Water Distribution Network Analysis of Bodditi Town by EPANET

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Abstract
The current water supply system used in Boditi Town is an intermittent supply and the network is a branched system with dead ends. The water is distributed to the network from the boreholes by pumping and then by gravity flow. This network system may or may not be reliable to the coming years. Hence, the study checks the reliability of the existing network and concludes about its suitability on the network for the future. The distribution system was evaluated by EPANET which has collection of links connected to nodes or junctions. Pressure at each junction, unit head loss at each pipe and flow of water were evaluated for major water distribution system with the help of EPANET 2.0 and pressure map was developed with help of Surfer 8 software. Water loss of the distribution system was estimated by water balance method. The distribution system analysis showed that 9% of the junctions have above maximum and 2% of the junctions have below minimum operating pressures. Some of the pipes in the distribution system have head loss greater than the selected performance indicator. To achieve efficient and reliable water supply system, i.e, to avoid long distance pumping, and to avoid high pressure, pressure zoning had made by using surfer 8 software. The average water loss of the distribution system rated to be greater than the selected performance indicator.
Keywords: EPANET, distribution system, head loss, pressure, performance indicator, Boditti Town.

1. Introduction

Water distribution systems in urban areas are continuously evolving to balance the increase in demand arising from urban development, change in consumption patterns, industrial development and other domestic uses. Water distribution systems are important to the community to deliver clean water from storage facilities to consumers through a complex and extensive pipe network. Distribution systems consist of a water supply source and a pipe network. The distribution network is responsible for delivering water from the source to its consumers at serviceable pressures and mainly consists of pumps, pipes, junctions (nodes), valves, fittings, and storage tanks.

The minimum pressure that should be observed at junctions throughout the system varies depending on the type of water consuming sector and regulations governing the distribution system, but a typical operating range is between 15-70m (MoWR, 2006). It is undesirable to have high pressures because it causes more leaks, breaks and causes water wastage; and the pressure below the minimum will not afford sufficient amount water to the customer. Excessive pressure can be reduced by adjusting speed pump (intermitent supply), installing pressure reducing valves, and dividing the distribution system in to different pressure zones. If pressure of the system is not adequate to produce adequate pressure in all areas, pressure zoning should be adopted (Zephania, 1988).

The extensive manner of distribution systems makes them susceptible to physical disruption. In water distribution network systems there are problems such as inequalities in service provision and water loss. These indicate that, water distribution inefficiencies. Water loss in water supply systems ranges from 15% to 30% in the developed world but elsewhere it is likely to range from 30% to 60% (Bridges, 1994). Since there exists water loss in distribution system, the loss has to be reduced, because revenue from water supply decreases and the water supply does not balance the demand. To introduce water loss reduction strategy, the service provision should be evaluated or monitored by using performance indicators. Performance indicators are widely used as an assessment tool to evaluate the effectiveness/efficiency of the performance of water supply services (Ong *et al.,* 2007).

1.1 Objective

The objective of water distribution system is to supply water to all customers. All customers must be supplied with sufficient quantity of water at the required pressure. The main purpose of this study is:

- To check the design of the distribution system.
- To estimate the water loss in the distribution system.

2. Materials and methods

2.1 Description of the study area

The study was conducted at Boditi Town which is located in Damot Gale Woreda, SNNPR regional state, Ethiopia, having a total area of 1368.115 ha. Geographically, it is located: 6º56'0" to 8º58'0" N Latitude and 37º50'0" to 37º53'0" E Longitude. The Town is at an altitude ranging from 1880 m to 2112 m. The Town is 365 km from Addis Ababa and 140Km from Hawassa.

