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Assessing Water Supply Coverage and Water Losses from Distribution System for Planning Water Loss Reduction Strategies (Case Study on Axum town, North Ethiopia)

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Abstract

Problems in provision of adequate water supply to the rapidly growing urban population in developing countries are increasing dramatically. Moreover, reduction of non-revenue water remains one of the major challenges facing many water utilities in Ethiopia in general and Axum water supply system in particular. This study mainly focuses on the status of water supply coverage and water losses in Axum town using statistical analysis and Water audit software. A statistical analysis was applied to analyse the current water supply coverage of the entire town and to develop distribution coverage map using Arc GIS software. Water meter test was conducted for samples from each size of meters installed in the distribution system of the town in order to quantify the water loss through meters of under registration. Water audit software was also used to analyze water loss components and the efficiency of the system was evaluated using different performance indicators. Discussions were made with Local experts' to support the quantitative analysis. From the result of the analysis, it was observed that the average daily per capita water consumption of the town is 12.8 litre/person/day. Thus, nearly 75% of the entire town population is getting water less than the basic service level and the average in-house or yard connection of the town is 27%. Besides, the total water loss in Axum water supply system is high enough up to 39.1% of the system input volume and about 8.84% of the total system loss is mainly due to meter under registration. In general, the low water supply coverage of the town was highly influenced by the availability of water. However, the main reasons for the high loss of water in Axum water supply system are the present way of water network management with ad-hoc maintenance and insufficient financial resources of the utility. Thus, it is necessary to identify the losses encountered in the water supply system so as to take remedial actions in reducing the water loss more significantly.

Key words: water supply coverage, non-revenue water, water supply system, water audit software, performance indicator, meter under registration.

1. Introduction

Problems in providing satisfactory water supply to the rapidly growing population especially that of the developing countries is increasing from time to time. Water supply systems in urban areas are often unable to meet existing demands and are not available to everyone rather some consumers take disproportionate amounts of water and the poor is the first victim to the problem (Bereket, 2006). Moreover, managing and reducing losses of water at all levels of a distribution system remains one of the major challenges facing many water utilities in most developing countries including Ethiopia. As a result of the overall shortage of water many water utilities are faced a problem in distributing the available water impartially among the residents. Beside to this poor management of the existing infrastructural asset increases the level of water losses in water supply (Mebet, 2007). Axum town is one of the towns that have been getting potable water supply system since the imperial regime. The rapid increase in population, economic development and awareness of health benefits of improved water and sanitation have been proven by WWDSE (2010) to cause rise in water demand, necessity of improved system infrastructure management and strategies to deliver clean and safe drinking water to customers. Even though distributing the available water and water loss from a utility's distribution system is a growing management problem in Ethiopia, there are few studies conducted on the existing water utilities in the country related to water loss and coverage. Although the Axum town water utility distribution system components were built decades ago and are currently in need of attention, issues related to the overall coverage of water supply and water loss from the utility are not investigated yet. Therefore, assessing the water supply coverage and water loss using statistical and water audit methods in order to develop strategies for the future is more urgent than ever. For that reason this study mainly deals with water supply coverage and loss assessment and developing strategies for the water loss reduction in Axum town water utility.

2. Methodology

The research process

The water supply coverage of the town was first evaluated before analysing the water loss. In evaluating the water supply coverage the focus was on the volume of consumption and level of water connection as these are highly related to the issue of water loss. After evaluating the distribution of water supply coverage in the town, the water loss from the distribution system of the utility was analysed. The total water produced and the actual water consumption as aggregated from the individual contracts (customer meters) was used as an input for the water loss analysis. Water meter accuracy test was conducted and the result was used as an input in the analysis of the total water loss components. The water loss analysis, both apparent and real, is carried out by using the top down water balance approach. Finally, based on the calculated performance indicators and key statistics comparisons has been made, and strategies for loss reduction are developed from international experiences.

Water supply coverage analysis

The water supply coverage of the town has been evaluated based on the average per capita consumption and level of connection per family. The average per capita consumption has been derived from the yearly consumption that was aggregated from the individual domestic water meters. Beside to the average per capita water consumption, the distribution of number of domestic connection per family has been also evaluated. Statistical analysis was used to evaluate the supply coverage for the entire town and supply coverage map has been developed using Arc GIS.

