Water Supply Coverage and Water Loss in Distribution Systems
The case of Addis Ababa

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by

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Abstract

Problems in provision of adequate water supply to the rapidly growing urban population in developing cities are increasing dramatically. As a result demand for additional water sources and infrastructure is growing. Moreover, nearly 50% of the water produced is lost at different levels of the distribution system before reaching the consumers. Addis Ababa, the capital city of Ethiopia is one of the developing cities suffering a high shortage of water as well as high water loss. Both financial and technical constraints are the main bottlenecks that hamper the city to satisfy the highly growing needs of its residents.

Quantifying and characterizing water loss and leakage in a city water supply system is by its nature a complex task. Leakage identification needs detailed field investigation sometimes using sophisticated equipment. In this study, an attempt is made to evaluate both the water supply coverage and the water loss with the available secondary data that was not particularly designed for this purpose.

The focus of this study is to evaluate the intra city distribution coverage of the water supply and evaluating the total water loss both at the city level and some selected sub-systems. Water production that is only available for the entire city and the water consumption as aggregated from individual customer meter readings was used to evaluate the total water loss at city level. Although the city water network is interconnected one from the other and the supply from each reservoir is usually not recorded, three sub-systems that have relatively isolated networks and production & consumption data were used to evaluate and compare the spatial distribution of the water loss. Moreover, records of some sample meters that get water from the same reservoir and are located in different ground elevations was evaluated so as to get some notion for any loss from customer meters.

The total water loss derived from the water balance both at city and sub-system level were compared using different performance indicators..

As it is difficult to directly characterize the causes of losses from a total water loss, in this study it is attempted to identify the possible causes of the loss indirectly by comparing the losses at different sub-systems in conjunction with elevation difference (potential pressure) and ages of the pipes among the sub-systems. Local experts' opinion that was collected through discussion during fieldwork has been also used to support the quantitative analysis qualitatively.

Finally a methodology was suggested to better identify the loss and remedial actions to be taken by the water authority to reduce water loss are recommended.

- ❖ Updating existing network data
- ❖ Measuring and evaluating water loss and leakage
- ❖ Setting performance indicators of water loss and leakage
- ❖ Need for Zoning and district metering areas (DMAs)
- ❖ Improving billing system and meter readings
- ❖ Establishing Pressure management
- ❖ Proper maintenance and renewal of networks
- ❖ Regular inspection of the water network

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1. Introduction

1.1. Background

According to the Global Water Supply & Sanitation assessment Report, 2000, the percentage of people served with some form of improved water rose from 79% (4.1billion) in 1990 to 82% (4.9 billion) in 2000. At the beginning of 2000, one sixth (1.1billion people) of the world's population was without access to improved water supply. The majority of these people live in Asia and Africa, where two out of five African's lack improved water supply and the 2000 coverage of water supply for the urban population of Africa and Ethiopia was 85% and 77% respectively. According to the millennium goal targets, the African urban areas will be accessed for improved water with in 15 years from the year 2000. On the other hand, in African largest cities, only 43% inhabitants have house connection water supply services.

The main problem that developing countries are faced to provide access to safe water for their citizens is shortage of resources. Moreover, the capacity of the citizens to pay for water that fully recovers the cost is very limited. For this reason many developing cities are faced great difficulty to expand the service and rehabilitating the exiting aged pipes. Generally, tariffs in developing countries are set well below the level needed to cover even operation and maintenance costs. Research has shown that low tariffs are set largely for political, rather than practical, purposes.

Limited institutional capacity is also one of the bottlenecks that hinder cities of developing countries for managing their infrastructure asset in general and water supply in particular.

Besides to low coverage, water losses (physical loss) in urban water supply is accounted to more than 50% of the supplies that mainly arise from:

- Leakage of pipes, joints and valves
- Over flowing service reservoirs and
- Waste of water through illegal connections and non-metered house connections.

Although leakage is one of the major causes for loss of water in a network distribution system, the loss of water through illegal connections and non-functioning meters is also contributing a lot that needs a proper management and monitoring system.

While developed cities have started using on-line continuous operation and monitoring service, the developing cities have great difficulties even to collect information on their previously performed operation and maintenance activities that could help them developing a strategy for the future. Many developed countries use water audit procedures to determine the efficiency of the system and to identify the location and magnitude of water losses.

There is also a need for some type of database or information system such as GIS to enable analysis of flows in the networks and provide early warning or indication of leakage. At present, although some cities in developing countries are introducing GIS based information system; many countries are still applying conventional methods for collecting, storing, processing and retrieval of information system, but the good news is that GIS have the ability to use previously collected and stored digital data that makes introducing GIS easy and not costly. Among many others, the ability of GIS to integrate information about a location from different sources and having functions with analysis of networks makes more important to use it in infrastructure management in general and water supply in particular.

1.2. Research Problem

Leakage is often a large source of unaccounted for water and is a result of either lack of maintenance or failure to renew ageing systems. Leakage may also be caused for poor management of pressure zones, which is resulted in pipe or pipe-join failure. Although some leakage may go unnoticed for a long time, detection of visible leakage also requires good reporting which includes some level of public participation. There is also a need for some type of database or information system such as GIS to enable analysis of flows in the networks and provide early warning or indication of leakage.

According to estimates of the United Nations (UN-HABITAT, 2002), Addis Ababa, which is projected to be the fourth largest city in Africa by 2015, has a current water supply shortfall of 25%. On top of the 25% backlog, as a cause of limited resources that as a result lead to poor maintenance and management of the water supply lines, leakage is observed as one of the main problems of the authority.

According to leak detection study project, the amount of unaccounted for water (UFW) in the network amounts to approximately 40%. This leads to a loss of approximately 10 million USD per year. AAWSA is tackling leak detection programs on a priority basis (UN-HABITAT, 2002)

Although the total loss of water can easily be estimated by comparing billing on water consumption and the total water produced and distributed to the network system, identifying the causes of the water loss and their spatial distribution is the challenge of many cities including Addis Ababa. For this reason many water companies that Addis Ababa water authority is among them are forced to consider the total loss as being caused by the physical loss like leakage, but in reality the causes for water loss include others such as illegal connection, non-functioning of water meters, etc.

On the one hand as every water point, being it is individual house connection or common water tap, is metered which supports a lot to introduce modern geographic information system, on the other hand due to lack of appropriate distribution and recording system of relevant information along the network, identifying and characterizing the loss of water in its spatial distribution is becoming very difficult

As the entire city water network systems are interconnected to each other with out separating which system is serving which area and how much water is distributed to which area, this makes the identification and the distribution of the water losses at different spatial locations difficult.

Thus, the city water authority has great difficulty to identify where and how much water is lost and what are the main causes for the loss of water that this research is going to focus.

1.3. Research Objective

1.3.1. Main Objective

The main objective of the research is to evaluate the supply coverage and explore the water loss in city water supply distribution and suggest a method to better identify and reduce the loss.

Taking the main objective as mentioned above, the following specific objectives are expected to be achieved:

1.3.2. Specific Objectives

- To evaluate the domestic water supply coverage and distribution
- To evaluate the total loss of water (unaccounted for water) at city level.
- The evaluate and compare the total water loss in selected sample areas (sub-systems)
- To explore the possible causes of water losses and possible solutions
- To suggest a methodology to support a city water supply authority to identify and reduce water loss in city water network distribution.

