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Water Distribution System Modeling to Reduce Leakage

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Abstract

Water loss is a common phenomenon observed in all water distribution systems. The process of water loss reduction is a basic part to increase the performance of a water supply system. The means presented in this study is aimed at evaluating water distribution pressure for the minimizing leakages in Dilla town water supply system network. Water CAD software was used to evaluate water distribution system, fixed pressure reducing valves (PRV) were installed at the most effective set of water distribution systems to reduced pressure as well as leakage quantities of water. An average water distribution pressure in the existing water distribution system was 58 m. Then, after the pressure reduced by pressure reducing valves (PRVs) average pressure dropped to 44 m, therefore, leakage in average reduced by 24%. The study concluded that the application of PRVs in the water distribution system as a promising solution for leakage minimization by reducing pressure in the water distribution networks, such as Dilla town.

Introduction

Water distribution systems (WDS) are a vital part of urban infrastructure and require high investment, operation and maintenance costs. It has been designed to satisfy the water requirements for a combination of domestic, commercial, industrial, and fire-fighting purposes. The system should also capable of meeting the demands and optimal pressure in each node within the distribution system at all times [1]. The water distribution system is subjected to deterioration with age and uncontrolled pressure. Thus, high pressure may cause pipe breaks, this is one of the most important parameters to exist leakage in the water distribution system [2]. Leakage in water supply networks make up a significant amount, sometimes more than 70% of the total water losses [3]. The main problems in the water distribution networks are hydraulic
leaks, where a hydraulic leak has been represented that the uncontrolled outflow of water that occurs in any section of the WD network. Therefore, it has serious consequences such as environmental pollution, economic losses and human health impacts. Leaks can occur often in damaged pipes, pipes with low maintenance, pipe joints or in some accessories such as elbows and valves, among others [4].

Leakage from distribution systems can represent a significant loss in water resources and hence there is pressure by regulators to reduce levels of leakage on all water undertakings [5]. There was a physical relationship among leakage flow rate and pressure, and the frequency of new bursts. Such as the higher or lower the pressure implies, to the higher or lower the leakage and the lower the pressure the lower the number of new bursts. Therefore, the pressure control strategy should be required to reduce excessive pressure as well as leakage in the water distribution system. Thus, recommended methods was required for reducing pressure in the system, these were as follows as variable speed pump controllers, break pressure tanks and fixed pressure reducing valve. However, the most common and cost-effective was the automatic pressure reducing valve [6]. On the other hand, hydraulic model (Water CAD) is the latest technology in the water conveyance system. Today, it is a critical part of operating water distribution systems to serving communities reliably and efficiently water demand both now and in the future [7]. In this study it was required to satisfy the water requirements for different purposes. The existing WDS in the study town does not satisfy the water demand because of the presence of high pressure in the WDS. Thus, it should have because water main breaks and the existence of leakage that were lead to unexpected insufficiency of water in town water supply systems. It should be also enabling reliable operation during irregular situations and perform adequately under varying demand loads. Therefore, the general aim of the paper was evaluation of existing WDS based on pressure modeling using Water CAD and Water Audit software model to reduce water loss in the Dilla Town Water Supply Systems, Southern Nation, Ethiopia.

Materials and Methods

Description of the study area

The study was conducted at the Dilla town, geographically located at latitude of 6° 25′ N and the longitude of 38° 18′ E, the study town is located approximately 360 km from Addis Ababa (capital of the country). The altitude of the town is characterized by the gentle slope from east to west an elevation difference between the 1680 m in the east dropping to 1,400 m in the west. The mean annual temperature at Dilla is 20°C, the warmest months are February to April when meaning daily maximums temperatures can rise above 30 ºC. The mean monthly rainfall and the mean annual rainfall is 109 mm and 1303 mm respectively (Figure 1).

Existing water distribution system and sources

The present waters distribution network in Dilla town consists of 306 pipes, 278 junctions, and 7 pumps. The town is studied through a normally branched network made of a mixture of Galvanized Iron (GI) and PVC/HDPE pipes with sizes ranging from 300 mm to 25 mm starting from borehole to every consumer. Figure 2 showed the existing water distribution system and sources, a total estimated length of distribution lines was covered by about
37.7 km. As observed from the drawn distribution layout; there are different

components of valves thus are a gate valve, check valve, air release valve, and pressure reducing valve or pressure gauge in sources was installed at a different location in existing WDS.