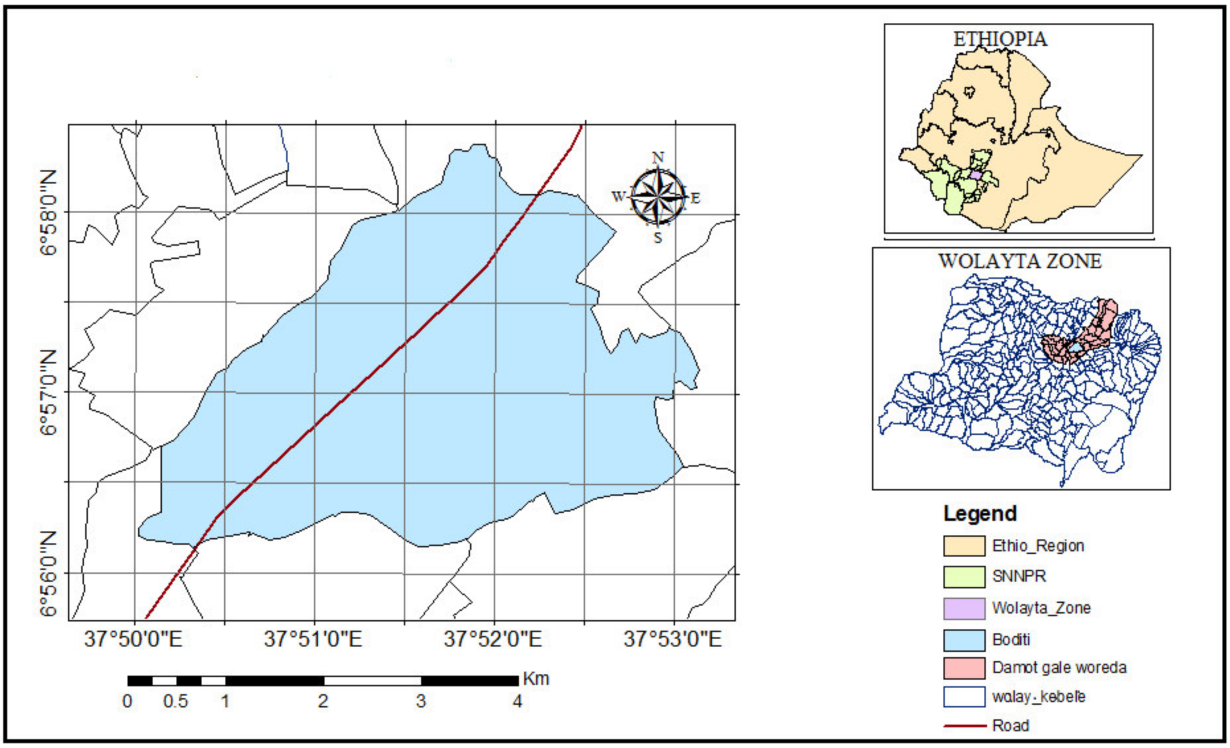

Figure 1: Location map of the Boditi Town.

2.2 Performance indicators used in the study

Performance indicators are variables whose purpose is to measure change in a process, i.e, monitoring the progress of a process, or performance indicators are used to assess the change resulting from a particular activity, i.e, evaluating the outcome of the process. There are six major groups of performance indicators. The complete group incorporates 133 indicators, of which 26 have been rated as top priority (Algre *et al*., 2000).

Table 1: Performance indicators used in the study.

Performance indicator	Description	Selected target
Pressure	Minimum and maximum pressure in pipes,	15m to 70m (MoWR, 2006),
unit head loss	Head loss in the water pipes	≤15m/km(TAHAL Consulting, 2003)
Water loss	Volume of water lost as percentage of water supplied.	20% (Tynan and Kingdom, 2002; Mwanza, 2004)

2.3 Water distribution network analysis

EPANET 2.0 software was used to evaluate the water distribution network. EPANET models a water distribution system as a collection of links connected to nodes or junctions. The links represent pipes and the nodes represent pumps, reservoirs and control valves (Rossman, 2000). The EPANET computer model for water distribution network analysis is composed of input data file and computer program. The data file describes the characteristics of the pipes, nodes, and pumps in the pipe network. The computer program solves the nonlinear energy equations and linear mass equations for pressures at nodes and flow rates in pipes. The pipe parameters consist of the length, inside diameter, and roughness coefficient of the pipe. The node parameters consist of the base water demand and elevation.

2.3.1 Head loss

The head loss input data used are pipe length, diameter, age and roughness coefficient. These data were obtained from the Town's water supply enterprise. The hydraulic head loss by water flowing in a pipe due to friction with the pipe walls was calculated by Hazen-Williams formula (Walski *et al.,* 2003) which is the most commonly, used head loss equation for drinking water flowing in distribution system.

$$H_f = \frac{10.68LXQ^{1.825}}{C^{1.852}XD^{4.87}} ------------------(1)$$

The frictional loss (H_f) is a function of the diameter of the pipe (D) in mm, length of the pipe (L) in m, flow rate (Q) in m^3/s and pipe roughness (C).