1.4. Research Questions

Specific Objective	Research Question
➢ To evaluate the domestic water supply coverage and distribution	➢ How much water is consumed by domestic consumers? ➢ What is the level of water connection?
➢ To evaluate the total loss of water (unaccounted for water) at city level.	➢ How much water is produced and distributed to the network system? ➢ How much water is lost in the entire city while compared with the water produced?
➢ The evaluate and compare the total water loss in selected sample areas (sub-systems)	➢ How much water is distributed by the sub-systems? ➢ How much water is consumed from the selected sub-systems? ➢ Is there any difference in magnitude of water loss among the selected sub-systems and the entire city?
➢ To explore the possible causes of water losses and possible solutions	➢ What are the possible causes of water losses in a city water distribution system? ➢ What are the possible solutions to reduce the loss?
➢ To suggest a methodology to support a city water supply authority to identify and reduce water loss in city water network distribution.	➢ What is the existing practice of the city water authority with regard to water loss management? ➢ What is the minimum required information to identify and characterize water loss in city water supply?

1.5. The Thesis Content

The thesis content consists of 7 chapters as structured below:

- Chapter one: Contains general background, the problem statement, the research objective, research questions, description of the study area and the outline of the research.
- Chapter two: Discusses literature related to water loss and leakage
- Chapter three: Discusses about the methodology, the data collection and preparation.
- Chapter four: Analysis of domestic water supply coverage of the city
- Chapter five: Analysis of water loss at city and local (selected sub-systems) level
- Chapter six: Discuss and suggest possible methodologies to identify and reduce water loss
- Chapter seven: Conclusions and recommendation.

1.6. Description of the Study Area

1.6.1. General

The study area, Addis Ababa is the capital city of Ethiopia that is located at about 80 7"northern latitude and 380 45" eastern longitudes. The city is situated at the down stream of the Enteto Mountain that as a result is having significant elevation differences among different localities. The present total population of the city is estimated nearly 3 million with an annual growth rate of 2.08%, while the total area of the city is estimated to be 540 square kilometres. At present the city is divided in to 10 sub-cities containing 203 kebeles* in total. Nevertheless the water authority is still using the boundaries of the old Weredas♣ and kebeles. The city Manager that is accountable to the mayor of the city is responsible to the provision of all the municipal services and is organized and performs its duties with 11 different offices that have their own legal entity. The Addis Ababa Water and Sewerage Authority (AAWSA) is a public institution in the city that is responsible for the supply of potable water and collection, treatment and disposal of water and sludge for the city. The authority is supervised by a board and directly responsible to the city manager. According to the overall structural development plan of the city, 100% water supply is planned to be ensured by the year 2010 and water consumption to reach the rate of 50 litters per capita per day during the same period. The main sources of water for the city is being extracted predominantly from two surface water reservoirs (dams) called Lagadadi and Gafarsa supported with water wells and springs.

1.6.2. Water Supply and Distribution

The city has started getting water supply in 1901. During the years between 1942 and 2001, many water supply projects have been implemented that the construction and upgrading of the Lagadadi dam and treatment plant, improvement of the distribution, ground water and spring development are among them (AAWSA, 2004).

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[*] Kebele is the lowest administrative units of the city (there are 303 old and 203 new kebeles in the city)

[♣] Wereda is the previous third level administrative boundary of the city.

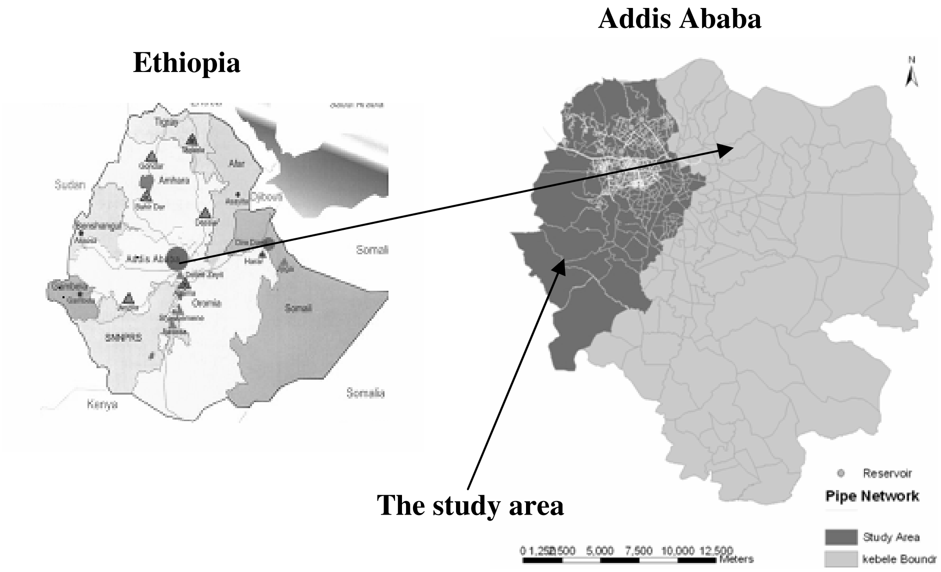

Figure 1-1 Location of the Study Area

Currently, around 220,000 m3/day of water is produced from different sources that among the others are Gafarsa and Lagadadi treatment plants that have design capacity of 30,000 and 150,000 m3/day respectively. The Gafarsa water line consisting of two 400mm steel pipes and the Lagadadi line partly comprising of 1400 mm (6.8km) and other a combination of two parallel lines of diameter 900mm and 1200mm (11.5km) are the main transmission lines that convey water from the treatment plant to the respective reservoirs.

The existing water supply system has 17 pumping stations and 22 balance/storage reservoirs ranging in capacity from 100 to 20,000m^3 with a total approximate storage capacity of 87000 m3. At present about 300 km^2 out of the 540km^2 total area of the city (56%) are served with water.

1.6.3. Water Demand and Consumption

One of the difficulties faced by the water authority is determining the accurate water demand of the city as the consumption during the past years that should have been used as a base is far below the actual demand due to shortage of water. Consumption of water for the city is therefore estimated based on the amount supplied rather than the actual demand. For these reason estimates of the future demand by the water authority is found to be uncertain. Keeping this in mind, the current situation as summarized by the water authority is as shown below (AAWSA, 2004):

- People having in-house services that are estimated about 4% of the total population use water on average between 80 and 100 litters per capita per day, while the remaining population with access to safe drinking water (94%) are served by yard connection and use between 15 and 30 litter/capita/day.
- Non domestic uses excluding industrial and industries water use are about 25 litter/capita/day and 7 litter/capita/day respectively. From the water used by industries about 40% is provided by the water authority while the remaining amount is produced by the industries themselves from deep wells.

2. Literature Review

2.1. 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 every one rather some consumers take disproportionate amounts of water and the poor is the first victim to the problem. The developing cities have great difficulty both financial and technical to develop and expand water supply projects and one of the difficulties among the others is managing and reducing losses of water at all levels of a distribution system. As a result of the overall shortage of water many cities 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. As this research deals with over all coverage of water supply and water losses in distribution systems, issues related to water loss and leakage like identifying and reducing losses will be reviewed in this chapter.

2.2. Urban Water Demand and Coverage

2.2.1. Urban Water Coverage

Water supply coverage provides a picture of the water supply situation of one specific country or city and helps to compare one country with others and the inter and intra city distribution with in specific country. The percentages of population with or with out piped water connection is a relevant indicator to compare the coverage of water supply in urban areas. Although the water supply coverage is better in urban areas while compared with the rural, the actual water supply coverage in cities of developing countries in general and African cities in particular is very low while compared to the demand.