Existing water sources

The total capacity of the each existing water sources was 63 L/sec; it has

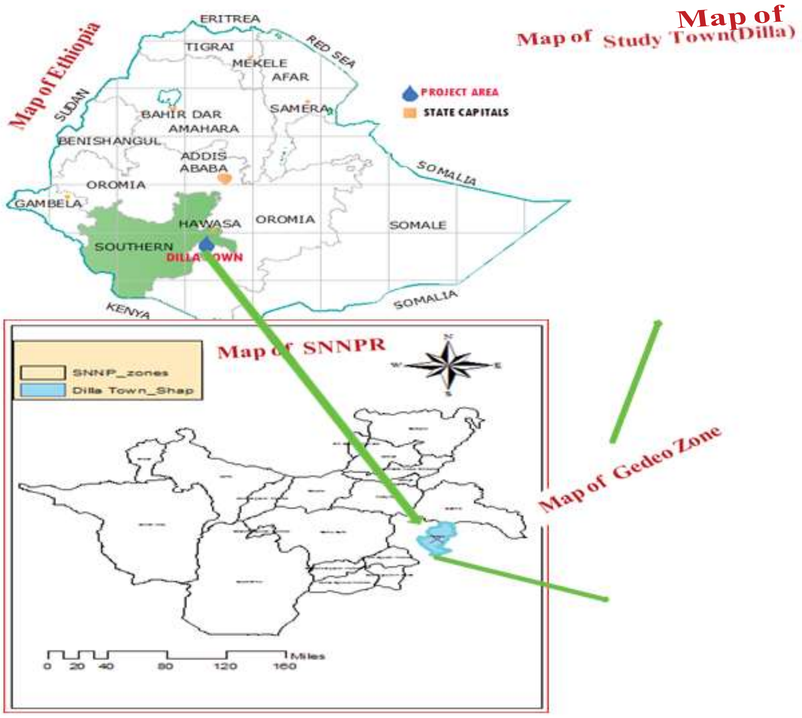

Figure 1. Location map of the study area.