2.3.2 Junction pressure

Input data of junction are elevation and base demand. These data were obtained by operating GPS at every junction in the water distribution network. GPS readings of elevation and coordinates of a reservoir, pumps at the boreholes and pipe junctions were collected. In water distribution system, baseline demand comprises customer demand and unaccounted for water (water loss). Nodal demand allocation was carried out by a method called simple unit loading. This method involves counting the number of customers at a given specified area or number of dwelling units/housing units which use water at a given node and multiplying that number by the unit demand (per capita per day). After consumption rates are determined, the water use is spatially distributed as demands or assigned to nodes or allocate average day demands to nodes, and nodal demand is calculated by using (Amdework, 2012):

$$\text{Nodal demand}(N_d) = \sum P_i \text{ X } Dj ----------------(2)$$

Where N_d = Nodal demand, P_i = population who use water from/at each node, D_j = per capital demand.

The total water loss of the Town was quantified based on the total annual water production that was aggregated from the working hours of the four boreholes and distributed to the system, and the water billed that was aggregated from the customer meter readings. The water balance method was used to estimate the water loss in the distribution system. This method calculates the total water loss in the distribution system from total flows not for a limited time period (Jastin, 1993). This describes the difference between inflows to the distribution system and all types of water consumption.

$$total\ water\ loss(\%) = \frac{[W_{tot.prod} - W_{tot.cons(billed)}]X100}{W_{tot.prod}} ------(3)$$

Where, W $_{tot.prod}$ = total water produced, W $_{tot.cons}$ = total water consumed.

3. Results

The water distribution network was developed by Arc GIS software and GPS data. Map of the Town clipped from the SNNRP map. GPS data displayed on the Town's map and digitized.

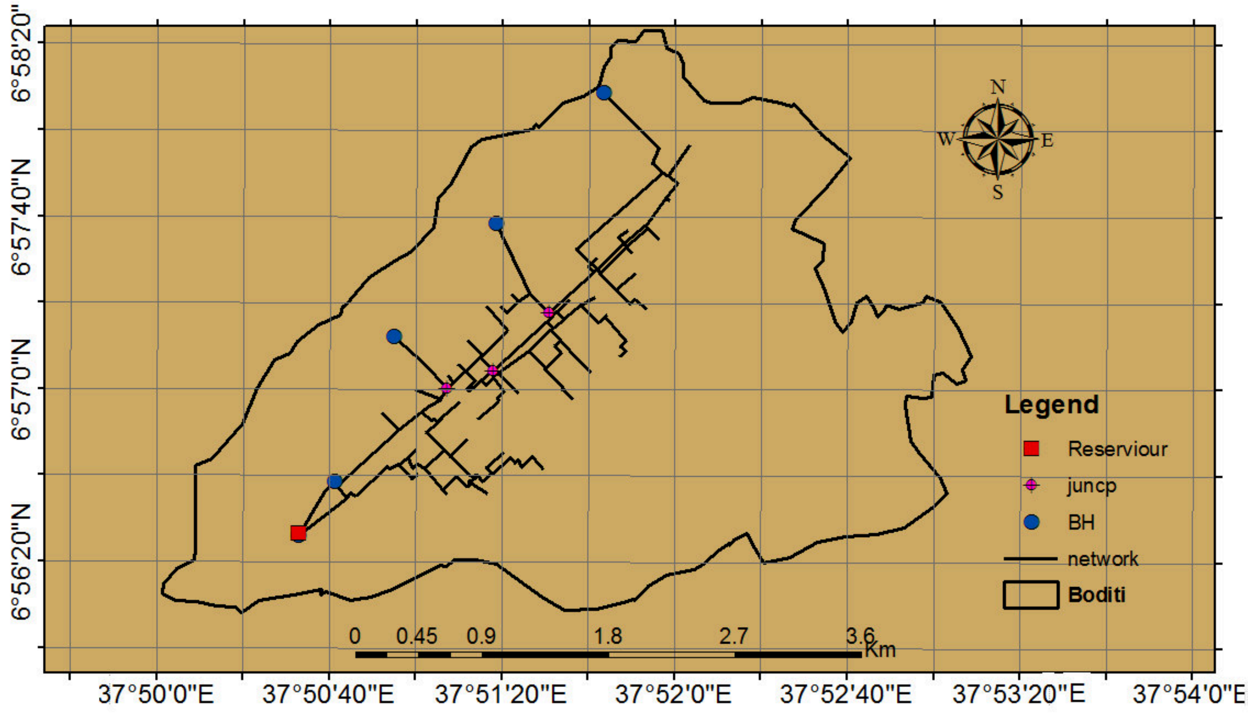

Figure 2: Water supply distribution network of BoditiTown.

