International Journal of Research Studies in Science, Engineering and Technology
Volume 7, Issue 6, 2020, PP 18-28
ISSN 2349-476X

Evaluation of Water Supply Distribution System and Hydraulic Performance of Hosanna Town

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ABSTRACT

This study is conducted to evaluate existing water supply distribution system of the town. The town gets water by classifying supply system into three pressure zones. About 66% of the town is categorized under pressure zone two and pressure zone one and three have no major problem hence, this study emphasizes on pressure zone two. Data for distribution system was evaluated by using WaterCADv6.5 software. The per capita domestic water consumption of Hosanna Town was found to be 42.9 l/c/d in the year 2020. The average water loss in Hosanna Town was 40%, which shows as it needs a matter of concern. During steady state analysis, 24% of the higher pressures in pressure zone two were observed due to low elevation and 3.96% of the lowest pressure recorded was due to high elevation. 72% of pressure zone two has pressure within the optimum range during steady state analysis. After hydraulic analysis, 15.53% of the identified nodes have pressure below 15m and 7.77% of nodes have pressure above 70m. Only 76.7% of the areas have pressure within the recommended limit during peak hour consumption. During minimum hour consumption, 1.98% of residents get water at low pressure due to high elevation of the area. 38% of the nodes have pressure above 70 m and only 59.41% of the area has pressure within the recommended limit. For the parts of the system that are located far away from the sources, and areas with high elevation are facing lack of water due to low pressure. The current water demand is found to be 2470 m^3/day and at the end of design period of 2040 years, it would be 17352m^3/day. In order to achieve a 15m minimum and 70m maximum pressure, it is necessary to provide pressure controlling valve and establishing boosting station. Finding for additional water source is also a fundamental issue to meet the current and future water demand.

Keywords: *Hydraulic performance, Simulation, Water distribution system, Water losses.*

INTRODUCTION

The distribution network is responsible for delivering water from the source or treatment facilities to its consumers at serviceable pressures and mainly consists of pipes, pumps, junctions (nodes), valves, fittings, and storage tanks. Water distribution networks play an important role in modern societies being its proper operation directly related to the population's well-being.

A completely satisfactory water distribution system should fulfill its basic requirements such as providing the expected quality and quantity of water during its entire lifetime for the expected loading conditions with the desired residual pressures (Misirdali, 2003).

Water distribution systems can be either looped or branched. Looped systems are generally more desirable than branched system because, in the looped system, breaking of pipe can be isolated and repaired with little impact on consumers outside the immediate area. On the other hand, in the branched system, all the consumers downstream from the break will have their water supply interrupted until the repairs are finished (Atiquzzaman, 2004).

Water supply and distribution systems serve many critical functions and play a large part in achieving human and economic health. Despite this, the performance of these systems often goes unnoticed until there is a major disruption or operational failure. While failure events are likely inevitable, often dramatic and costly, day-to-day, inefficient performance of WDS also entails great economic, social and environmental burdens.

Performance measurement is a key issue in engineering behavior and control of any WDS.

The most common challenges in water distribution networks include water quality degradation, capacity shortages, infrastructure aging and deterioration, and increasing demand (Jalal, 2008).

In water utility systems, significant amount of water is lost as leakage while it transport from source up to consumers. Water loss represents inefficiency in water delivery and measurement operations in rising main and distribution networks. When the productivity increased, investments in new infrastructure will lead to more effective and efficient water services (Dighade et al., 2014).

Because of rapid population growth and high water losses from the distribution network, the total water demand of the system in many developing countries exceeds available production capacity. To limit total demand and provide an equitable distribution of available water, intermittent water supplies with reduced system pressures are often introduced. (Petingeduld and Zdeneksvitak, 2006).

Materials and Methodology

Description of Study Area

Hosanna Town is capital of Hadiya Zone which is found in Southern Nations and Nationalities Regional Government Administration Region of Ethiopia. Hosanna town is located between 833000N and 835000N latitudes and 373000E and 374000E longitudes in UTM coordinates. The town is located in between 2140m and 2380m elevated lands above mean sea level & 230 km away from the Country's Capital city Addis Ababa to the southern direction via Alemgena&Butajira Road.