According to the Global Water Supply and Sanitation Assessment 2000 Report, the African largest cities are having 43% house connection or yard tap, 21 % served by public tap while 31% of the population are un-served (WHO, 2000).

A household is considered to have access to improved drinking water if it has sufficient amount of water (20liters/person/day) for family use, at an affordable price (less than 10% of the total household income), available to household members without being subject to extreme effort (less than one hour) a day for the minimum sufficient quantity), especially to women and children) (UN-Habitat, 2003).

On the other hand a minimum quantity of 25 litres of potable water per person per day provided at a minimum flow rate of not less than 10 litres per minute with the source being available within 200 meters from a household and the supply not interrupted for more than seven days per year (i.e. water should be available 98% of the time) is considered as a basic service for southern African cities' domestic water supply (Wallingford HR., 2003).

2.2.2. Water Demand Management

Water demand is defined as the volume of water requested by users to satisfy their needs. In a simplified way it is often considered equal to water consumption, although conceptually the two terms do not have the same meaning (Wallingford HR., 2003). In most developing countries, the theoretical water demand considerably exceeds the actual consumptive water use.

Water demand management refers to any socially beneficial action that reduces average or peak water withdrawals or consumption form either surface or ground water, consistent with the protection or enhancement of water quality (Tate, 2000). According to Rothert and Macy (2000), water demand management is the adaptation and implementation of a strategy by a water institution to influence the water demand and usage in order to meet any of the following objectives: economic efficiency, social development, social equity (Mwendera et al., 2003).

Urban water demand is classified in to different category that domestic water demand that includes in-house-use and out-of-house-use is among the others. In-house-use includes demands for drinking, cooking, sanitation, house cleaning, laundry and car washing while out-of-house-use includes like garden watering, swimming pools, public stand pipes for public uses and fountains, etc. Urban water demand is usually quoted in terms of litre per capita per day (l/cap/day).

Despite the variation in residential indoor water use from household to household, a typical pattern (referred to as the water use profile) can be developed to provide a reasonable representation of indoor water use, based on the different indoor water use components (kitchen, bathroom, laundry, and toilet) and household occupancy. (Mitchell et al., 2000).

In many African cities urban water demands are often non-homogeneous owing to a range of levels of service occurring within the same urban area. Levels of service can vary from household connections to standpipes or to no service at all (Wallingford HR., 2003). As an example, an overview of urban water supply for southern African largest cities is shown in Table 2-1 below.

Table 2-1 Overview of Urban Water Supply for Southern African Larger Cities

Country	Largest City	Population of Largest City (Million)	Water Production for the Largest City (l/person/day)
Angola	Luanda	4.0	30
Botswana	Gabarone	0.13	286
Democratic Republic of Congo	Kinshasa	5.7	86
Lesotho	Maseru	0.27	81
Mauritius	Port Louis	0.15	200
Mozambique	Maputo	0.97	133
Namibia	Windhoek	0.27	-
Seychelles	Great Victoria	0.12	140
Swaziland	Mbabane	0.94	100
Tanzania	Dar Es Salaam	3.0	150
Zambia	Lusaka	1.21	225
Zimbabwe	Harare	2.38	156

(Source: Wallingford, 2003)

2.3. Water loss and leakage

Regardless of the magnitude that greatly varies from city to city or from one area to another, water loss is a problem experienced in all water distribution systems. The first and foremost cause of water loss is leakage. Water put to inappropriate or excessive uses may also be considered as loss. Water that is unaccounted for because of measurement errors, including inaccurate meters, forgotten users, and unmeasured uses, are also some of the causes for water losses.

Unaccounted for water (UFW) is one of the commonly used methods for evaluating the water loss that is usually defined differently by different writers that some of the definitions indicated here under

2.3.1. Some Definitions of UFW

There is no universally applied or accepted definition of unaccounted-for water. In general, unaccounted-for water (UFW) is the difference between the water supplied to a distribution system and the water that leaves the system through its intended use (Richard G. et al., 2000)

UFW may be defined as percentage of the water produced from the raw water source which is not accounted for (MWAC, 1999).

UFW is defined as the difference between water delivered to the distribution system and water sold (Yepes, 1995)

The term Unaccounted-for Water (UFW) refers to an accumulated range of losses that will be experienced by a Water Utility when comparing the system demand of a hydraulic water network with the quantity of water that is acknowledged as consumed by the water consumers residing within the network (UNEP, 2000)

Although the above definitions seem to have differences, all have in common that they took the water produced and distributed to the system as an input and the water consumed or exported from the distribution system as an output.

From the local context, the UFW has been defined as the water loss calculated as the difference between the amount of treated water produced and supplied and the total amount of water billed and collected. The volume of water consumption due to the inaccuracy of the water meters as well as the lump sum payments made by the customers when their meters can not be repaired are also taken in to account for the determination of the UFW (AAWSA, 1997).

On the other hand because of the widely varying interpretation of the term 'Unaccounted-for water' (UFW) worldwide, the IWA* task forces do not recommend use of this terms. If the term UFW is used at all, it should be defined and calculated in the same way as 'non-revenue water' (NRW) (Farley and Trow, 2003).

2.4. Methods of measuring and comparing water losses

2.4.1. Measuring water losses

The unaccounted for water (UFW) expressed as percentage of the total consumption and the minimum night flow (MNF) per connection are the most commonly used methods of measuring losses. UFW is the measure of losses over a period as the difference between the amount of water put in to a system and the metered or estimated quantity of water taken by consumers, while MNF is an indicator of the probable rate of losses at a given time.

Night flow measured in moderately sized sectors (up to around 3000 service connections) are extremely useful for identifying the presence of existing unreported leaks and bursts, and the occurrence of new ones. However, continuous night flows can also be used for assessing annual average real losses (Farley and Trow, 2003).

Unaccounted for water is a useful indicator of probable losses, but it may overestimate them because supply meters tend to under-record consumption. In UK, figures for unaccounted for water tend to be unreliable because the un-metered consumptions have to be estimated and can be 10% in error. Attempts to compare the performance of different undertakings by measuring some uniform figure for domestic consumption can be misleading. Many factors influence unaccounted for water and differ from one undertaking to another, standards of housing, rates of occupancy, age of mains, length of mains per 1000 population served, proportion of trade and bulk supplies, ground condition, etc. (Twort A.C. et al., 1994).

The minimum night flow (MNF) per property connection is a better indicator of loss rates on part of a system. However, figures of this type are affected by the characteristics of an area; in dense urban areas there will be more blocks of flats with large storages which may fill at night. Nevertheless, the MNF is a good direct indicator of the state of parts of a system (Twort A.C. et al., 1994).

On the other hand, "Weimer referring to fully metered situations, considers that "the annual water balance can initially only be taken as a guide as the calculations are susceptible to errors, analyses show this uncertainty in the calculated annual losses to be +/- 46% (Lambert and Wallace, 1993).

Different countries use different methodologies to evaluate the losses like the U.K. leakage practitioners and planners consider leakage almost exclusively in terms of night flow rates,

* International Water Association

rather than as a calculation of annual losses as in West Germany. Each method has its respective merits. 'Annual losses' are used for retrospective assessment of overall performance and long-term demand forecasting. 'Night flows' are used by practitioners responsible for leakage control and prioritization of leakage control activities. Any conceptual model therefore needs to be able to link night flows with annual losses in a consistent manner (Lambert and Wallace, 1993)

Although percentage figures are rarely meaningful when comparing different organizations, they can be used to indicate the extent of reduction of water loss by a single water supplier (WHO, 2001).