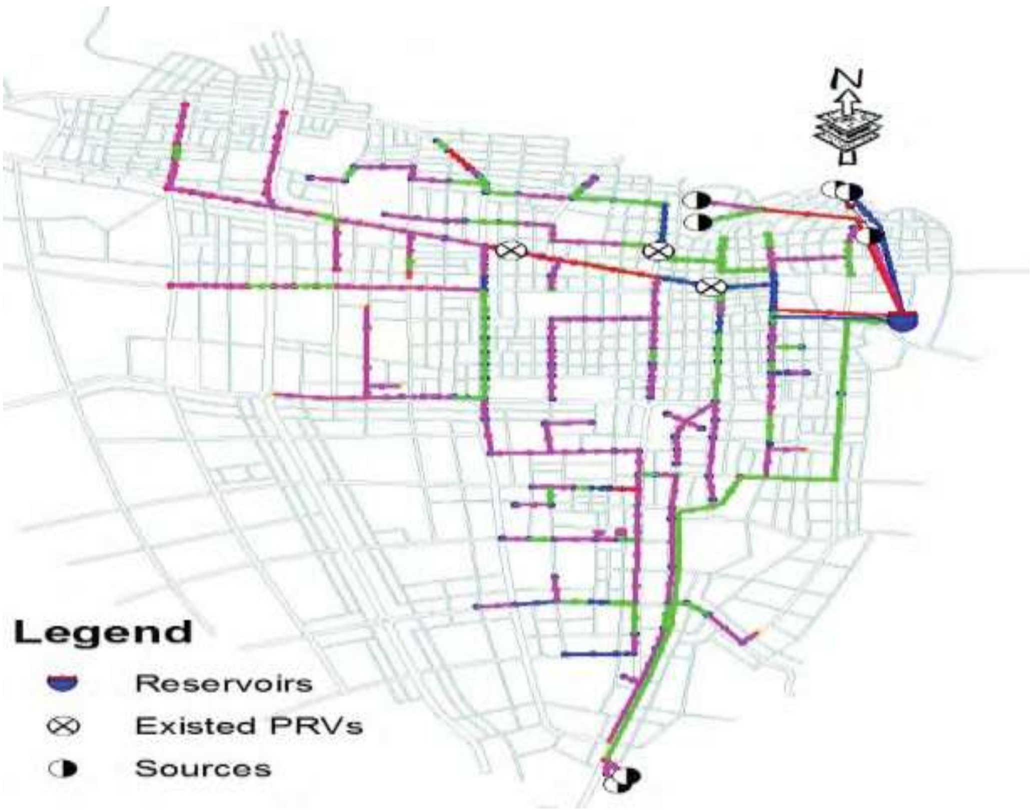

Figure 2. Existing water distribution system and sources.

been taken as total functional water production capacity excluding two newly added boreholes (Table 1).

Pressure zones and location of reservoirs

There were three reservoirs currently existed in the town two old existed and new added concrete circular ground reservoirs, with a capacity of 150 m^3, 200 m^3 and 500 m^3 respectively. However, one the newly constructed reservoir is still now not functional. The town has been proposed two pressure zones, the higher pressure zone reservoir (HPZ-R) at an average ground elevation of 1655 m and lower pressure zone reservoir (LPZ-R) at 1541 m (Table 2).

Population and demand distribution

Based on the projection done by CSA (2007) the population of the town was 77,856 at the end of the design period and forecasted using the geometric method. At the end of the design period 2030, the average daily demand, maximum daily demand and peak hour water demand of the town were estimated as follows 9,339 m^3/day, 12,141 m^3/day, and 16,811 m^3/day respectively.

Water distribution network data

In order to achieve the objectives of this study water distribution network data collection was carried out such as pipe data (length, diameter, material types); junction data (elevation, water demand, reservoir and tank section) has been collected. The primary and secondary data has been obtained from the Dilla Town Water Supply Service Enterprise (DTWSSE).

Selection of modelling software and data analysis

The collected data have been analyzed and implemented by using Water CAD, Version 6.5 hydraulic modeling software program for evaluation hydraulic parameters of the water distribution system. The nodal pressure in all water distribution systems has checked especially at the point of the lower and higher elevation of the distribution system. The existing water distribution system design network has been evaluated for the representative of the existing situation. Excess pressures formed in the water distribution system managed by installing a pressure reducing valve at most strategic points in the network to reduce the quantity of leakage by reducing pressure.

Water loss analysis

In order to analysis water loss, all the required data collection was carried out such as water supplies data, authorized consumption and billed data, waterloss data, system data, and cost data. To acquire the total loss of water in the town, the total volume of water supplied to the distribution network obtained was 5,483.81 m^3/day. Next, Water audit technique or water balance has been used to water loss analysis. whereas, approaches taken that of real loss control included such as pressure management and active leakage control (quantifying existing leakage and leak detection and reporting techniques). The volume of metered and unmetered water taken by registered customers. The total annual water produced and distributed to the distribution system and the water billed that was aggregated from the individual customer meter readings have been used to quantify the total water loss for the entire town. Then, the difference between production and water consumption was quantified as total water loss.

Results and Discussion

Water production and consumption

The water production rate of the town water supply has increased from 942,952 m^3 in the year 2014 to 2,001,590 m^3 in the year 2018, whereas water consumption increased from 471,476 m^3 to 940,747 m^3 during the same period. As illustrated in Table 3 an average of 51% of the total quantity of water supplied has been undertaken for losing (Table 3). This figure has to be showing that the critical water insufficiency in town is due to high water loss. The quantity of water loss in the study town is higher when compared with the average loss for developing countries proposed about 50% [8] whereas, water loss on the monthly basis used mainly to identify the seasonal variation of water losses 2018, considering the average monthly data for analysis the maximum loss was recorded in July, August, September, and October). Whereas the minimum monthly water loss was recorded in January, February and December were shown in Figure 3. As to understand from the monthly loss trend chart, the loss has been depended upon seasonal variation and operation and maintenance activities of the utility. Therefore, the maximum loss was observed during the rainy season in the study town, and also declines it relatively at the time of the operation and maintenance activities. The reason for this situation is the difficulty of leak detection at the rainy season and also difficult to identify and visualize them because they stay simply unseen flowing along with runoff for a long period. The other main reason is when declining consumption which pressure will show increments in the system that impliesto increment of leakages.