Population

Based on CSA 2007 the population census result, the current population of the town is projected to 116468 at the end of 2020.

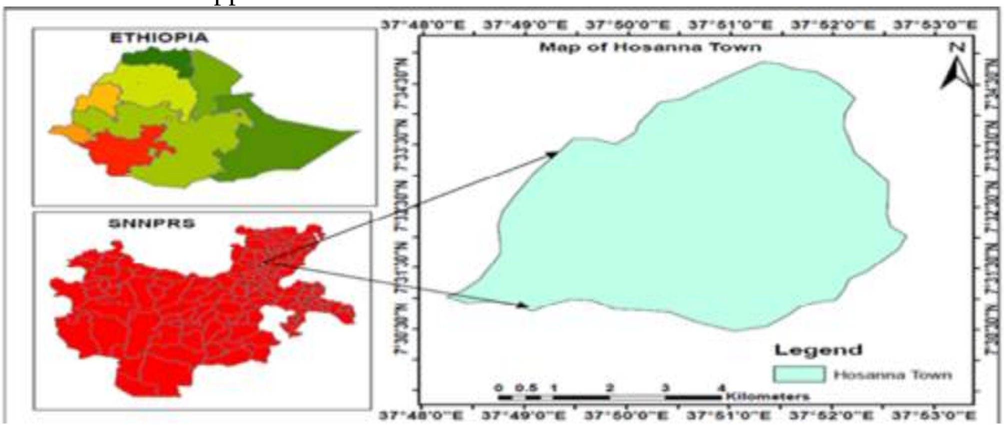


Fig1. *Location Map of the study area*

Material

This research was mainly conducted to evaluate existing water supply distribution system in Hosanna town. To achieve the goal of the research, the materials used are digital camera, computer, and WaterCADV6.5.

Research Design

The water per capita consumption of the town was first evaluated with annual consumption with in specific year. After evaluating the water per capita consumption, the percentage of the water loss was estimated. The total water produced and actual water consumption as aggregated from the individual contracts (customer meters) was used as an input for water losses analysis.

After evaluating the total water losses, the possible causes of water losses were tried to be identified. Then the performance of water distribution network was evaluated by following standard guidelines. Lastly, estimating the current and future water demand of the town was conducted by considering per mode of service.

Data Collection

Primary data were collected though face-to-face interview with Hosanna Town Water Supply and Sewerage Enterprise office staffs, field observations and measurement, photographs of relevant sites and infrastructures were taken.

Secondary data were collected from reviewing of documents from Hosanna Town Water Supply and Sewerage Enterprise office, journals, and related reports.

Population Data

Based on CSA 2007 the population census result, the population of Hosanna Town was

73790 in 2009. After one year the population was 77184 at 2010. According to CSA (1998) the growth rate of southern region was given from (2006-2030). Based on this growth rate, the growth rate of the population in town was extrapolated from year 2031 to 2040. Then population number for twenty years period; from 2020 to 2040 was forecasted for the study.

Data Analysis

To analyze the data which is collected from different sources, both qualitative and quantitative methods was used. From the quantitative methods, the descriptive statistical methods like percentage, graphs and cross tabulation was used in order to come up with the appropriate result.

In addition to this, qualitative methods like narration were employed in the study. Excel was used to analyze the data obtained from office and the field survey data for distribution system was evaluated by using Water CADV6.5 engineering software. Analysis of the model for existing system has been made by running the model at current year daily average, at peaking and temporal variations of demand with different scenarios. This research was used hydraulic network analysis software Bentley WaterCADV6.5. The performance Evaluation of the system was observed under steady state, peak hour consumption, minimum time consumption and its performance was evaluated based on hydraulic conditions.

Steady-State Simulation

It is the simplest simulation type and solves the system of equations as if the system Junction, demands and tank elevations kept constant that means the demand at every node not changing throughout 24hours of a day.

Extended-Period Simulations

Demand patterns: - the amount of water that consumed in the morning when everyone is getting ready for work is different at midnight. The extended-period simulation was chose for this analysis because of its capability to model varying demands. The total simulation time was 24 hours with a three-hour time-step. Analysis at peak and minimum time consumption was simulated to identify the current problems of the system.