Nodal water demand allocation was carried out by multiplying the number population who consume water at a given node and average daily water demand (per capita per day). In 2013 the average water production of the Town was estimated to be 231,309m^3/year. 633m^3/day of water was used to allocate average daily demands to 97 nodes/ junctions.

3.1 Water distribution network analysis

The net work analysis result of unit head loss and pressure are shown in Figure 3.

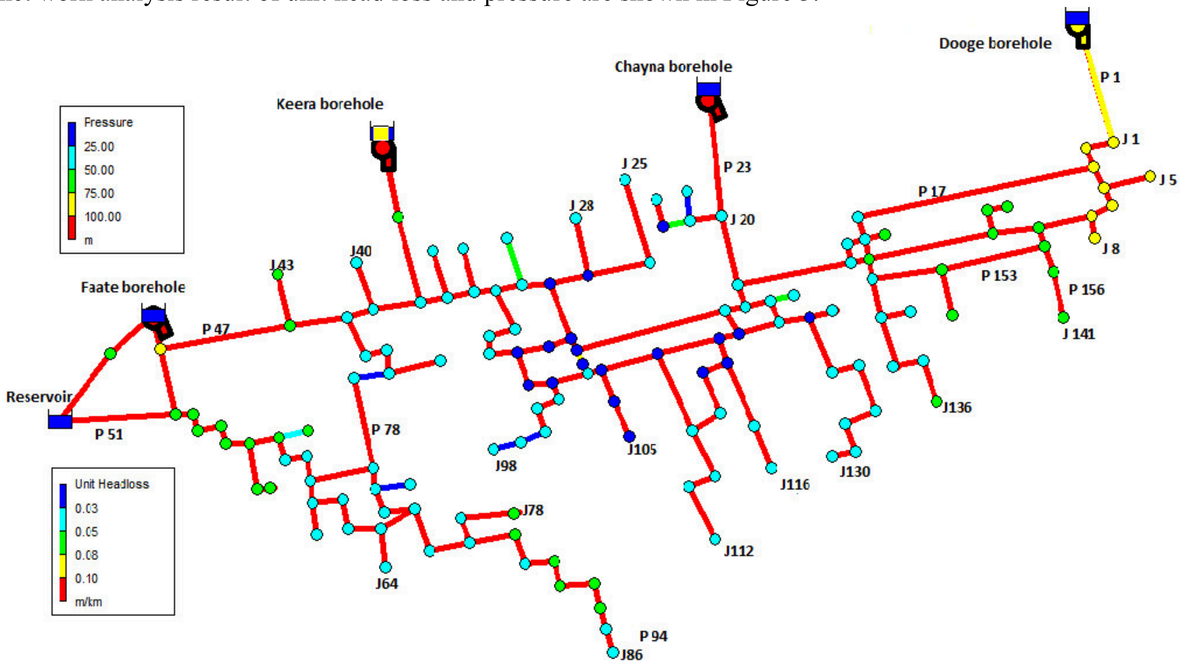

Figure 3: Water pressure distribution network of Boditi Town.

The minimum and maximum operating pressure in the water distribution system are expected to be 15 m and 70 m (MoWR, 2006). In the distribution system, 9% or 12 junctions have above the maximum operating pressure(70 m) and 2% or 3 junctions have below the minimum operating pressure (15 m)[Appendix-1].

With the age of pipes, their internal surfaces become rough which reduces the flow with a fixed pressure supply. The head loss gradient is allowed to be ≤15 m/Km) (TAHAL Consulting, 2003). In the distribution system, 30% or 44 pipes (6165m) have head loss greater than 15 m/Km[Appendix-2]. Their ages are 16 - 40 years. For example, in the distribution network, mains and sub mains from Catholic Church to Dmot Gale Woreda Finance office, West of Health Center, West of Idiget primary school, East and South of Warka Sefer, in front of Public Library, East of Tobacco Enterprise, pipes of Faate borehole have unit head loss greater than 15 m/Km.

The diameters of pipes have effect on head loss (Water Pipeline Design Guidelines, 2004). In the distribution network, the diameters of main lines at the West of Health Center, West of Idiget primary school and East of Warka Sefer have diameter less than 50 mm. These are 11% (1549m) or 19 pipes of the total main lines. Their diameter is less than 50 mm and 16-20 years. One pipe 4% (200 m) of the total sub-mains, in front of Public Library has diameter less than 38 mm and has ages 31-40 year. The head losses of these pipes were found to be greater than 15 m/Km.