Evaluation of the existed water distribution systems

Pressure in the water distribution network for these selected junctions is shown in Figure 4. The results of the model outputs shown that the maximum pressured occurred at J-234, the average pressure has occurred at J-221 and the minimum pressure has occurred at J-157. The peak water hourly water demands were 8.98 m at J-234, as 44.18 m at J-221 and 137.39 m at J-157. The results were in water pipeline design guideline as recommended pressure in WDS in the ranges of 10 to 70 m [9]. However, under special circumstances, where the pressure main is allowed to exceed 70 m but the model outputs shows that there is a wide gap between this recommendation (Figure 4).

Table 1. Existing water sources.

S. No.	Borehole	Borehole yield (L/sec)	Geographical Location			
			Easting	Northing	Elevation (m)	Status
1	Chichu-1	5	423466	705370	1529	Working
2	Chichu-2	5	423491	705412	1529	Working
3	Marema	8	423848	709231	1572	Working
4	Mengesha	8	423848	709370	1569	Working
5	Millinium	12.5	424437	709426	1561	Working
6	Lagadara TP	15	424458	709407	1565	Working
7	Hiwotbiran	9.5	424538	709200	1600	Working
8	Kalihiwot	64	423682	707173	1571	New added
9	Hostel	9	423413	706811	1559	New added
	Total	**136**				

Table 2. Reservoir information of the system.

Label	Elevation (m)	X	Y	Capacity (m^3)
Concrete Service R-1	1656	424704	708554	200
Masonry Service R-2	1655	424705	708513	150

Table 3. Water production and Consumption (m^3) for the Years 2014-2018.

Year	Water production (m^3)	Billed water consumption (m^3)	Water loss (m^3)	Water loss (%)
2014	942952	377181	565771	50
2015	709798	321176	388622	49
2016	861909	368337	493572	50
2017	1301029	688375	612654	51
2018	2001590	1266829	734761	53
Average	**1,163,456**	**604,380**	**559,076**	**51**

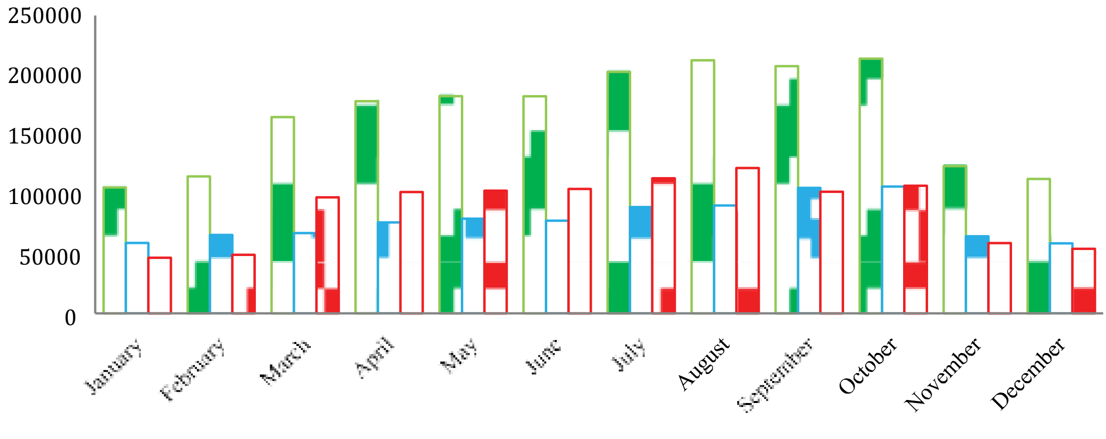

Figure 3. Monthly averaged water production, consumption and loss trend.