Pressure

The pressure at nodes depends on the adopted minimum and maximum pressures within the network, topographic circumstances, and the size of the network. The minimum pressure should maintain to ensure that consumers' demand provided at all times. The maximum pressure also contains limitation of leakage and leads to water losses in distribution system. The operating pressure in the distribution network is given in Table 1.

Table1. *The operating pressures in the distribution network (MOWR, 2006b)*

Pressure	Normal condition	Exceptional conditions
Minimum	15 m	10 m
Maximum	60 m	70

Water CADV6.5

Water CAD is a powerful tool for design, analysis and improves the existing urban water distribution system. A model was developed utilizing Water CAD software (Water CADV6.5 for Auto CAD 2007 software).

Water CAD is selected for this study because of it is aided with good quality of manual, integration with other external software, like Auto CAD, GIS background support and Microsoft excel, it requires less effort and shorter time to build a model than others, rule based controls and ground elevation extraction from shape files and CAD drawings. The other capabilities of the Water CAD software are evaluating the hydraulic parameters for different demands at a single node with varying time patterns, solving different frictional head losses using Hazen-William, DarcyWeisbach, determining fire flow capacities for hydrants, model tanks, including those, which are not circular and model various valve operations (Bhadbhade, 2004).

Hosanna Town Population Projection

Several models are used to forecast the population number. In projecting the future population, geometric increase method and regional population growth rate was used to all towns in Ethiopia for every five years interval (Amdework, 2012). Therefore, the geometric increase method was adopted for this study for the purpose of future population forecasting since it is mostly applicable method for growing towns having vast scope of expansion pattern like Hosanna town. The urban population growth rate of Southern Region is given in Table 2

Year	Urban Growth Rate	Rural Growth Rate
2006-2010	4.6%	2.5%
2011-2015	4.3%	2.3%
2016-2020	4.1%	2.1%
2021-2025	3.9%	1.8%
2025-2030	3.7%	1.5%

Source: *Volume I Statistical Report of CSA (1998).*

Population for the next twenty years (until 2040) is projected using geometric increase method as follows. $P_n = P_o\,(1+\frac{r}{100})^{\,n}$

Where, P_o= initial known population

P_n= population after n years;

r = growth rate and

n= number of years of the concerned period

Result and Discussion

Potable Water Supply Coverage

Table3. *Annual water consumption of Hosanna Town*

Year	2015	2020	2025	2030	2035	2040
Population	95269	116468	141022	167492	195114	231738
Demand (l/c/d)	41.8	42.9	44.9	46.8	47.9	49.4

As shown in Table 4.1, the per capita domestic water consumption of Hosanna Town was found to be 42.9 l/c/d in the year 2020. According to MOWIE, 2015, the quantity of domestic water requirement in urban areas of Ethiopia can be taken up to 50 l/c/day. Accordingly, the domestic water demand of Hosanna Town is within the standard limit. As it is indicated in Table 3, the per capita water demand of the town is in increasing trend as time goes. The main reasons for these are; the increase in the population number, pump failure and seasonal fluctuation of the water sources.

Water Losses Analysis

The total designed water production capacity of the system is 9417.6m^3/day. However, the actual production of water has been lower than the expected capacity. Production data computed for five boreholes shows that actual average production of water at present from the system is 1555.2m^3/day assuming pump functioning for 18 hours per day, which is 41.86 % of its capacity (3715.2m^3/d) if pumps work for 24 hours. Additionally, the actual average production of the spring is 100% (7862.4m^3/d). The volume of the water supplied and billed water (consumption) for seven consecutive years was shown in Figure 2.