2.4.2. Comparing water losses

The amount of water loss differs from country to country, city to city and even from network to another network with in one city. Different countries use different indicators to evaluate their status in comparison with others and to compare the distribution of water loss from one location to other location of a distribution system in order to take action based on the level of loss. As stated above comparison using UFW expressed as a percentage has limitation when used for comparison as it highly depends with the volume of the water produced.

The traditional performance indicators of water losses are frequently expressed as a percentage of input volume. However, this indicator fails to take account of any of the main local influences. Consequently it can not be considered to be an appropriate performance indicator (PI) for comparisons (WHO, 2001).

Depending upon the consumption per service connection, the same volume of real losses/service connection/day, in percentage terms, is anything from 44% to 2.4%. Thus countries with relatively low consumption like the developing countries, can appear to have high losses when expressed in percentage terms; in contrast, percentage losses for urban areas in developed countries with high consumption can be equally misleading (Farley and Trow, 2003)

To avoid for the wide diversity of formats and definitions related to water loss, many practitioners have identified an urgent need for a common international terminology that among them task forces from the international water association (IWA) recently produced a standard approach for water balance calculation with a definition of all terms involved as indicated in Table 2-2 below..

Table 2-2 IWA Standards International Terminology

<table>
<tr><td rowspan="9">System input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption (including water exported)</td><td rowspan="2">Revenue water</td></tr>
<tr><td>Billed Un-metered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water (NRW)</td></tr>
<tr><td>Unbilled Un-metered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Metering Inaccuracies</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer Metering</td></tr>
</table>

(Source, Farley & Stuart)

According to IWA the above abbreviated terminologies are defined as below:

- System Input Volume is the annual volume input to that part of the water supply system
- Authorized consumption is the annual volume of metered and/or non-metered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorized to do so. It includes water exported, and leaks and overflows after the point of customer metering.
- Non-Revenue Water (NRW) is the difference between system input volumes and billed authorized consumption.
- Water losses are the difference between system input volume and authorized consumption, and consists of apparent losses and real losses.
- Apparent losses consist of unauthorized consumption and all types of metering inaccuracies.
- Real losses are the annual volumes lost through all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

2.5. Causes of water losses

Leakage is usually the major component of water loss in developed countries, but this is not always the case in developing or partially developed countries, where illegal connections, meter error, or an accounting error are often more significant (Farley and Trow, 2003). The other components of total water loss are non-physical losses, e.g. meter under registration, illegal connections and illegal and unknown use (WHO, 2001).

2.5.1. Leaks in Water Distribution Systems

From one municipality to another and even from one location to another, the causes of leaks will vary depending on the nature of the soil, the quality of construction, the materials used, the pressure levels and the utilities operating and maintenance practice (AWWA, 1987).

Leakage is often a large source of unaccounted for water (UFW) and is a result of either lack of maintenance or failure to renew ageing systems. Leakage may also be caused for poor management of pressure zones, which result in pipe or pipe-join failure. Although some leakage may go unnoticed for a long time, detection of visible leakage also requires good reporting which also needs a strong public participation. Although leakages after water meter has its own contribution to the overall wastage of water, it is not considered as of the total unaccounted for water, as it would be paid for.

It is important to distinguish between total water losses (some times called unaccounted for water (UFW) and leakage. Total water loss describes the difference between the amount of water produced and the amount which is billed or consumed. Leakage is one of the components of total water lost in a network, and comprises the physical losses from pipes, joints and fittings and also from over flowing service reservoirs (WHO, 2001).

The amount of leakage from a reticulation system varies from location to location, due to differences in construction methods, age, and condition. The condition of the reticulation system is affected by soil movement, corrosive conditions, pipe material, workmanship, age, supply pressure, number of joints and connections, and the occurrence of bursts/cracks result from overburden loading or water hammer (Heeps, 1977), (Mitchell et al., 2000). Leakage reduction as a whole is a complex task which requires coordinated actions in different areas of the water network management such as direct detection and repair of existing leaks, pipe rehabilitation program, pressure control system, etc. and many companies use a mixture of these.

Many cities have separated the network into `leakage districts', and have installed water flow and pressure meters to monitor each district. The registered data are checked and necessary actions taken. Data on bursts and leaks are collected and evaluated to estimate the future need of rehabilitation. During the last 10-20 years, several cities have started to use computer-based water network records. These databases contain information on network properties, such as pipe material, construction year and diameter and failure information (where, when, failure description, etc.). By simple analyses of these data or by employing more complex statistical methods, information is collected to show differences in failure rate for different pipe properties (Hadzilacos and Kalles, 2000).

2.5.1.1. Pressure and leakage

In many water network systems, even though the total demand and the total loss of water can be known rather easily, information about the possible influence of local pressure upon demand is sadly lacking that as a result creates difficulty to assess and compare the demand and loss of water in its spatial distribution. Pressure distribution system on the one hand contributes to the increase of leakage, when it is more, and on the other hand when it is low contributes to the shortage of water that as a result causes for unequal distribution of water among residents. To alleviate such problems, some water authorities develop a zoning scheme where by the complete water distribution network is broken down in to manageable segments that can be easily metered and monitored and analyzed.

The leakage from water distribution systems has been shown to be directly proportional to the square root of the distribution system pressure as indicated by the relationship below (Wallingford HR., 2003).

$$\textit{Leakage } \alpha \textit{ (distribution system pressure)}^{0.5}$$

Burst rates are also a function of pressure. The strength of the relationship, and the quantification of it, is not as well understood as the relationship between flow rate and pressure. However, there is still considerable evidence to show that burst frequency is very sensitive to pressure. Evidence shows that the rate of increase of bursts is more than linearly proportional to pressure. Indeed it has even been suggested that there could be a cubic relationship. i.e. burst frequency proportional to pressure cubed (Farley and Trow, 2003).

Pressure variation in distribution network is caused, among others, by changes of demand of users. The demand usually reaches a peak in the morning when people are at home and preparing their meal and its second peak in the evening.

If one compares daily diagram for total demand of the whole system with corresponding data captured at the level of (relatively small) demand management areas one will discover that the first has much smaller amplitude in comparison with the later. The minimum night flow (MNF) is relatively higher and the morning/evening peaks are less prominent (Obradovie, 2000).

Frequent starts and stops of pumps, closure and openings of control valves that induce water hammer are also some of the causes to be mentioned for pipe breakage and water loss through leakage. The position of reservoirs also has a great impact on the pressure distribution.

'Distribution Losses" is the sum of losses from four different parts of the distribution system; trunk mains, service reservoirs, distribution mains and communication pipes. The combination of these assets in individual Companies and supply areas are widely variable, as are the variations of pressure which are known to significantly affect leakage (Lambert and Wallace, 1993).

The elevation at which it is desirable to position a service reservoir depends upon both the distance of the reservoir from the distribution area and the elevation of the highest buildings to be supplied. If the distribution area varies widely in elevation it may be necessary to use two or more service reservoirs at different levels, so that the lower areas do not receive an unduly high pressure. Generally, 45 to 75 meters static pressure is that which best suits the domestic distribution systems. Pressure below 45 meters will be likely to cause trouble in supplying extensive distribution areas; pressure above 90 meters, tend to result in excessive leakage losses (Twort A.C. et al., 1994).

The critical points which would first run dry if pressure is reduced are usually areas located at the highest elevation and excessive pressures can be reduced by adjusting the speed of pumps in areas supplied by pumping, installing a pressure reduction valves (PRV) and dividing the system in to different pressure zones.