The pressure of the distribution system was extrapolated by EPANET to areas with pipe networks of 141 junctions. This extrapolation indicates the contour plot of pressure in the distribution system. The pressure distribution is not an illustration of pressures at taps only, but it includes the pressure at all different nodes in the water distribution network system. The pressure contour plot works true due to pump heads and flows. The pump curves and reservoir heads were displyed during the network analysis.

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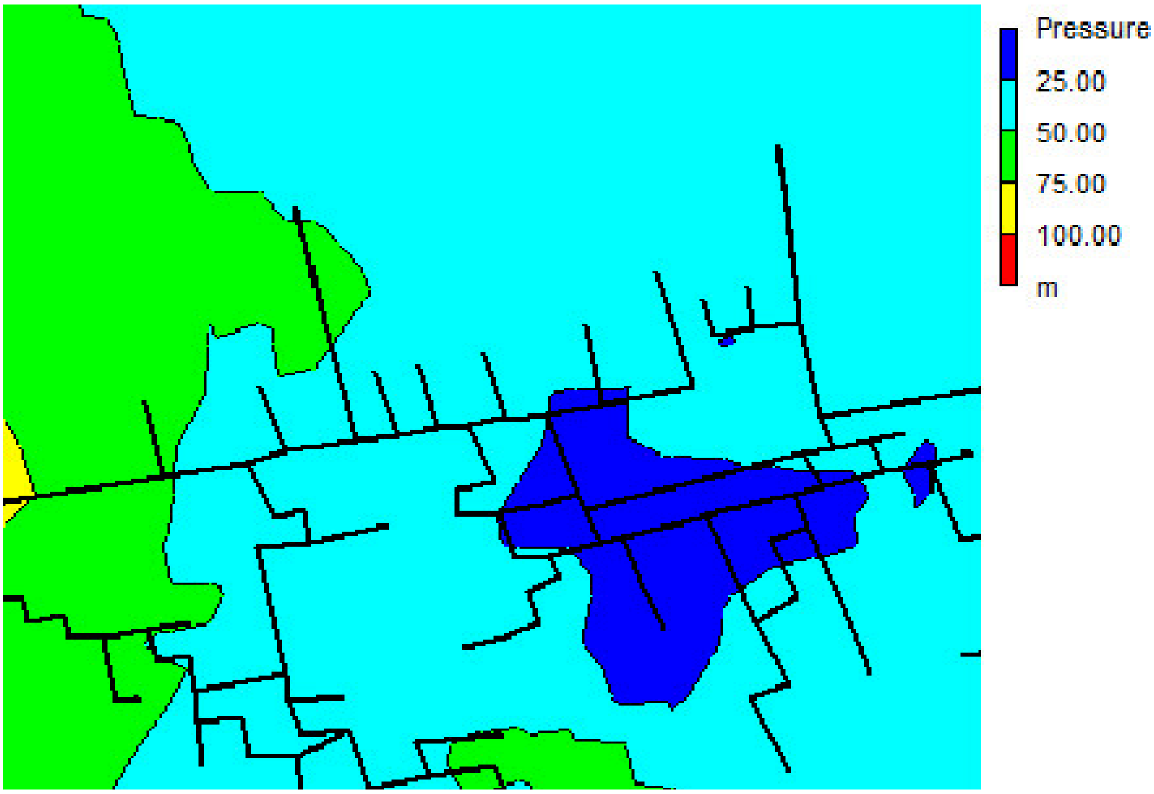

Figure 4: Pressure distribution in the network system of Boditi Town

There are extremes of of high and low pressures throughout the system due to topographic variation of the Town. The area of Faate borehole near to the asphalt road, is marked by high pressure above 70meters. Since the topography of the Town slopes to the East and areas starting from Tobacco Enterprise downward along the asphalt road is marked by hgh pressure above 70 meters. On the other hand, areas starting from back side of Damot Gale Woreda Finance Office, Post Office, infront and back side of Town's Manucipality, Stadium Sefer, Public Library, marked by low pressure areas. Areas starting from back side of Post office to Selam Sefer marked by very low pressures, below 15 meters. The other areas, most parts of the distribution system marked by serviceable pressures or pressure range in between 15 meters and 70 meters.

Areas starting from Tobacco Enterprise to the East highly slopes down and marked high pressure zone in the distribution system. These areas marked from junction nine to one. In these areas, water is pumped in to distribution system along the slope. The water has got energy from both pump and gravity. The pressure of these areas are increasing marked up to 90 meters at the junction five. The pressure profile of the these areas indicated in the Figure 5.

