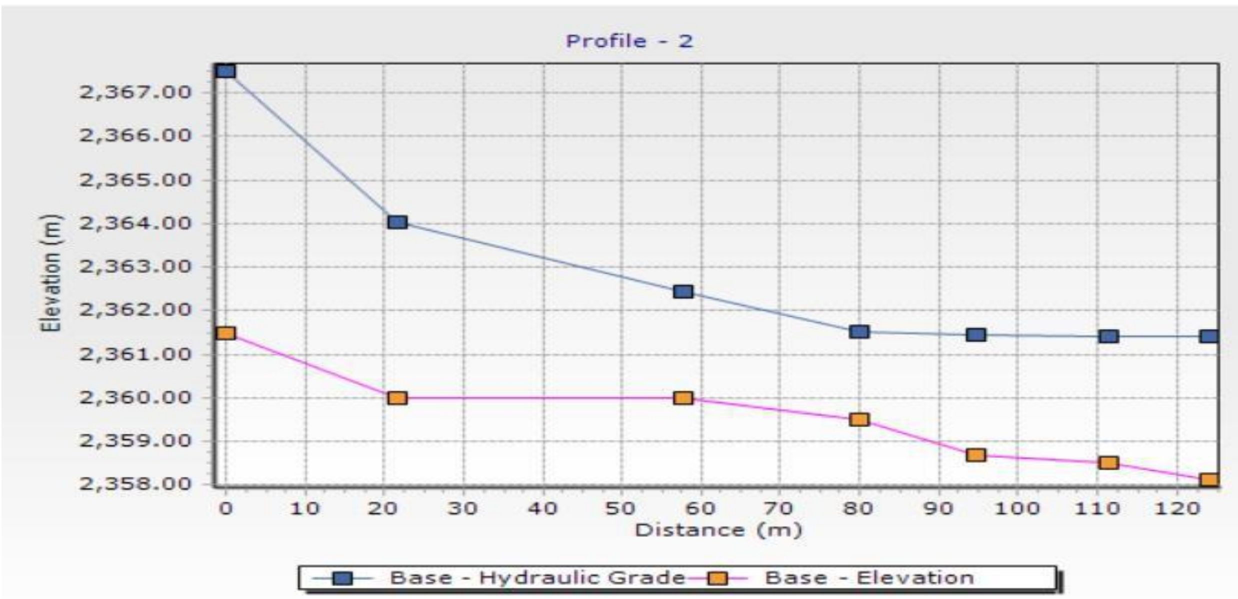

Figure 10: Hydraulic grade line versus Base Elevation from Tank and distribution system

3.7 Analysis of Pump capacity

The amendment of pump is one of the important elements, which add energy to the system. Since water can flows from the higher energy location to the lower energy. Pumps used to boost the head at desired locations to overcome desired piping head losses and physical elevation difference for future required volume of water distribution network. A pump curve represents the relationship between the head and flow rate can deliver water at nominal speed settings. Pump head is the head gain imported to the water by the pump and plotted on the vertical of the curve in meter. According to field observed data and model-simulated result, the pump brake horsepower, and maximum water power were collected as 55.83 kW and 24.4 kW, respectively. Therefore, 78.67% of the pump efficiency was shown that currently these pumps were operating in a good performance and did not deliver sufficient water to the treatment plant continuously.

Network pressure zoning is necessary for the existing water distribution networks or in the study of the development plans of facilities and water distribution networks of towns and villages with a gap at the level of the town. Pressure zoning at the level of a network includes all the measures that would keep the pressure within the standards or pressure management. The developed pump head curves during model simulation work were presented in the Figure 11.