Pressure control valves are some times installed in outlet mains from service reservoirs in order to reduce the pressure to low lying zones, or to limit increases of pressure at night to reduce leakage. Pressure reducing valves (PRVs) throttle automatically to prevent the downstream hydraulic grade from exceeding a set value, and are used in situations where high downstream pressures could cause damage (Walski et al., 2003).

Figure 2.1below illustrates a connection between pressure zones without a PRV, the hydraulic grade in the upper zone could cause pressures in the lower zone to be high enough to burst pipes or cause relief valves to open.

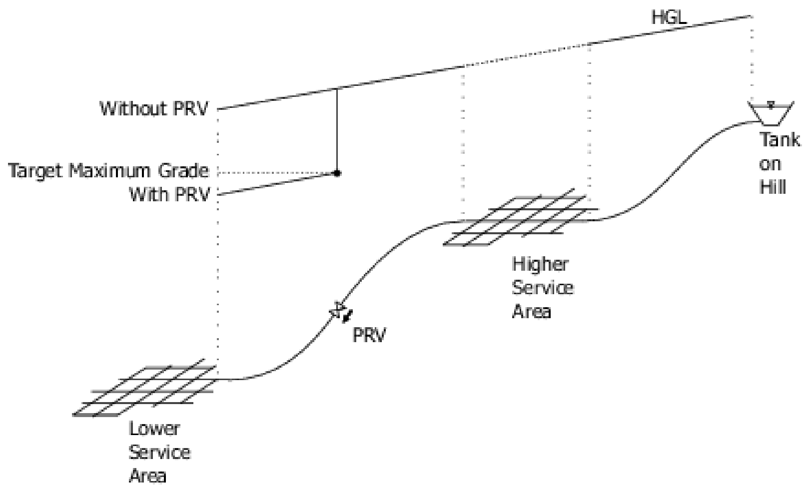

Figure 2-1 Schematic network illustrating the use of a pressure reducing valve
Source: (Walski, Chase & Savic)

In making a decision to install pressure control devices it should be born in mind that if the device fails to operate, which usually happened if the equipment is not properly maintained, then the down stream mains will be subjected to a sudden increase.

Reducing pressure on the other hand may make existing leaks more difficult to find, because they make less noise, or do not come up to the surface. Therefore, pressure reduction should be coordinated with leakage detection and repair operations (Farley and Trow, 2003).

2.5.1.2. Ages of Pipes and leakage

Although there are no scientifically based criteria for defining the useful life for water mains, there has been a growing concern that many older urban water distributions are deteriorating that as a result massive rehabilitation will be required to replace mains older than some predetermined number of years in age or “useful life”.

Pipe age and material are important factors contributing to the burst probability of pipes that as a result cause lots of water loss. However, as this information is mostly not available especially for aged pipes, it is usually estimated using the history of the urban development.

Reports from undertakings collected by the WRC, and evidence from elsewhere suggest that leakage rates from mains are of the order of 100 to 200 l/hr per km for newer mains and 150 to 300l/hr per km for older mains. Assuming an average of 100 connections per km these figures would represent 1.0 to 3.0 l/hr per connection (Twort A.C. et al., 1994).

Leakage is frequently the largest component of UFW and includes distribution losses from supply pipes, distribution and trunk mains, services up to the meter, and tanks. The amount of leakage varies from system to system, but there is a general correlation between the age of a system and the amount of UFW. Newer systems may have as little as 5 percent leakages, while older systems may have 40 percent leakage or higher (Walski et al., 2003).

Although age is considered as an indicator for predicting the break rate of mains, some studies have shown that it is not the major determinant factor for main water break rates. Poor design, deterioration of pipe material and unanticipated load condition will also result in pipe breakage.

2.5.1.3. Effects of Corrosions on leakage

Corrosion is the problem that is created as water supply pipelines are in continuous contact with soil surrounding it and the water moving through it. The water itself or the surrounding soil may cause problems that will affect the performance and life of the distribution pipes in the system. The majority of the main breaks occur at locations where the pipe wall has been weakened due to corrosion of metal pipes.

Corrosion of the external surfaces of cast-iron or steel pipes can, under some conditions, be a significant problem. Therefore, ductile-iron or steel pipelines placed in aggressive soils must be protected by coatings with corrosive resistant materials. The characteristics of the soil in which a pipe is placed affect the rates of corrosion.

Recent estimates indicate that the cost of water main breaks in Canada is about $80 million per year. One reason that this cost is so high is that most water mains in Canada are made from either cast or ductile iron. As these pipes age, they are weakened by corrosion, causing an increased number of breaks (IRC, 1996).

Designing against corrosion, selection of appropriate materials and usage of protective coating and lining during installation can help for the prevention of corrosion but not limited:

Some soils such as clays and other highly organic soils can be extremely corrosive, though corrosive condition can exist in non-corrosive soils too. Soil conditions are responsible for the exterior corrosion of metal structures under or in contact with the ground.(Laike Selassie, 2004)

2.5.2. Meter error and water loss

Under registration of customer meters is also one of the causes of water loss. Like the ages of pipes, ages of meters also has an impact to the increase of water loss. Customer meter errors include errors due to accounting procedure and errors due to under or over registration of the meters. Many countries especially developing countries are experienced losses of water due to under registration of meters that many of them put meter replacement policies to alleviate the problem.

The selection of customer meter types and classes may be limited by water quality considerations, as well as technical and economic considerations. Economic replacement policies for residential meters based on selective testing programs in the National Reports generally indicate changeover periods between 5 and 10 years. Where customers are served by way of roof tanks, the probability of customer meter under-registration is increased, because of the tendency for a greater part of the consumption to pass through the meter at rates less than the Q minimum specified for the meter (Lambert, 2003).

The cities of Africa appear to use meters for 78% of domestic consumption and the yearly meter replacement is about 8.8%. Considering that meters typically under read as they age, it is likely that considerable proportion of unaccounted for water is experienced by metering errors (WHO, 2000).

Domestic water meters tend to under register for two reasons, i) malfunctioning due to deterioration with use, and ii) inability to measure low flows accurately. Much larger under registration can occur where maintenance of meters is poor (Twort A.C. et al., 1994).

An under registering meters and any meter stoppage could be noted immediately if meter readers are alert to compare readings of one specific meter with its past readings, but in reality this situation doesn't happen.

2.6. Consequences of water loss and Leakage

The primary consequence of leaks in a distribution system is financial. Reduction in water loss enables water utilities to use existing facilities efficiently, alleviate shortage of water supply, improving the supply capacity to consumers and the reduction of operational expenditures that are related to power and chemical costs. Reduction of water losses extends the service life of existing water supply components that as a result to meet the present as well as the future needs of residents with out construction of many new water facilities. Beside to low revenue generation as a result of under-recording of faulty meters, or totally uncharged due to illegal connections and unregistered consumption, leakage also greatly contributes to loss of revenue. The operation and maintenance costs including price of energy, chemicals and other items that are constantly rising will also be aggravated by the increase of water loss due to leakage.

Beside to directly affected production and management costs, leaks have great consequence on the quality of services. The water that escapes from leaks may also cause a damage of structures such as sinking of roads and other properties. When the leak becomes more serious or a pipe bursts, service may be interrupted totally that many people will be severely affected.

2.7. Leakage monitoring and control

The losses of water are inevitable in the process of supplying thousands of customers spread over a large area started from reservoirs at the treatment plants, through a complex network to the individual customer.