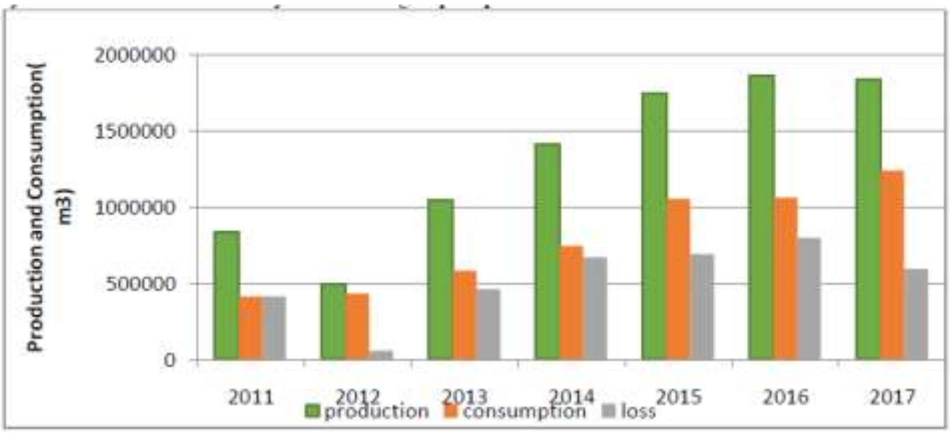


Figure 2: Water production, consumption and Loss for Hosanna Town water supply service

Total water loss or unaccounted for water (UFW) is the difference between the volume of water produced, and the volume that is billed or consumed. As it is shown in figure 2, for years 2011 and 2012, source of water supply for the town were only five boreholes. In year 2011 the water production was about 800,000m^3 and from this quantity only half of it was billed appropriately. In year 2012 the water production was reduced to 49029m^3 due to pump failure, power shortage, and decrease yield of borehole3. The springs were added to the water supply system in year 2013 to fill the gap between increasing water consumption and water production. In year 2014, bore borehole 6 was added to the system and once again water production was increased. After bore hole 6 there was no additional source to the system, but the pumps have been kept maintained to increase water production for the town. The percentage of water loss in the town water distribution system is given in Figure 3. The average amount of water loss was 40% and only 60% water was actually reached the consumers. According to Mckenzie et al (2006), the system efficiency is good (acceptable) if above 75% of water produced reaches the consumer. Thus, Hosanna Town water supply system is not good.

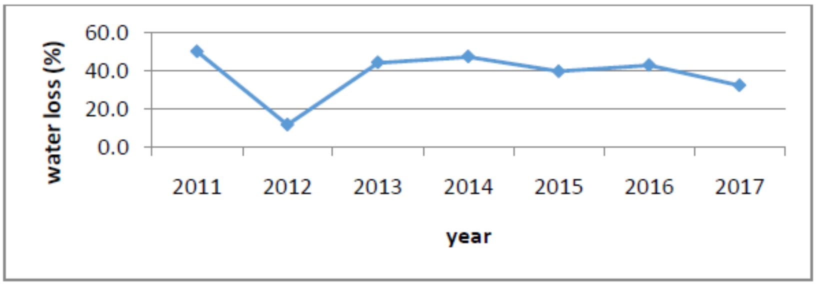


Figure3. *Water lost in percentage*

Total Water Loss or Unaccounted for Water (UFW)

The total annual water produced and consumed within the specified year (2011 to 2017) were 9232023 m^3 and 5540769 m^3 respectively and the total annual water loss was 3691254 m^3 that accounts to 40% of the produced water. Saroj (2008) classified and described UFW as acceptable, which could be monitored and controlled, when the loss is less than 10%, intermediate, which could be control when the loss is 10-25% and a matter of concern which reduces the water supply when the loss is greater than 25%. Accordingly, the average water loss of Hosanna Town was 40%, showing that it is under a matter of concern.

Pipe Type and Length of the System

Input parameters for pipes which are; diameter, length, roughness coefficient and status obtained from AutoCAD drawing design report As shown in Table 4., major part of the distribution system is covered by pipe of 50 mm diameter and Pipe of 350 mm diameter is the lowest which are 45.45% and 0.61% respectively.

Table4. *Pipe size distribution in diameter*

Diameter (mm)	Length(m)	%
50	25,605.03	45.45
63	3,643.27	6.47
80	5,099.30	9.05
100	12,436.45	22.07
150	4,682.95	8.31
200	3,181.50	5.65
250	1,350.87	2.40
350	342.60	0.61
Total	56,341.97	100.00

In terms of material type, UPVC is the major pipe type in distribution system. As shown in table 4.3, 48.93% is UPVC and GI pipe is used in smaller percentage 45.45%.