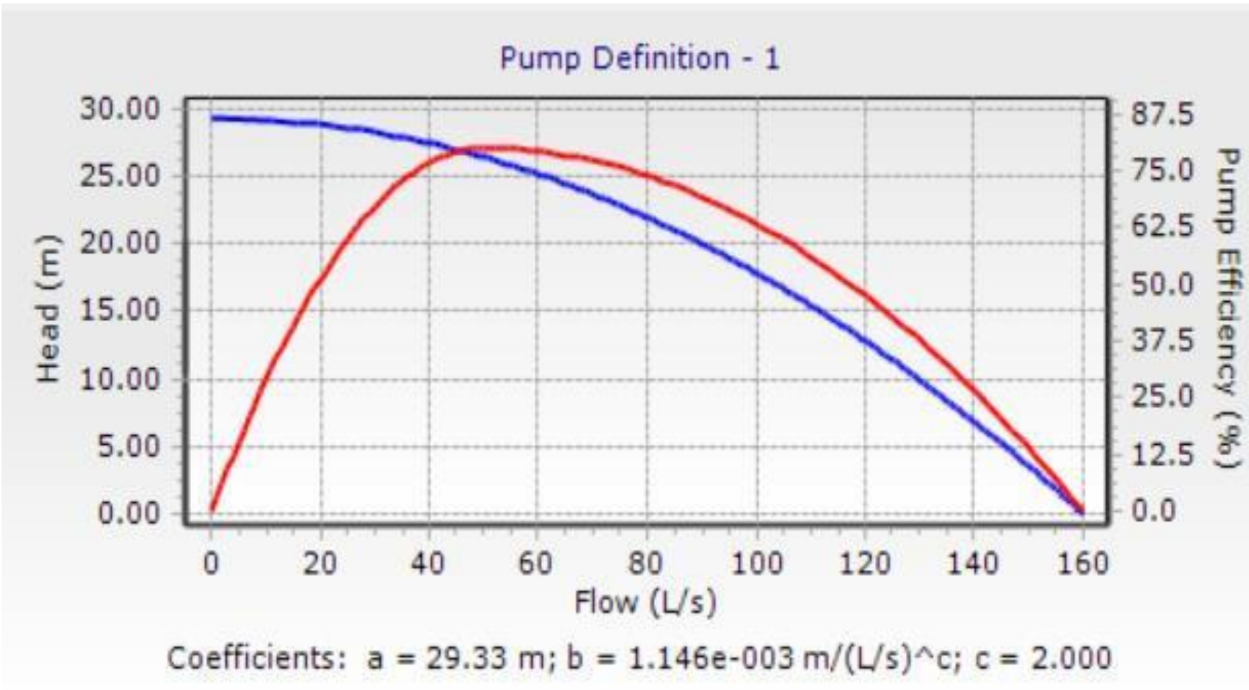

Figure 11: Raw water pump capacity and its efficiency / Pump head verses flow curve

A pump is defined by its characteristic curve, which relates the head added to the system to the flow rates. As described on Figure 11, the red colour shows as the head decreases the amount of discharge pushed by the pump increases. While the blue colour shows as the pump efficiency decrease the amount of discharge pushed by the pump increase.

3.8 Velocity Analysis

Through the distribution networks, about 18 pipes in the system have a velocity less than the minimum limits, of minimum velocities which is 0.05 - 0.3 m/s. Minimum velocities should be avoided from the system to avoid stagnation and water quality problems. A minimum velocity of 0.3 m/sec can be taken, but for looped systems, there are also pipelines with sections having velocity <0.05 m/sec. The maximum static head within a pressure zone was limited to 100 m. The minimum dynamic head was established at 22 m and the maximum velocities of major transmission mains <

2.5 m/s. Maximum velocities of distribution mains < 2 m/s and the minimum velocities range 0.05-0.3 m/s within the system.