Leakage monitoring and control in pipe reticulation systems is critical in ensuring the efficient performance of the system. Pipe systems are commonly used for distributing water to areas of consumption. If pipes are worn out, large volumes of treated water may be lost through leakage as a result of high pressures of flow. Leakage control is possibly one of the most difficult tasks for water engineers. Even in developed countries, about 15–20% of the distributed water is lost through pipe leakage. It is therefore important to ensure that leakage monitoring and control is given the attention it deserves by all water supply authorities and consumers (Mulwafu W. et al., 2003).

Water leak detection is a systematic method of locating visible and non-visible leaks in a distribution system through visual inspection; pipe locators and leak detection equipment (proactive leak detection); and Pressure control, etc. Depending on the type, leakage could be identified from the simplest of using visualization till using sophisticated equipments as discussed below.

2.7.1. Identifying Leaks through Visual inspection

In this method only those leaks that become self-evident are located and repaired. A leak may be self-evident because water shows on the surface or may become so upon investigation following consumer complaints such as poor pressure or noise in the plumbing system (Wallingford HR., 2003).

Bursts of large mains are often visible and are not considered as major causes of high water losses as these incidents are quickly spotted and repaired or isolated. This method is widely applied and requires regular inspection by the respective authority and it does not need special professional skills.

2.7.2. Identifying Leak using Detection Equipment

Most of the water is lost through numerous small holes, which are very difficult to locate, as the pipes are laid underground that usually need special equipments to locate the leak and repair.

This method involves teams of inspectors seeking to locate leaks by systematic direct sounding on all stopcocks, hydrants and valves through the distribution system and listening for the characteristic noise of leaking water. As water under pressure exits a crack or a small hole, the pipe wall and the surrounding soil emit sound waves in the audible range. Water impacting the soil and circulating in a cavity creates lower frequency waves that have limited transmission through the ground. Through the use of surface microphones, leaks can be located with greater precision. The leak noise detected will depend upon the position at which a sounding is made (Wallingford HR., 2003).

2.7.3. Location of Large leaks by Pressure Control

A large leak in a small network can be located by measuring the pressure during the time of minimum water supply especially during the night. This can be done by shutting of the valves in successive sections of the distribution starting from the supply.

Pressure control does not directly involve leakage detection, but sudden drops in pressure may indicate to a possible leak. In general, reduction in pressure leads to reduced rate of escape through each leak and may also affect the number of leaks occurring. Pressure reduction is relatively cheap and can be quickly effected, but lower pressure may also increase the leak population by making them less detectable. Pressure reduction can be achieved in a number of ways such as reducing pumping heads, installing break pressure tanks and using pressure-reducing valves. The control of pressure surges and cycling is likely to reduce the numbers of bursts and leaks that occur, especially in plastic pipes. Pressure control is a necessary tool for the technical management of the system and combined with any other method of water loss estimation could give very useful information in order to identify the causes of water lost through leakage (Wallingford HR., 2003).

Operational pressure control is a cost effective method for reducing leakage over whole sub-systems, and for reducing the risk of further leaks by smoothing pressure variations. The planning studies under the assumption of perfect knowledge of demand and network model (including leakage) allow for the estimation of the maximum potential savings resulting from the optimal control of PRVs (Ulanicki and Bounds, 2000).

Beside to the above indicated methods, leaks can also be detected through other methods or tools such as continuous monitoring of night flow, calculating with empirical formulas, leak inventory and reporting methods, etc.

2.8. Conclusions

The literature review was focussing on the issues related to the water supply coverage and losses of water in a distribution system, causes of water losses, the consequence of water loss, methods of evaluating water loss, etc. The literatures were reviewed considering expected methods and approaches needed in the following analysis chapters. Although it was tried to assess relevant literatures, some additional inputs from literatures will be referred while discussing relevant issues in each analysis chapters.

In many developing countries on the one hand the level of water coverage is very low while compared to the developed world on the other hand water loss is comparatively very high and difficult to manage both technically and financially. Many countries use the unaccounted for water expressed in percentage terms to compare the level of water losses among different countries or different cities. Nevertheless, some literatures do not recommend using it for comparison among different areas as it is highly affected by the magnitude of production. Moreover, evaluating water loss using a night flow monitoring that is usually expressed as per length of mains or number of service connections is a good indicator especially for evaluating the physical loss, but it is not an easy task especially in developing countries where data is usually scarce.

The three methods of measuring water loss will be used in analysing the water loss in this study and the appropriate method will be recommended considering the local condition.

The methodological aspect will be addressed in detail while discussing and suggesting appropriate methodology for better evaluating and reducing water loss in chapter six of this study.

3. The Research Methodology

3.1. Introduction

Based on the research objectives and questions stated in the introduction chapter the method how the research was carried out is discussed in this chapter. The methods of data collection and data preparation are also discussed in this chapter. Generally the research is divided in to two major parts, analysing the water supply coverage and the water loss analysis. The water loss analysis is also divided in to two levels, the entire city analysis and that of the local level (sub-system). The monthly water production and consumption data was used to evaluate the water loss at all levels. After evaluating the water loss, the causes for the loss was tried to be identified using the different factors that have an impact to the water loss like the pipe ages, the ground elevation (topography) and customer meter records..

3.2. The Research process

The water supply coverage of the city 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 coverage in the city, the total water loss was analysed sub-divided into two levels, the entire city and sub-system level. The total water produced and the actual water consumption as aggregated from the individual contracts (customer meters) were used as an input for city level analysis, while for the local level analysis, data on water production and consumption that has been previously recorded by AAWSA for monitoring purpose was used.

After calculating the loss at all levels, comparison has been made using different methods of measurement in order to choose a suitable method fit for the local condition. After evaluating the total water losses at the two levels, the possible causes of water losses were tried to be identified by comparing the losses in conjunction with some factors having an effect to the water loss like ages of pipes and ground elevation differences (potential pressure*). Meter reading records of some sample customer meters that get water from the same reservoir and located at different locations has been also analysed for possible losses of water through customer meters.

The research methodology is shown in the process diagram of Figure 3.1 below

* Potential pressure = expected pressure due to elevation differences of settlements from respective reservoir