Average daily per capital consumption

The volume of water consumed for domestic purpose has been aggregated to all 23 districts of the town so as to analyse the distribution of the water supply coverage among different localities. The annual consumption data has been converted to average daily per capita consumption using the number of population. The average daily per capita consumption of each district was derived using the following expressions:

$$\text{Per capital consumption (l/person/day)} = \frac{\text{Annual consumption (m3)} * 1000\text{l/m3}}{\text{Population number of each district} * 365 \text{ days}} \quad (1)$$

Level of connection per family

In order to compare the distribution of the water connection among the different districts, the total numbers of connections per district are converted to connection per family using the population data of each district by the following expression.

$$\text{Connection per family} = \frac{\text{Total number of connection by district}}{(\text{Number of Population by district/Average family size})} \quad (2)$$

Water loss analysis

The water loss in the town water supply distribution system was evaluated using top-down water balance method. Detail analysis of the water loss components has been done using the AWWA water audit software version 4.2.

Performance indicator Assessment

Non-Revenue Water: as % of system input volume

Percentage by volume is still recommended as a basic financial PI for non-revenue water but a basic PI for real loss from a water resources viewpoint, it should not be used for assessing any aspect of operational performance management of water losses (Liemberger & Farley, 2004). It is given by the Expression:

$$\text{NRW (\%)} = \frac{(Qin - Qrevenue)}{Qin} * 100\% \quad (3)$$

Where Q_{in} = annual system input volume

$Q_{revenue}$ = annual billed volume

Non-Revenue Water: as % of cost of running system

The detailed financial PI for non-revenue water is based on the percentage by value of the water, rather than the percentage by volume (Mutikanga *et al.*, 2010). A general expression for estimating this metric is:

$$\text{NRW (\%)} = \frac{\text{cost of Non revenue water}}{\text{cost of operating system}} * 100\% \quad (4)$$

Apparent loss per service connection

The purpose of this operational indicator is to evaluate the volume of apparent losses per service connection in the utility system. This is a useful indicator to compare between utility systems (Sarah, 2006). It is calculated as:

$$\text{Apparent loss (l/con/day)} = \frac{VApparent}{Nc} \quad (5)$$

Where $V_{Apparent}$ = volume of apparent loss per day (m^3/day)

N_c = number of service connections

Real Losses per service connection

The objective of this performance indicator is to measure the efficiency of the water supply system (Mutikanga *et al.*, 2010). It is given by the expression:

$$\text{Real loss (l/con/day)} = \frac{VReal}{Nc} \quad (6)$$

Where V_{Real} is the volume of real loss per day (m^3/day)

Infrastructure leakage index

It is the ratio of the current annual real losses (CARL) to the unavoidable (technical minimum) annual real losses (UARL). It is calculated as follows (Liemberger & Farey, 2004).

$$ILI = \frac{CARL}{UARL} \qquad (7)$$

3. Results and discussion

Average daily per capital consumption

The average domestic water supply coverage of the town is found to be 12.8 l/capital/day. This average per capita consumption is very low while compared with the country standard used for design purpose (30 to 50 l/capital/day) and even it is lower than that of the minimum standard set by UN-Habitat as a basic need (20 l/capital/day). Out of the total 23 districts of the entire town, 18 with 51 thousand inhabitants (nearly 75%) are getting water less than this basic service level.

The histogram and map of average daily per capita consumption distribution developed for the entire town was shown in Figure 1 and Figure 2 respectively.