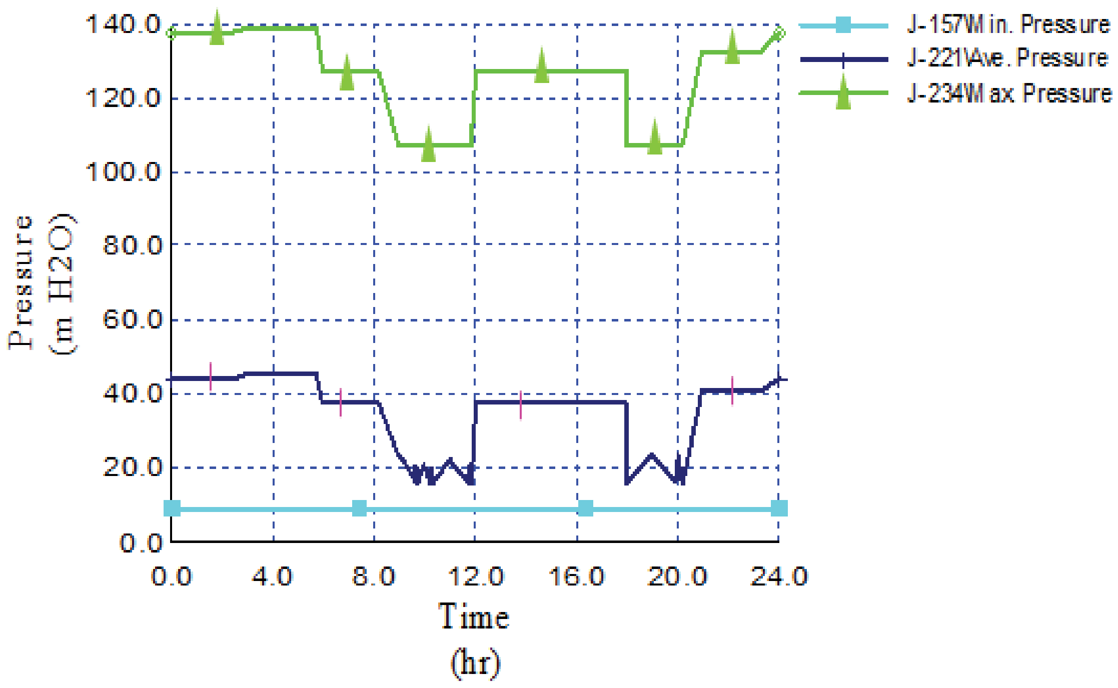

Figure 4. Time series plot for the selected junction's gravity main.

The pressure standard declared by Ethiopian Ministry of Water, Irrigation and Electricity for the minimal and maximum acceptable water pressure in the water pipeline in the range of 15 m to 70 m in order to this recommendation the value is not valid. About 27.70% of the junctions in the study area were found above the maximum pressure requirement limitation that was near to Buuno Kebele, Odaya'a Kebele and Dilla University Samara campus Table
4. Whereas 1.44% of the node was obtained below the minimum limitation pressure required that was around the old prison district especially Bareda Kebele. The result presented that the water pressure in some of the junctions was not functional and not working according to the standard set by Ministry of Water, Irrigation and Electricity. The obtained result indicates that 29.14%

of the nodes are out of this recommended range in the case study site (Figure5) [10].

Hydraulic model interpretations on post proposed solution

The hydraulic model result obtained from the post proposed solution and presented in Figure 6. On the proposed model, the maximum, average and minimum pressure have occurred at J-234, J-163, and J-157 and its values at peak hourly demand were 8.98 m, 44 m, and 70 m respectively (Figure 5).

Minimum pressure was around to an old prison district and maximum

Table 4. Results of existing pressures in WDS at peak hour demand.

Pressure range m H2O	Junctions in Number	Percentage (%)
≤ 15	5	1.8
15 to 20	16	5.76
20 to 30	40	14.39
30 to 40	67	24.1
40 to 50	70	25.18
50 to 60	33	11.87
60 to 70	32	11.51
Above 70	15	5.4
Total	**278**	**100**