Table5. *Distribution of pipe material types at Hosanna Town*

Pipe Type	Length	%
HDPE	21450	45.45
UPVC	71955	48.93
DCI	32000	0.61

Water Distribution Network Simulation

In this study, the distribution network of the town is put in three different pressure zones, namely; Pressure Zone One, Pressure Zone Two and Pressure Zone Three due to the elevation differences in each Pressure Zones. From these Pressure zones, pressure Zone Two covers the largest area of the Town's distribution networks where it accounts about 66% of the area. In this zone water from two springs is collected to the reservoir volume of 2000m^3 from which distribution work starts.

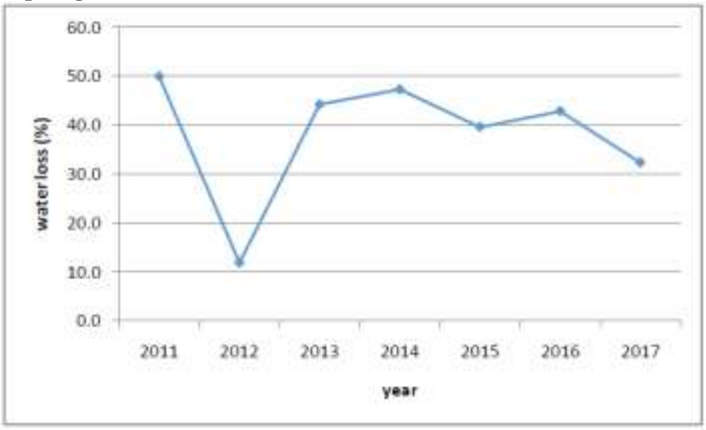


Figure4. *Water distribution network map of Hosanna Town for pressure zone.*

Pressure Distribution During Steady State Simulation

During steady state analysis 24% of the higher pressures in pressure zone two of town >70 were observed at the different junctions due to low elevation and 3.96% of the lowest pressure recorded was junction (23, 24, 27, and 87) due to high elevation. Majority of this zone has pressure within the optimum range during steady state analysis which is 72%.

Table6. *Distribution of pressure at steady state analysis*

Pressure(m)	Nodes	%
>70	25	24
60-70	17	16.83
50-60	8	7.92
40-50	8	7.92
30-40	21	20.79
20-30	15	14.85
15-20	3	2.97
<15	4	3.96
Total	101	100

Pressure Distribution During Peak Hour Consumption

After hydraulic analysis, 15.53% of the identified nodes have pressure below 15m. Particularly junctions 106, 121,104, 128, 110, 100, 44 and 103 were having negative pressures of -28.6m, -25.3m,-21.5m, 19.7m, 12.8m, 8.7m, 7.92m and-3.99m respectively at peak time consumption. The ranges of lowest pressures recorded were from -16.937m to 13.93m during peak hour consumption. 7.77% of nodes have pressure above 70mand only 76.7% of the areas have pressure within the recommended limit (15 to70 m) during peak hour consumption. The above discussions are also summarized in table 7 below.

Table7. *Distribution of pressure at peak hour consumption.*

Pressure (m)	Nodes	%
>70	8	7.77
60-70	10	9.71
50-60	15	14.56
40-50	11	10.68
30-40	17	16.50
20-30	17	16.50
15-20	9	8.74
<15	16	15.53
Total	103	100

The pressure distribution of nodes with negative pressure at peak hour consumption is given in Figure 5 below.