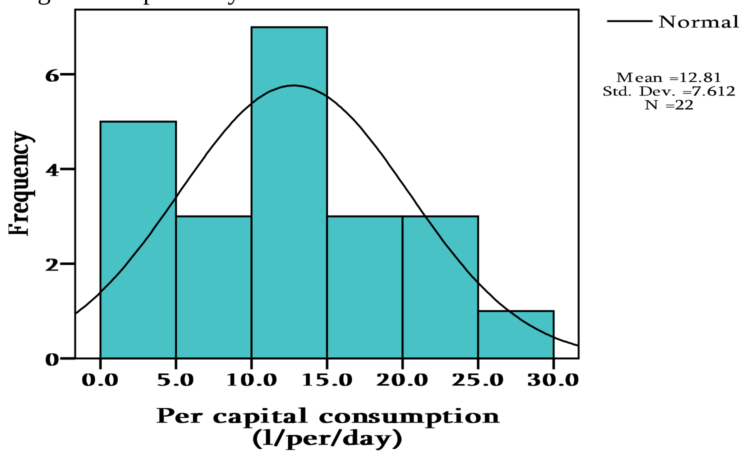

Figure 1 Histogram of the average daily per capita consumption after excluding outliers

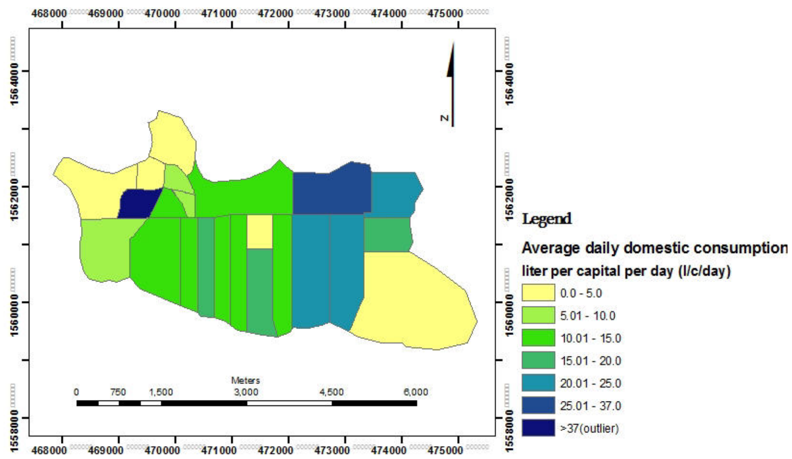

Figure 2 Distribution map of average daily per capita consumption by district

Level of connection per family

In this analysis the total numbers of domestic connections (5068) with in the town and the average family size (3.4) in urban areas for Tigray region according to the census of the 2007, are used for determining the average number of connection per family. Like that of the per capital consumption after evaluating for outliers, the average connection per family for the entire town is found to be 0.27. This implies that at average more than three and half families or thirteen persons are sharing one connection or water tap. In other words the average in-house or yard connection of the town is about 27%.

Correlation between population and water consumption

Although the level of water supply coverage both in quantity and connection differ among different districts, the number of population and volume of domestic consumption shows moderate and positive correlation. The moderate correlation coefficient (0.432) may show that the number of population and total water consumption are linearly correlated to each other, but some districts are still deviating from the correlation line.

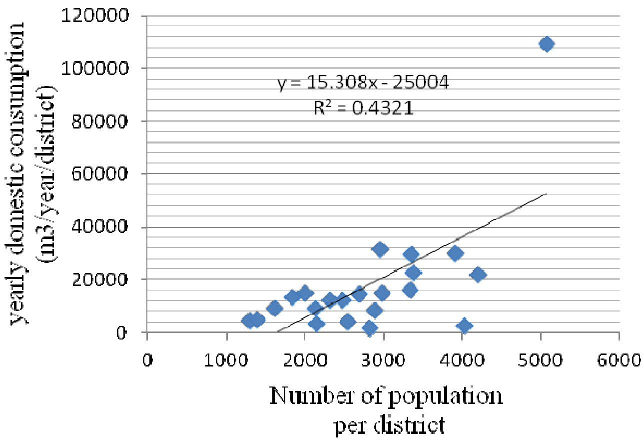

Figure 3 Scatter plot for volume of water consumption and number of population

Some districts having lower number of population but consume more water. This implies that either the people living in these areas are relatively rich and/or they have better chance of getting water due to their location or network condition. On the other hand some districts are observed with extremely low consumption while they have higher number of population. This may reflect significance of illegal water consumptions. However, according to the opinion of the local experts, illegal consumption of water is not the problem of the town; rather the main problem is getting continuous and enough supply of water.