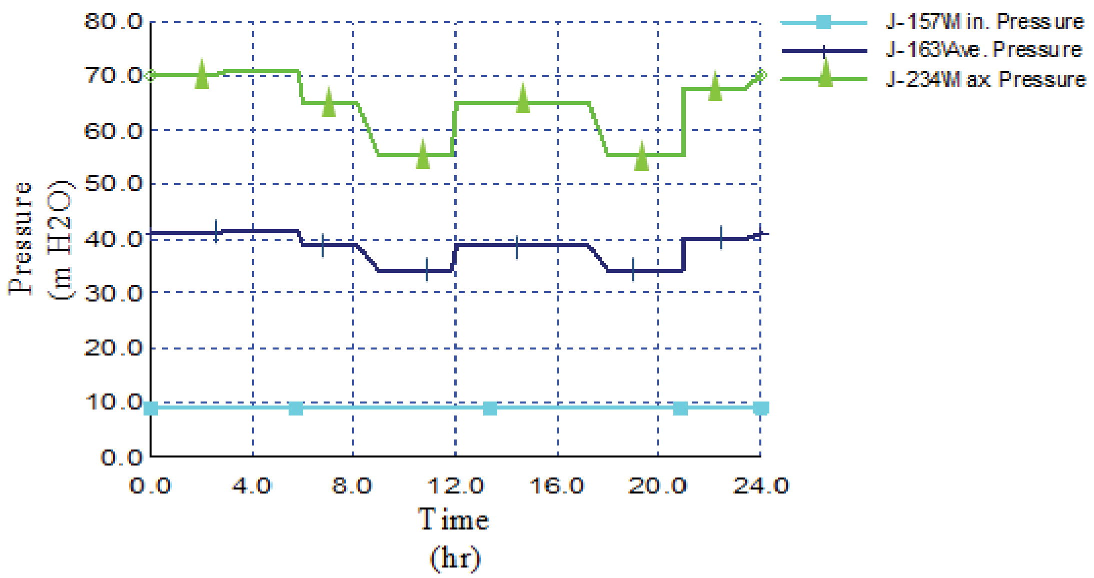

Figure 5. Maximum and minimum pressure in the water distribution main.