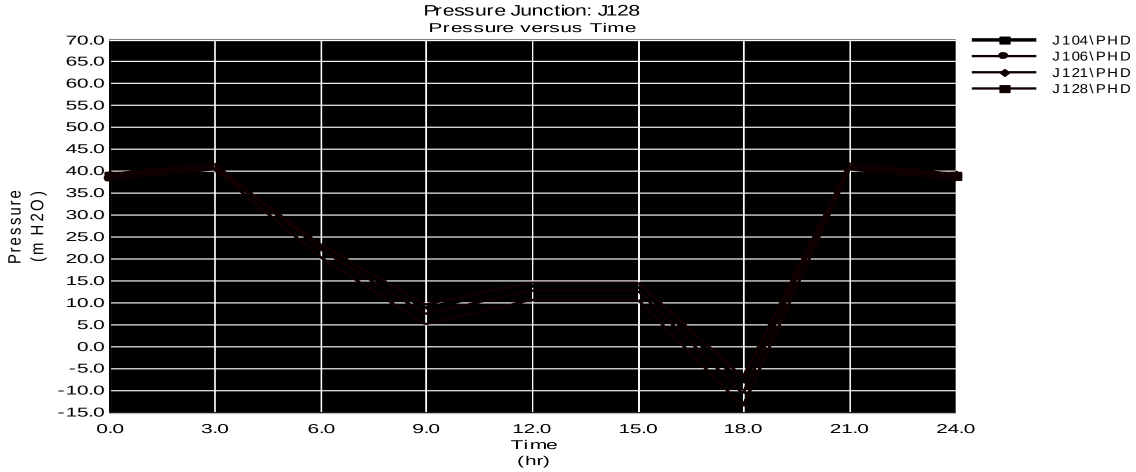


Figure 5:- Pressure distribution of selected nodes with negative pressure at peak hour consumption.

Households located on higher elevations site gets water at low water pressure. Variations of pressure during day and night create operational problems, resulting in increased leakage and malfunctioning of water usages. The water users located in higher elevation relative to supply points get less water and they fetch after users located in lower elevation are satisfied or close their water taps. Most of residents far away from reservoir site in pressure zone two cannot get water with the required pressure head even during night where maximum pressure is expected in the network. The total area of low-pressure head is 15.53% during peak hour consumption and 1.98% during minimum time consumption two. Effects of distance and elevation in pressure distribution of selected nodes are shown in Figure 6.

Figure6. *The effects of elevation difference and distance on pressure.*

Figure7:- Pressure map of water distribution during peak time consumption for pressure zone two. As shown in the figure7 above, junctions colored with magenta are junctions with shortage of pressure which accounts for 15.53% of the area.

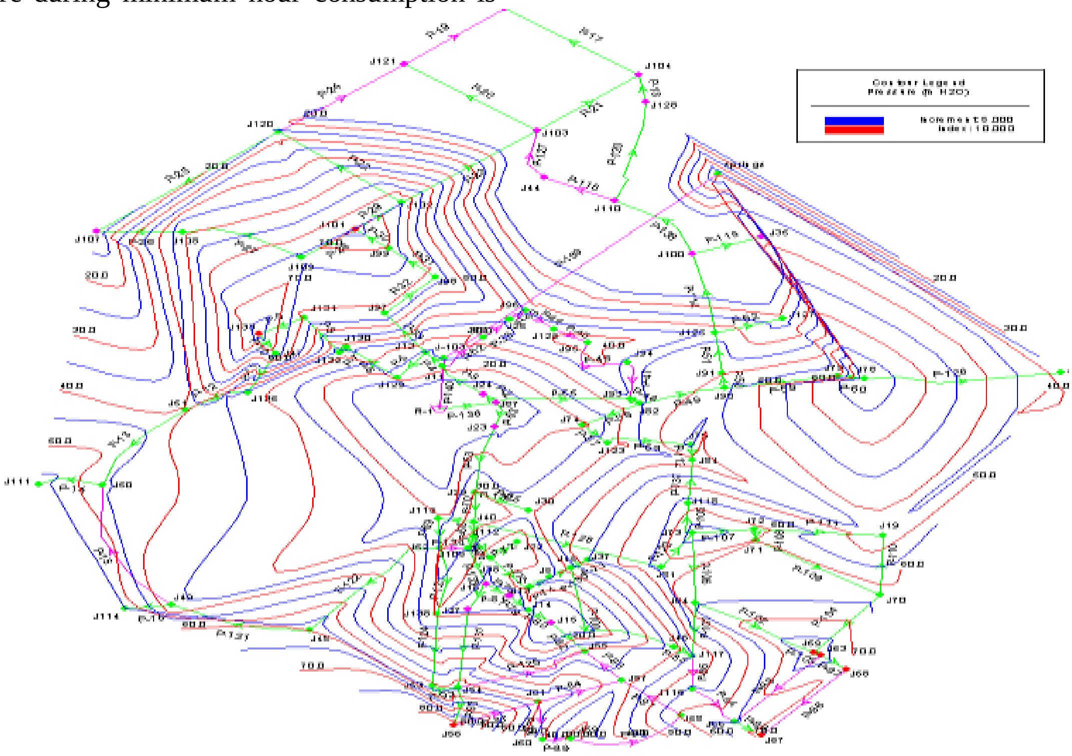
Velocity Distribution During Peak Hour Consumption

During peak hour consumption, 78.15% of velocity in water distribution network is within given limit and 21.85% of the velocity during peak hour consumption is less than 0.6m/s and there is no velocity greater than two.