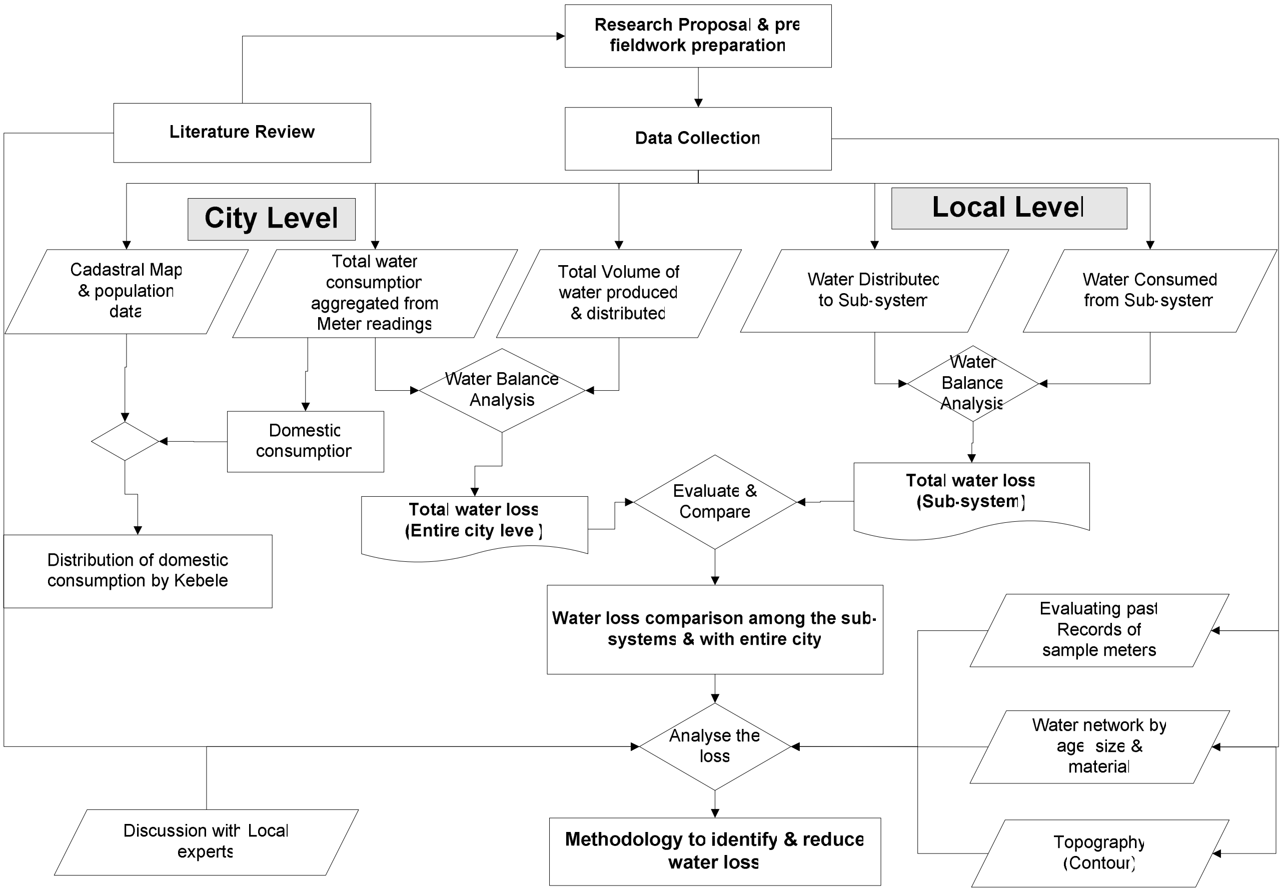

Figure 3-1 Research Methodology (Process Diagram)

3.2.1. Selection of Sample Study Areas

Availability of data was the major factor considered during selection of sample Areas. The following main criteria have been considered in the selection of the sample kebeles.

- Availability of data. As water production data for specific locations was only found for three sub-systems out of thirteen with in the city, all the three sub-systems are taken for analysis.
- Sharing of data with other MSc. Studies. In order to share relevant data from similar MSc. studies under going parallel, this was also considered during selecting the study area.
- Topographic condition of the city

Taking the above criteria in to consideration 144 kebeles out of 303 kebeles was taken for evaluating the distribution of water supply coverage including the three sub-systems are also located. Beside to these, two kebeles located at one of the sub-systems and some how representing different ground elevations were taken to evaluate the records of the meter readings (consumption) some how in detail.

3.2.2. Water supply coverage

The water supply coverage of the city 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 of each kebeles that has been 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 city and supply coverage map has been prepared for nearly half of the city. Number of population as forecasted to the year 2004 has been used to evaluate the average per capita consumption.

3.2.3. Water loss analysis

3.2.3.1. City level water loss analysis

In order to identify the total loss of water in the city, the total volume of water supplied to the network distribution system was compared with the actual water consumption. In this case, the data on consumption were aggregated to city level. Unlike the water consumption, the water production was only found at city level except for three sub-systems that records on water distributed to each of the sub-systems was found for some duration.
The other factor considered in the city level analysis was comparing seasonal changes of water loss particularly the summer (rainy season) and winter (dry season) so as to use the results of the two seasons for characterize the possible causes of the water losses.

3.2.3.2. Local level (sub-system) water loss analysis

Using the production and consumption data of the sub-systems, water loss analysis was made in the same way to the city level analysis. After calculating the water loss in each of the sub-systems, the losses were compared among each sub-system and with that of the entire city.

3.3. Data Collection

Prior to the fieldwork, cadastral information prepared by the Addis Ababa municipality about 10 years ago was used as a base for the selection of the study area. Beside to these a telephone communication was made with the Addis Ababa water and sewerage authority in order to preliminarily ensure the availability of the basic data the study.
It was planned to collect secondary data from AAWSA and other respective offices of the city and supportive qualitative information through discussion with local experts of AAWSA.

3.3.1. Secondary Data Collection

3.3.1.1. The City Water Network

A digital water network for the entire city including their attribute like the size, age and material of the pipes has been collected in AutoCAD format. The collected pipe network mainly comprises of main pipes and secondary pipes that covers the major part of the city. No tertiary pipes (pipe less than 50mm diameter) were collected as they were not available in digital format. The data on the network has been found from two sources with in AAWSA, one from the GIS unit that contains both the main and secondary pipes and the other from the planning department of the authority which comprises of only pipes of size 100mm and above.

3.3.1.2. The sub-system Water Network

Basically the entire city is sub-divided in to thirteen sub-systems based on the topography of the city, but in practice the pipe networks at the local level were interconnected to each other. Among the thirteen sub-systems, three of them were found having data. Volume of water supplied by each of the sub-systems and volume consumed from was collected for the duration of July 1999 to May, 2002.

3.3.1.3. The City Water Reservoirs

The information on location of most of the water reservoirs were collected in conjunction with the main water network on the city. The reservoir's data including their capacity, years of construction and material of construction were also collected. The locations of some of the reservoirs were not exactly indicated in the network, and the document found from the planning department indicates only the surrounding where they are located. Some of the reservoirs serve as transfer point to other reservoirs located elsewhere in addition to serving as a distribution to the surrounding areas. At the time of the field visit, AAWSA were having a total of 41 service reservoirs with a total capacity of 80,930m^3 located in 24 different locations (AAWSA, 2004).

3.3.1.4. Contour of the City

Although a 5 meter interval contour were available before the fieldwork, it had a basic problem like discontinuity in the contour lines and most of the contour lines were missing their elevation values. For this reason getting other sources was necessary that finally a 20 meter interval of contour with its corresponding digital elevation model (DEM) was found from the planning department of AAWSA.

3.3.1.5. Water Production

The main sources of water supply for the entire city are the "Lagadadi" and "Gafarsa" dams located 25 km east and 12km North West from the city respectively. Some few years ago additional water wells were drilled in the eastern down stream part of the city called Akaki.

According to the draft document of Sector Development Programme of AAWSA, currently around 220000m^3 per day water is distributed from Gafarsa, Lagadadi and Dire reservoirs; Akaki ground water scheme and a number of wells and reservoirs.

According to the information found during discussion with the experts from the authority, almost no other water sources were available apart from the wells and springs that were already included to the city distribution network. As there was no organized data, the water production has been collected from each of the sections responsible to the two dams and the sub-surface water section of AAWSA. Beside to the water production for the entire city data on monthly water distributed to three isolated sub-systems were collected for durations from July 1999 to May 2002.

3.3.1.6. Water Consumption

In order to evaluate the water supply coverage and the water loss, consumption data of each Kebele were collected from the computer information section of AAWSA. There are more than 200, 000 number of customers with in the entire city. Beside to consumption (meter readings), the data includes information on Wereda* and Kebele and unique number and address of customer meter (contracts).