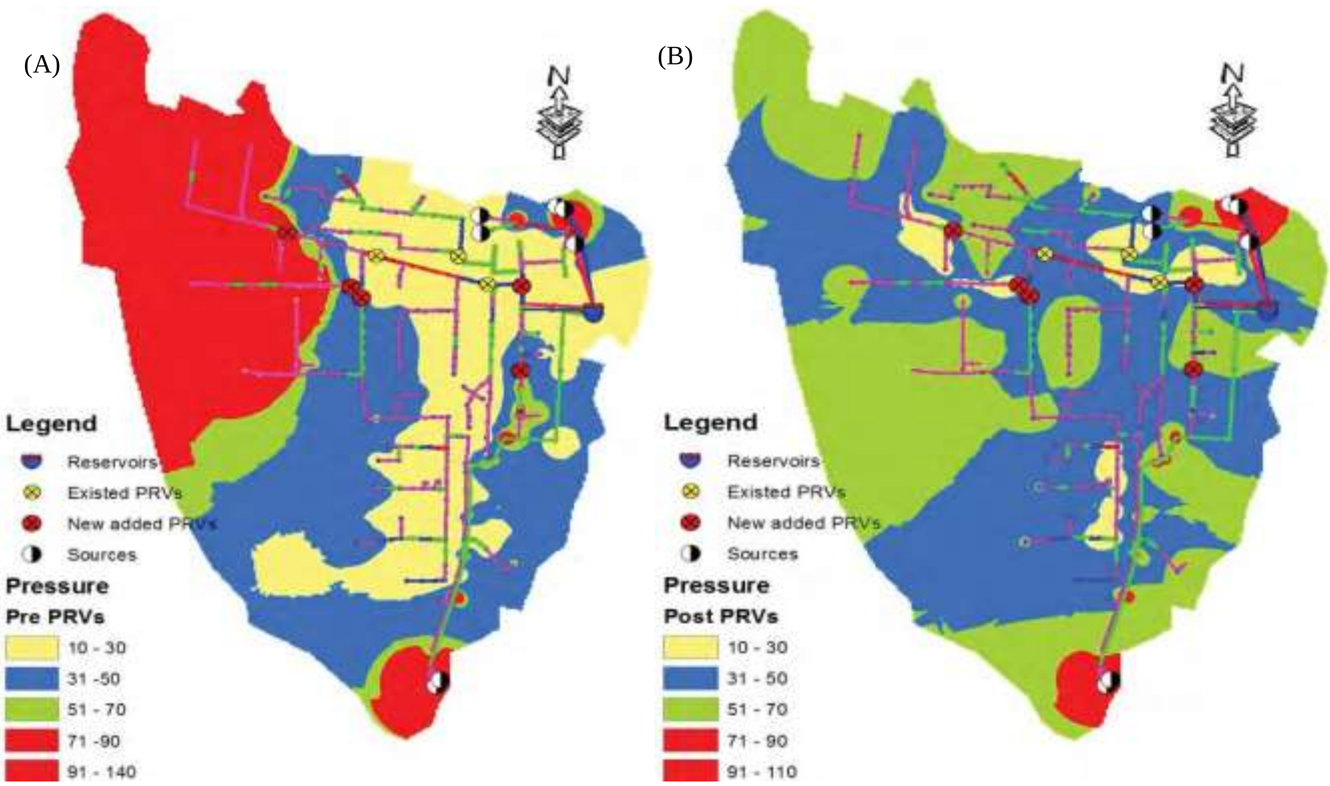

Figure 6. Pre-pressure modeling map (A) and post used pressure reducing valve (B).

Table 5. Optimum pressures in water distribution systems.

Pressure range m H2O	Junctions in Number	Percentage (%)
≤ 15	5	1.8
15 to 20	16	5.76
20 to 30	40	14.39
30 to 40	67	24.1
40 to 50	70	25.18
50 to 60	33	11.87
60 to 70	32	11.51
Above 70	15	5.4
Total	**278**	**100**

Table 6. Difference between water pressure pre and post-PRVs installation.

Junctions	Existed system (m)	Post PRVs installing (m)	Decrease pressure in (%)
J-8	106	38	64
J-18	79	67	15
J-106	114	46	60
J-219	129	61	53
J-234	138	70	49
Average	**113.2**	**56.4**	**48**

pressure was around Dilla University Odaya'a campus. When comparison this result to the recommendation in South African proposed that a minimum pressure was 12 m for the low-income area. In addition as USA design criteria guidance manuals recommended that the minimum pressure is 14.1 m. It was compared with Ministry of Water, Irrigation and Electricity recommendation that was acceptable operating range through distribution network were 15 m to 70 m. Therefore, compared to these guidelines Dilla town current model simulation outputs were acceptable.

As shown in Table 5, on the proposed WDS 92.8% junctions were found under satisfies the recommendation but about 1.80% of junctions were obtained below the minimum requirement that was around the old prison residential area and the reaming 5.40% junctions were above that of maximum standard. As results illustrated in Table 6, there is a big difference between the pressure before PRV and post PRV installing for the randomly selected Junctions. Hence, pressure post PRV installing results at nodes J-8, J-18, J-106, J-219, and J-234 are decreasing in percentage 64%, 15%, 60%, 53%,and 49% respectively. Also, the result that post PRV installing showed that the pressure of the nodes is smaller than that of the before PRV installing. The reduction of pressure about 10% means equivalent to the reduction of leakage by 10%. Therefore, reduced leakage can expected 64%, 15%, 60%, 53%, and 49% for each randomly selected nodes respectively. In addition the option of pressure control strategy can yield reductions in leakage up to 20-30% [5,6]. When to evaluate entire of the existing water distribution system (WDS) An average pressure which of the total junctions in WDS was 58 m, whereas post installing pressure reducing valves (PRVs) was reduced to 44.1 m. Average water loss for five consecutive years was 51% of the water supplied. Therefore, after installing pressure reducing valves (PRVs) the result showed that water loss in averagely reduced to 24%.

Pressure statistical comparison

Figure 6, showed that pressure model map difference between pre and post PRV installation. Certainly, the comparison showed that the water pressure in the distribution system has been fulfilled above design criteria during the post PRV installing, except pressure main are some extents out of above the maximum acceptable recommendation.

Conclusion

This study presents evaluation of the water distribution systems using Water CAD and Water Audit software. The study specially focused on water loss reduction in the Dilla town water distribution network system using a pressure reducing option. Consequently, the evaluated results of the existing water distribution system (WDS) an average pressure are 58 m; Average water loss was 51% of the water supplied. Although after using pressure reducing valves (PRVs) average pressure that reduced to 44 m. Therefore, the result showed that water loss in averegely reduced to 24%. When we compare the outputs, water pressure in WDS post-PRVs installing was smaller than that of the pre PRVs installing. Based on the finding, the expected output of this research will have a proportion of optimum water use. Finally, the results have significant by helping the town and all stakeholders for the planning of future works. It also provides a basic background brief for further researchers.

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