Figure 8, shows velocity in distribution network in peak hour consumption for selected pipes.

Pressure Distribution during Minimum Hour Consumption

During minimum hour consumption, 1.98% of residents get water at low pressure. This is due to high elevation of the area which creates a low level of reliability of water users on the supply system. As shown in Table 8, two of the identified nodes have pressure below 15m and 38% of the nodes have pressure above 70 m. Thus, only 59.41% of the areas have pressure within the recommended limit (15m to70 m) during minimum consumption. The results for pressure during minimum hour consumption is summarized in Table 4.7 and its detail self-explanatory table is put in appendix A_4 andA_5



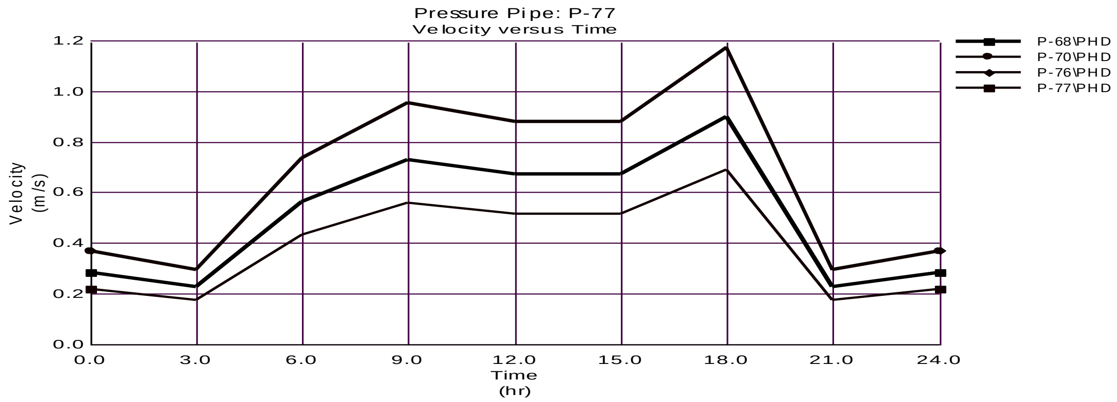


Figure8. *Velocity distributions for selected pipe*

Table8. *Distribution of pressure at minimum hour consumption*

Pressure (m)	Nodes	%
>70	9	38.61
60-70	12	11.88
50-60	6	5.94
40-50	21	20.79
30-40	11	10.89
20-30	9	8.91
15-20	1	0.99
<15	2	1.98
Total	101	100.00

Population and Water Demand Projection

Population Projection

In the 2007 census analytical report, CSA has established growth rates for all regions in the country. The rate that CSA has set for urban population projection of SNNPRS is shown in Table 1. This was considered for population projection. The population of Hosanna Town was estimated to reasonably quantify the inhabitants of the area until the end of the design period (2040). Using geometric mean formula, the population of Hosanna Town was forecasted and the detail is presented in the table 9 as follows.

Table9. *Forecasted Population*

Year	2010	2015	2020	2025	2030	2035	2040
Population number	77,184	95,269	116468	141022	167492	195114	231738

Water Demand Projection

Water managers forecast future water demand for a variety of purposes. These analyses can help managers understand spatial and temporal patterns of future water use to optimize system operations, plan for future system expansion, or for future service and expenditures. There are several mathematical methods in use for estimating future water demand. For this particular study, per capita use approach was adopted due to the availability of data and the simplicity of the method. Thus, population was projected from 2020 to 2040 by geometric increasing method using regional growth rate and then the corresponding water demand per mode of service was estimated until 2040.