Water loss analysis

The total water loss has been also evaluated based on percentage of system input volume, length of main and number of connections. Generally, based on the analysis results the total water loss from the system is 290,148m^3/year and is approximately 39.1% of the system input volume. This figure is higher compared with the average for developing countries (35%) according to Kingdom *et al.* (2006). The main reasons for this high loss of water are the present way of water network management with ad-hoc maintenance in which the problems are tackled only when there is clear evidence of failure and the insufficient financial resources of the utility.

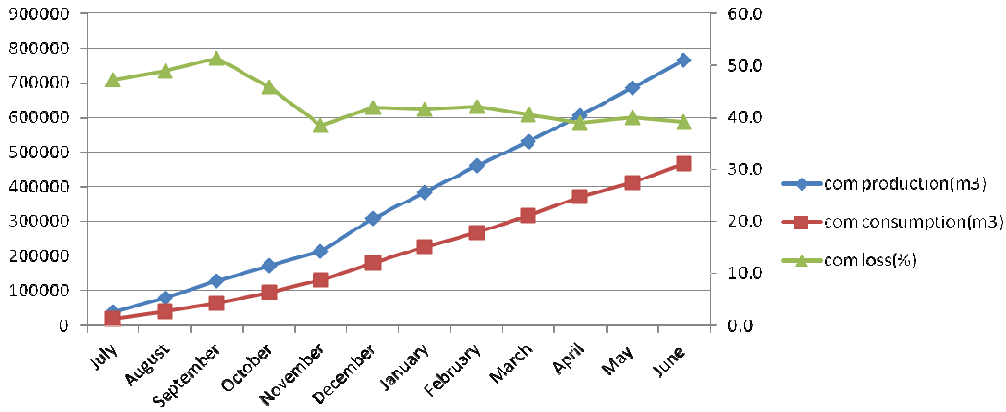

Figure 3 Monthly total water production, consumption and loss distribution curve based on cumulative values

As can be seen from the cumulative loss percentage curve there is seasonal variation on the loss from the distribution system. The loss percentage during the rainy season (July-September) is higher as compared with the long dry season. One of the reasons for this seasonal variation is lack of leak detection activities. As a result in the rainy season losses on the surface can go unnoticed for a long period of time as it is difficult to visually inspect them. However, in the dry season the losses from the system can simply inspected visually as they brought themselves to the surface and actions will be taken to control the losses as a result the loss percentage will be minimized.

Apparent loss

This component of the total water loss volume includes the loss due to unauthorized consumption, customer metering inaccuracies and data handling errors and is aggregated to 27,576m^3/Year. This loss amount covers 9.5 % of the total system loss. This result signifies more of the loss in the system as real loss which is mainly caused due to deterioration of the existing distribution system infrastructure.

Unauthorized Consumption

This volume of water includes theft and illegal connections. As there is no any means to determine this quantity of water, its volume is estimated based on the system input volume. Accordingly the unauthorized consumption amounts to 1,916m^3/Year.

Customer Metering Inaccuracies

The total volume of loss due to meter in accuracy in the system is 25,660 m^3/Year. This apparent loss of water accounts for approximately 3.35% of the system input volume for the fiscal year and translates to lost revenue of approximately 64,150 Ethiopian Birr. Generally, in the case of Axum the main reason for this high meter under registration is the deterioration of water meters with age, resulting in inaccurate readings. This is highly influenced by the lack of water meter testing and replacement programme and unlimited service year for meters in the distribution system.

Real loss

This category includes the volume of water lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering. In this specific study the real loss volume is found to be 262,572m^3/Year. This figure indicates the deterioration of water supply system, water supply management problem and urgent need of a leakage control program.

Unavoidable Annual Real Losses (UARL)

This category represents the allowable volume of real losses from the system, which estimates a volume of leaks that are undetectable or would be uneconomical to repair during the year. This can help to evaluate the feasibility of real loss minimization (provides better understanding of real loss components). Based on the analysis this volume for Axum town water utility is 178,580m^3/Year.

Potentially recoverable real loss

The recoverable real loss which indicates the amount of real loss that can be recovered through active leakage control strategies/practice is found to be 83,992m^3/Year. The figure signifies the need for active leakage control strategies and efficient system management.