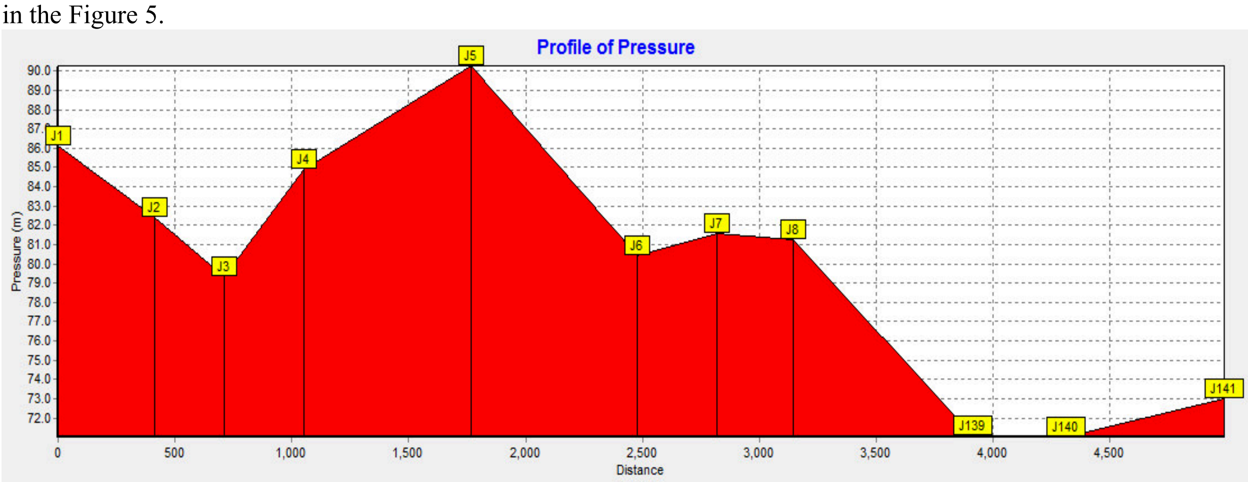

Figure 5: Pressure profile of some junctions of Boditi Town

3.2 Water loss of distribution system

The total annual water produced and distributed to the supply system and the water billed that was aggregated from the customers meter reading data were used to quantify the total water loss for the Town. The difference between water production and consumption indicator reflects the water loss, which can be rated as a percentage of the difference. Based on the last seven years data collected from Boditi Town water supply enterprise, the water production, consumption and unregistered volumes were estimated shown in Table below.

Table 2: Water balance of Boditi Town water supply system (2007-2013)

water balance (year)	System input volume (water production, m^3)	Consumed Volume (m^3)	Unregistered volume (m^3)	UFW (Water loss %)
Year 2007	167,076	109,651	57,425	34.3
Year 2008	185,487	120,420	65,067	35.0
Year 2009	193,032	123,775	69,257	35.8
Year 2010	192,158	124,694	67,464	35.1
Year 2011	221,025	147,456	73,569	33.2
Year 2012	224,936	151,207	73,729	32.7
Year 2013	231,309	151,359	79,950	34.6
Average	202,146	132,995	69,152	34.4

Based on Table, both water production and consumption were increasing from 2007 to 2013.The annual water loss increases from 2007 to the end of 2009, and decreasing from 2009 to 2012.In 2013, the annual water produced and distributed to the system within specified year was 231,309 m^3 and the aggregated annual water loss as derived from the above expression was 79,950 m^3 which account to 34.6%.

3.3 Pressure map of Water distribution system

Nodes with low pressures are located at higher elevations and nodes with high pressures are located at lower elevations. In the study Town's water supply system, nodes with low pressures are far away from the pump and located at elevated positions. In the supply netwok, these areas starting from back side of Damot Gale Woreda Finance Office, Post Office, infront and back side of Town's Manucipality, Stadium Sefer, Public Library, marked by low pressure areas. Specifically, areas starting from back side of Post office to Selam Sefer marked by very low pressures, below 15 meters. To this area, gravity is insufficient to supply water at adequate pressure. The pumps were located at the lowest position in which unable to pump the water to all positions in the distribution network. To indicate the pressure map of the Town's water supply system, pressures of 141 nodes were identified and analyzed by surfer 8 software and the results are summarized in the Figure 6.