Per Capita Demand Establishment

Based on working standard of the town the per capita demand of water per mode of service is 70, 40, 30 and 25 for Private house connections, Private yard connection, Private yard shared and Public taps urban respectively (MoWR, 2006). Based on the town master plan and the past trends, the change in water demand annually for Private yard connection and Private house connections are in increasing order. For public tap users it is in decreasing order for the year 2020 to 2025 and then it keeps constant for the rest of design period. The Private yard shared is decreasing throughout the design period. Based on these standards as a base line value, per capita water demand throughout the year was projected up to 2040 and put in Table 10 below.

Table10. *Per capita water demand*

Year	2020	2025	2030	2035	2040
Population	116468	141022	167492	195114	231738
Demand (l/c/d)	42.9	44.9	46.8	47.9	49.4

Projection of Domestic Water Demand

Estimation of water demand per mode of service and estimation of population by mode of service was used to calculate the average per capita water demand. The average per capita domestic water demand for each year was computed by combining water demand by mode of service and population percentage distribution by mode of service for the year 2020 to 2040. After the per capita water demand for each mode of service has been determined, the adjustments for climate and socio-economic factors were assumed to be unit according to the Town's design criteria. Once the total domestic water demand is projected, the other demand categories were projected as per the standard. The detail of adjustment and domestic water demand for each mode of service is presented in Table 12.

The total water demand of the town was determined by summing up the adjusted domestic water demand and Non-domestic water demands. In estimating the overall water demand for Hosanna town, 20% of total water demand was allocated for losses. The current maximum daily demand is 12405.42m^3/day and at the end of the design period (2040) it is 27287.84m^3/day. The design maximum water production capacity of the source is 11577.6 m^3/day but the current average daily production is 9936 (m^3/day) which is very low due to less working hour, reduction of boreholes yield, pump failure and lack of maintenance. Currently, the gap between existing supply and demand is 2470m^3/day. The gap will be 17352m^3/day in the year 2040. This indicate that need for the development of additional water sources to satisfy the 17352 m^3/day water demand of Hosanna Town for year 2040.

Table11. *Water demand projection of Hosanna Town for the year 2020-2040*

Year	2020	2025	2030	2035	2040
Growth rate	4.10%	3.90%	3.70%	3.10%	3.30%
Population number	116468	141022	167492	195114	231738
Domestic demand, m3/day	4996.477	6331.888	7838.626	9345.961	11447.86
Domestic animals m3/day	194.1	214.3	234.5	261.3	278.1
Institutional + commercial (20% of	999.2954	1266.378	1567.725	1869.192	2289.571

domestic demand), m3/day					
Industry m3/day	1465	1899.566	2351.588	2803.788	3434.357
University Community in No.	16000	18000	20000	22000	25000
University community demand (60l/c/day) (m3/day)	960	1080	1200	1320	1500
Total daily demand m3/day	8614.873	10792.13	13192.44	15600.24	18949.89
UFW %	20	20	20	20	20
UFW m3/day	1722.975	2158.426	2638.488	3120.048	3789.977
Average daily demand m3/day	**10337.85**	**12950.56**	**15830.93**	**18720.29**	**22739.86**
maximum daily demand, m3/day(1.2 x average demand)	12405.42	15540.67	18997.11	22464.35	27287.84
Maximum daily demand l/s	143.5812	179.8689	219.874	260.004	315.8314
Existing system capacity boreholes working for 18 hours, in l/s	30	30	30	30	30
Existing system capacity by considering efficiency of 80% for boreholes and two springs l/s	115	115	115	115	115
Additional demand, l/s	28.58121	64.86886	104.874	145.004	200.8314
Deficit, %	**19.90595**	**36.06453**	**47.69731**	**55.76991**	**63.58817**

Conclusion

The findings of this study shows that water loss in the study area is as high as **40%** of the produced water due to billing error, illegal connection, water theft, leakage during installation and pipe bursting. The population number of the town is increasing from time to time with increasing demand on the existing water supply system of the town. As a result, per capita water supply of the town gets lower and lower. The main cause of water supply interruption is shortage of water from the source, lack of maintenance, improper function of pump and interruption of electric power in pumped pressure system.

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Citation: *Amanuel Adane Anore. "Evaluation of Water Supply Distribution System and Hydraulic Performance of Hosanna Town" International Journal of Research Studies in Science, Engineering and Technology, 7(6), 2020, pp. 18-28.*