Performance indicators

Non-Revenue Water

The detailed financial PI for non-revenue water is based on the percentage by value of the water, rather than the percentage by volume (Mutikanga *et al.*, 2010). Accordingly for this case the loss was expresses as percentage by cost of operating system and is found to be 17.4%. This figure shows that the water loss from the distribution system results in 977,498 Birr loss in the fiscal year of the study period.

Apparent loss per service connection

The apparent loss per service connection in Axum water utility is 12.2 l/connection/day.

Real loss per service connection

The real loss per service connection in Axum water utility is 116.14 l/connection/day. This shows that the distribution system of Axum water utility is more susceptible for burst and leakage.

Infrastructure leakage index

This PI is a measure of how well a distribution network is managed for the control of real losses, at the current operating pressure (Liemberge & Farey, 2004). Based on the analysis the ILI value for Axum is 1.47. This ILI value shows that the current annual real losses are assessed as being around 1.5 times as high as the unavoidable annual real loss for the system. In other words options may exist for lowering annual real loss volume to around two third of the current annual real losses, if there are no changes in the current pressure management regime.

In practical terms, ILI values close to 1.0 mean that world-class leakage management is ensuring that annual Real Losses are close to the Unavoidable or Technical Minimum value at current operating pressures. However, in the case of Axum with aged distribution system and lack of leakage management activities, achieving lower ILI value shows inapplicability of the PI for the town water utility.

Water loss reduction strategies

The ultimate goal of the NRW reduction strategy is to reduce the level of losses to a point where the acceptable level or economic level of losses is reached and maintained (Farley & Liemberger, 2005). Nonetheless, in order to provide an initial reference point for the start of the program, a preliminary target is proposed. This target for the case of Axum is to reduce water losses from the current 39.1% to around 23 % of the annual system input in targeted year 2020. Based on this study and the existing water supply situations of Axum the following short and long term strategies are outlined in order to improve the existing situation and that help to achieve the target.

The areas which are given most focus in the strategy are data collection, record keeping, meters accuracy and pipe and shut valve replacements. The first phase concentrates on collecting accurate data for future needs and improving the efficiency of the water network by renovating shut valves. The second phase aims to control pressure to agreed levels and replace pipes systematically. The monitoring of the system which is started in the first phase should be maintained during the second phase as well, especially to give beneficial feedback to the managers of the water sector.

4. Conclusion and recommendation

This study has attempted to evaluate and update the local situation with respect to the water supply coverage and water loss in Axum water supply system. The study has also proposed appropriate strategies and techniques for the reduction and control of non revenue water.

The water supply coverage of the town is very low compared with the minimum standard set by UN-Habitat as a basic need for drinking and sanitation alone (20l/per/day). Nearly 75% of the entire town population is getting water less than this basic service level. Although there is overall shortage of water in the town, predominantly the existing amount of water is fairly distributed among the different localities except few districts that consumed much water although their number of population is either low or moderate and vice versa.

Generally, in the old settlement areas of the town low level of connections per family and per capita water consumption was observed. Hence, it is concluded that the low financial capacity of the inhabitants, the topographic nature (higher elevation) of the areas and the available traditional pond as the main reasons for the low coverage in the areas.

Despite the low water supply coverage, the total water loss in the focused area is up to 39.1% of the total system input volume. This is the main issue that Axum water supply system is presently struggling with. The main reasons for this high loss of water are the present way of water network management with ad-hoc maintenance and insufficient financial resources of the utility. Therefore, a proactive approach should be adopted, in dealing with the operation and maintenance of the water supply scheme, to prevent complete damage of the water supply network over a period of time and sustain health-based targets of the water supply system.

Even though the seasonal water loss comparison was undertaken for one year duration, the percentage of total water loss is higher during the rainy season as also proved from the local experts' point of view. The main reason behind that is the difficulty of tracing leaking pipes during the rainy season.

In general, the water loss analysis result revealed that, leakage and customer meter errors are the main causes of the water loss in Axum water supply system. The main reason for this is the deterioration of system infrastructure with time. Therefore, due attention should be given while additional water sources are planned for the future that a proper management of the existing infrastructure in general and the water network in particular is paramount.

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