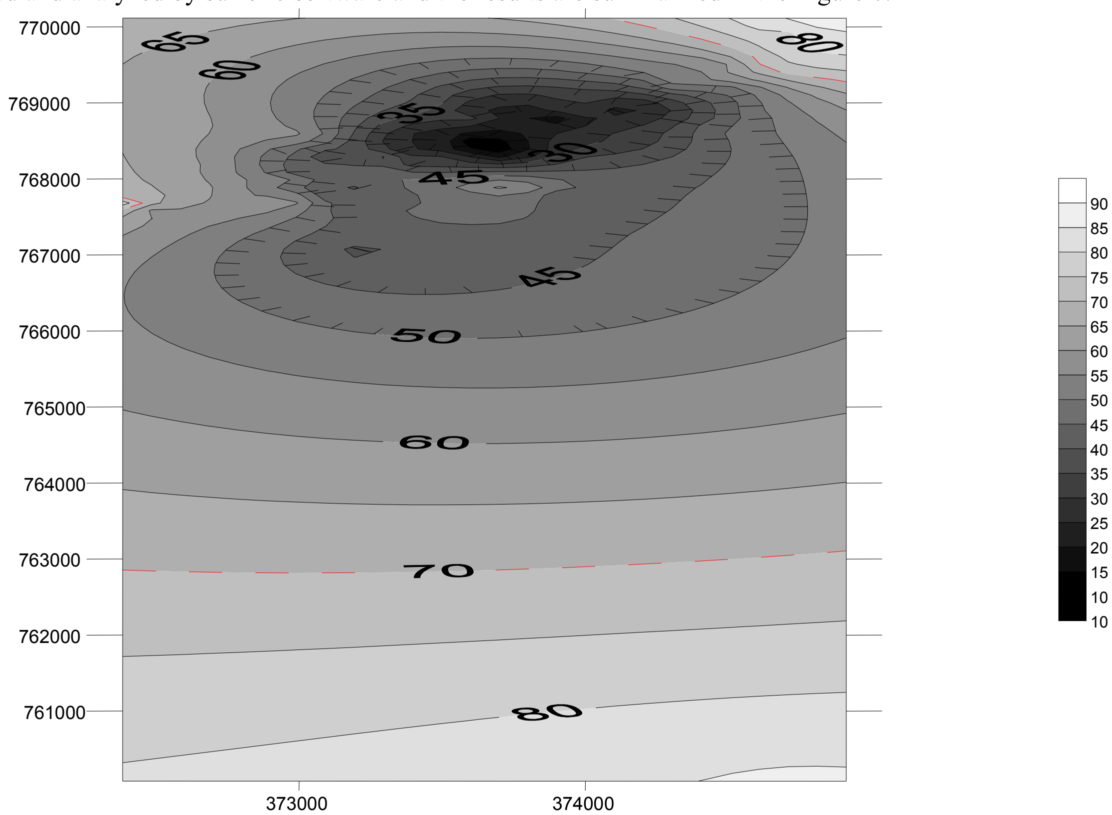

Figure 6: Pressure map of water distribution system of Boditi Town

4. DISCUSION

Out of 141 junctions analyzed in the distribution system, 9% of the junctions have above the maximum operating pressure (70 m) and 2% of the junctions have below the minimum operating pressure (15 m). In the distribution system of the Town, 30% of pipes (6165 m) have head loss gradient greater than 15 m/Km and their ages were greater than 16-40 years. In the distribution link analysis, 11% mainline pipes (1549 m) and 4% of sub-main pipes (200 m) have less diameters than the Minimum Design Criteria. As a result, their head loss gradients become greater 15 m/Km.

The performance levels obtained in this study based on both age and diameter of the pipes were above the selected target. The performance levels of pressures were below and above the selected target. Unit head losses in water distribution pipes ≤15 m/Km, the minimum and maximum operating pressures in the distribution system are 15m and 70m respectively. The violation of performances of unit head loss, pressure in accordance with Design Criteria results in low and high water pressures in the distribution system. The low pressure creates shortage of water and high pressure creates pipe burst in the distribution system.

In the distribution system, there areas marked by high and low pressure areas, so that water supply is not reliable. In case of Boditi Town, water supply problem is due to inadequacy of pressure in the pipes and water shortage from the source. Water supply service of the Town should attempt to ensure optimal pressure in distribution systems. Pressure zones are set to regulate pressure in locations in which large elevation changes creat high pressure at the lower elevation of the supply system and not serviceable pressure at the higher ends (Zephania, 1988). Based on the pressure map, the Town's water supply system proposed to have two pressure zones with reservoir installation to regulate serviceable pressures. Pressure zone one in between longitude of 372000 to 374000 (from Faate borehole to Saint Mary Church), Pressure zone two in between longitude of 374000 to 377000 (Saint Mary Church to end of the Town).