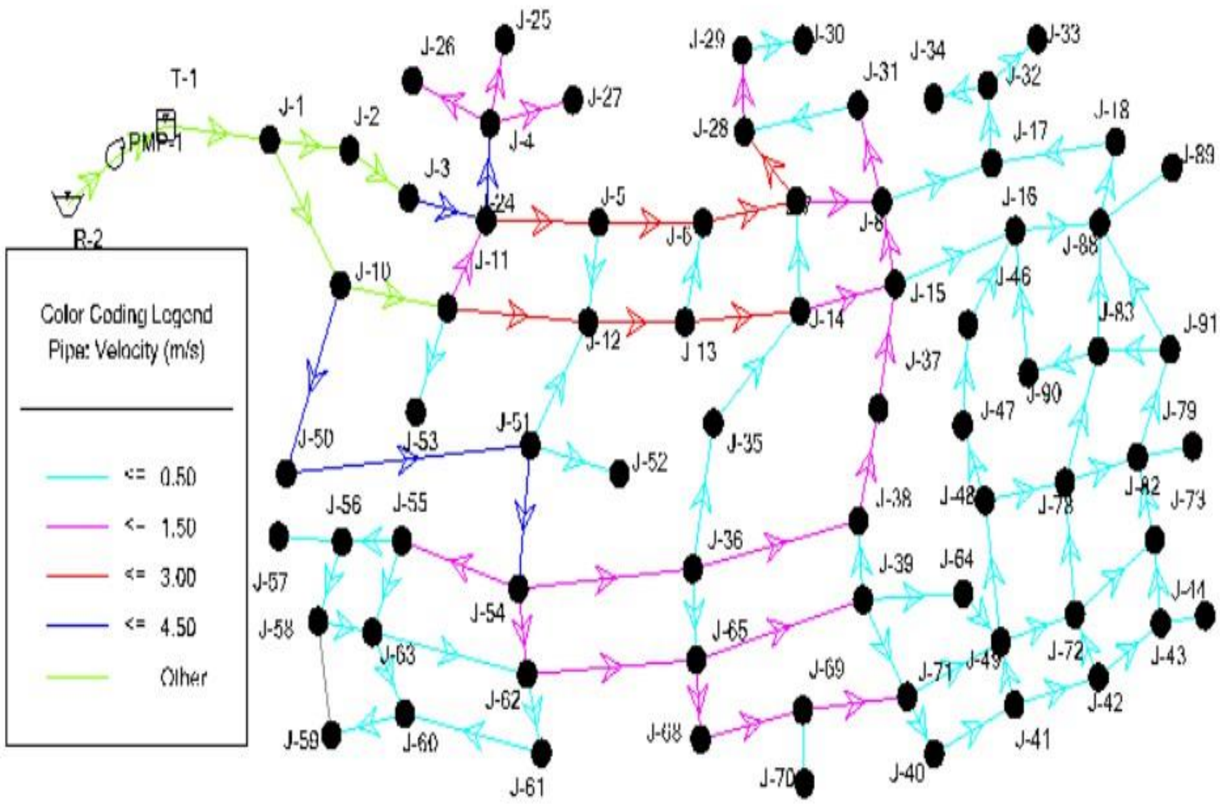

Figure 12: Velocity map of links for average day demand

The red color which has been described on the figure 12 with velocity value less than or equal to 0.6 m/s, which indicates below velocity permissible range areas. Almost half of the distribution network described by Green color on Figure 12 were in different areas like management offices, Agricultural offices, Health centers areas, Digalu direction and etc, was with in permissible velocity range (0.6 m/s- 2 m/s). The magenta color presented on this figure with velocity value range of 2 m/s - 3 m/s were areas around Medalalem church and bus station, was above permissible value (2 m/s). The flow and pressure distributions across a network are affected by the arrangement and sizes of the pipes and the distribution of the demand flows. Since a change of diameter in one pipe length was affected the flow and pressure distribution everywhere, network simulation is not an explicit process pipe network analysis involves the determination of the pipe flows and pressure heads that satisfy the continuity and energy conservation equations (Rossman,*et al*., 2000).

Although the both design guide line have different values on the same idea, the study was conducted using velocity standards given by MoWR water supply design criteria (2006). High consumption of water was occurred at morning time (8:00 AM).

Table 2: Ranges of velocity in the water supply distribution Simulation at (8:00 AM).

Velocity range (m/s)	Count	Count (%)
< 0.6	112	34.25
0.6 - 2	165	50.46
≥ 2	50	15.29
Total	327	100

As indicated in Table 2, 34.25 %, 50.46 % and 15.29 % of the pipes are below, within and above the permissible range of velocity respectively. 20.55 % of the pipes of existing Tulu-bolo town water supply distribution system are within the permissible range of velocity (Mesfine, 2017). While by comparing the permissible velocity value of Tulu bolo town with Alibo town, the Alibo town velocity value was more permissible. The diameter of pipes distributed in Alibo town half of water supply distribution network was effective for satisfactory flow of water; this was the reason why Alibo town water supply distribution network velocity values were more permissible.

4.CONCLUSION

The study analysis the main challenges of water distribution networks, which could limit the quantity of water supply due to the volume of existing reservoirs size and pre-urbanization (population expansion). To provide the minimum pressure and prevent increasing pressure which increases in water tragedies and unnecessary use of water, pressure should be carried out by the appropriate selection of the tank and pressure zoning of the network. The existing water distribution network of Alibo town was designed for an estimated population of 69,160. However, the current population figures out 118,339, which is being served beyond the design life and low coverage in the town, which causes scarcity of drinking water supply in the town. Accordingly, there was a complaint from the customer because their demand was not being met to fulfill their satisfaction since the distribution system is intermittent.

In the distribution network system, the same velocity can be less than the permitted level of MoWR and the negative pressure junction can also occur in the systems of networking distribution. Some of the nodes have low values of pressure, steady-state analysis ($-5 \leq P \leq 10m$), and nodes having high values of pressure, steady-state analysis ($80 \geq P \leq 128.45m$). The software finds the lowest allowable diameter for each pipe segment that allowed the system to function, or more specifically, to meet the minimum pressure requirements at all junctions.

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