5. RECOMMENDATIONS

The following recommendations may be helpful in achieving efficient provision of water supply in Boditi Town.

- To maintain serviceable pressures or to have minimum and maximum pressure ranges in the supply system, pressure zoning along with reservoir installation should be made.
- Pipe installation need to be looped to have low flow velocities, reduced head losses, provide better residual chlorine content and resulting in greater capacity.
- To reduce water loss in distribution system, renewal of aged pipes and installing properly sized pipes for mains and sub-mains.

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Notes:

Appendix 1-Network Table – Nodes

Node ID	Demand (CMD)	Head (m)	Pressure (m)	Node ID	Demand (CMD)	Head (m)	Pressure (m)
J1	0.00	2090.08	86.08	J13	0.00	2077.41	55.41
J2	0.00	2087.42	82.42	J14	0.00	2077.43	43.43
J3	0.00	2085.36	79.36	J15	18.60	2077.40	50.40
J4	0.00	2084.88	84.88	J16	0.00	2078.68	47.68
J5	39.10	2084.27	90.27	J17	1.00	2077.20	44.20
J6	0.00	2084.44	80.44	J18	1.50	2077.38	42.38
J7	0.00	2083.55	81.55	J19	4.00	2072.62	28.62
J8	15.10	2083.28	81.28	J20	14.60	2071.41	27.41
J9	1.50	2081.35	69.35	J21	2.20	2071.39	26.39
J10	2.50	2079.32	56.32	J22	1.00	2071.39	28.39
J11	4.00	2079.14	55.14	J23	0.00	2071.38	24.38
J12	6.00	2079.05	57.05	J24	4.00	2071.37	30.37
J25	25.10	2081.06	37.06	J33	0.00	2087.62	28.62
J26	7.00	2081.47	32.47	J34	6.00	2087.58	32.58
J27	0.00	2082.19	24.19	J35	3.00	2094.50	36.50
J28	10.00	2081.99	31.99	J36	3.00	2094.49	38.49
J29	12.00	2082.23	24.23	J37	9.50	2098.75	39.75
J30	0.00	2085.28	26.28	J38	14.60	2104.97	55.97
J31	4.00	2085.27	27.27	J39	4.00	2101.94	41.94
J32	0.00	2087.38	28.38	J40	7.00	2101.85	46.85

Appendix -2. Network Table – Links

Link ID	Flow (CMD)	Velocity (m/s)	Unit Head loss (m/km)	Link ID	Flow (CDM)	Velocity (m/s)	Unit Head loss (m/Km)
P1	-16.23	0.06	0.14	P24	7.20	0.04	0.17
P2	236.79	0.87	20.53	P25	1.00	0.01	0.00
P3	236.79	0.87	20.53	P26	4.00	0.02	0.06
P4	166.76	0.61	10.72	P27	4.00	0.04	0.23
P5	39.10	0.22	2.17	P28	-25.10	0.14	1.69
P6	127.66	0.47	6.54	P29	-32.10	0.18	2.66
P7	127.66	0.47	6.54	P30	10.00	0.10	1.25
P8	15.10	0.34	7.32	P31	-42.10	0.15	1.48
P9	112.56	0.41	9.17	P32	-234.99	0.86	35.84
P10	66.01	0.38	10.12	P33	4.00	0.02	0.06
P11	10.00	0.15	3.03	P34	-238.99	0.87	36.98
P12	6.00	0.09	1.18	P35	-305.34	1.12	58.19
P13	53.51	0.31	6.86	P36	6.00	0.06	0.48
P14	-14.69	0.08	0.35	P37	-311.34	1.14	60.34
P15	18.60	0.11	0.55	P38	3.00	0.03	0.13
P16	-70.03	0.40	6.38	P39	-317.34	1.16	62.51
P17	-70.03	0.40	6.38	P40	-152.10	0.87	26.81
P18	57.05	0.33	7.72	P41	207.14	0.76	16.02
P19	-35.24	0.20	3.16	P42	-174.73	0.64	17.82
P20	-36.74	0.21	1.93	P43	7.00	0.07	0.55
P21	91.29	0.52	10.42	P44	-185.73	0.68	19.95
P22	192.83	0.49	5.77	P45	-205.18	1.17	71.15
P23	424.57	1.08	37.96	P46	16.10	0.09	0.25