3.3.1.7. Cadastral Information

This data was collected in collaboration with other colloquies doing a similar study. The cadastral information of the city was collected from the planning commission of the Addis Ababa. The data includes information on buildings, parcels and blocks for each 303 Kebeles which are located in 28 former Weredas. The data was about 10 years old that was not updated in between.

3.3.1.8. Population and other documents

Beside to a census document of the country (10 years old), number of population by each Kebele projected for the year 2002 (1994 E.C.) has been also collected from the planning commission of the city. Besides to these, some relevant documents were collected from the water authority.

3.3.2. Primary Data Collection (Discussion with local Experts)

Although the study predominantly was planned to be conducted using secondary data, in order to support it qualitatively a discussion with local experts of AAWSA has been also made. Please see the checklist for the discussion with the experts in Appendix I.

3.3.3. Data Preparation

3.3.3.1. City Water Network

The data on city water network that has been collected from two sources was in AutoCAD format, one of it from the planning department of AAWSA that comprises of pipe sizes greater or equal to 100mm and including reservoirs location while the other consists of all pipes from size 50mm and above and was collected from the GIS unit. As the network containing only the main pipes was comparatively updated recently, this has been used with a combination of the pipe sizes less than 100mm collected from the GIS unit.

Before exporting the AutoCAD format network in to ArcGIS, reviewing the network in its original format was necessary that AutoCAD software has been installed in order to do so. While the network were reviewed in its original format, the pipe diameter, year of construction (replacement) and its material type were found written as an annotation that makes it difficult to export as it is in to ArcGIS. On the other hand a specific code has been assigned as a layer to each annotation. After reviewing which type of code does represent to which description in AutoCAD, the network has been exported to ArcGIS using the ArcTool Box.

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* Wereda is the former third level administrative boundary

After exporting both the networks from AutoCAD to ArcGIS, the pipe sizes less than 100mm were selected and exported to be used in combination with the pipes of size greater or equal to 100mm that has finally been merged together. After merging the two source networks, three new fields for diameter, material type and year of installation has been created in ArcMap then after the corresponding values were filled by calculating from the codes describing these three items. The process diagram showing the procedures of the network data preparation is shown in Appendix III below. Please see the network plan of the city together with the city contour in Appendix VI

Indicating the location of reservoirs is also important as these are the main feeders to the network. Using the location of reservoirs as indicated in the network and taking the capacity of each reservoir from a separate document, their location has been digitized and is shown together with the network plan.

3.3.3.2. Water Consumption

The data collected for more than 200,000 customers with in the entire city was a large file. Due to its bigger size, this data has been collected divided by six branch offices. The data has been collected in Excel format by exporting from Oracle. One of the difficulties faced in this data was that the house number of the customers was not recorded in a similar way as of the cadastral information. In order to convert these house numbers as to match with that of the cadastral information, the data has been converted to Microsoft Access that the house number has been changed using the SQL query "UPDATE TABLE SET New House Number = RIGHT(Old house number, 4)" in order to get the house numbers that were written as the four last digits in the data. The data of each branch was joined in ArcGIS environment to combine the 12 months consumption of each branch. Finally the data was exported to SPSS for further required analysis and aggregation. As the number of customers is different in each month due to adding new customers or cancellation of old ones, combining the individual tables together so as to evaluate and aggregate the records was time consuming.

The consumption data was collected for each month by six branches. The consumption of each contract has been combined for each of the six branches in order to get the twelve months (annual) consumption in one combined table. Contract number was used as a unique identifier to combine each customer's consumption. After this, the consumption was aggregated by Kebele and finally to the entire city. As there were totally 72 separate tables (6 branches x 12 months = 72), combining these together and aggregating first by kebeles of each branch and then all kebeles together to get the annual aggregated consumption for a total of 303 kebeles was time consuming. ArcGIS, MS-Access and SPSS software were used through the process. Please refer for the detail procedure in Appendix V.

As the data is very large, investigating its quality before aggregating to different levels was necessary as it was not possible to do it during the fieldwork, since the data was not collected in time due to failure of the computer system of the authority. While investigating the quality of the consumption (meter reading) data, some problems were observed that as a result need to be systematically evaluated before aggregating at different levels. The main problems observed are listed as below:

i. Availability of significant differences on different monthly consumptions.

While the consumption data was reviewed, significant differences between consecutive months were observed that might be caused due to non-regular reading of meters. This has been also explained by the local experts. Beside to non-regular meter readings, the authority do not have a cross checking mechanism for any significant differences between consecutive months. For this reason on the one hand large consumption and on the other hand zero consumption for long consecutive months were seen in some of the individual consumptions. Despite the zero and some higher values observed in the monthly consumption of individual contracts, the aggregated values were used for this study as these aggregated values were not affected much as the lower and higher individual values can be balanced to each other.

ii. Repeated Contract numbers and monthly consumptions

Contract numbers are the unique identifier of any meter or customer. Even though meters are changed due to different reasons, the contract number remains the same. While this was the case, some contract numbers were found repeated in the monthly consumption records. The reason for the repetition of the contracts was due to changing of water meters. The existing system of AAWSA does not show the old or changed meter during changing of meters. Although the repeated contracts was identified using the summarizing technique in ArcGIS, it was not possible to identify which reading is the correct value. Of course most of the meters repeated were having either the same value mostly in case of repeating twice and two equal values as one of it negative and the other positive with another third value as positive (probably the correct value) were the dominant types of errors observed as shown in the example of Table 3-1 below.

Table 3-1 Example of repeated Contracts and their values

Repeated_Contract_South200403				
Contract	Wereda	Kebele	Consumption (m^3)	Count of Contract
81356	19	57	61	3
81356	19	57	-61	3
81356	19	57	24	3
80683	19	57	113	3
80683	19	57	-289	3
80683	19	57	289	3
80655	19	55	0	2
80655	19	55	7	2
80563	19	57	20	6
80563	19	57	0	6
80563	19	57	45243	6
80563	19	57	0	6
80563	19	57	-45243	6
80563	19	57	0	6

After the repeated contracts were identified using the summary technique it has been joined with the original table again in order to identify their magnitude and the nature of the repetition. The process of identifying the repeated contracts and calculating their values is shown in Appendix IV. While the magnitude of the repeated contracts were evaluated, the total consumption of the repeated contracts were not as such significant as compared to the total consumption of each month, as most of the negative values are counter balanced by the equal magnitude of positive values. Please see Appendix II for the magnitude of repeated contract values in comparison with the total consumption of each branch.

3.3.3.3. Sub-system data preparation

The data collected particularly for the sub-systems are monthly consumption and production for the duration of July 1999 – May 2002 as well as network of each sub-system in AutoCAD format. The preparation and conversion of the AutoCAD format network has been done using similar procedure to that of the entire network. In order to evaluate records of sample meter readings, some specific blocks of two kebeles were selected that their consumption data was combined for two and half years (January 2001 – June 2004). The city's DEM was also sliced partly for the sub-system using ILWIS software in order to prepare the map of elevation difference (potential pressure) from each of the reservoirs supplying water to the sub-systems.

3.3.4. Cadastral Information

The cadastral information that has been prepared about ten years ago by the Addis Ababa municipality fully covers all the 303 Kebeles of the city. The information is stored for each Kebele in coverage format. For the purpose of evaluating the distribution of water coverage by Kebele, 144 kebeles were selected that their blocks were merged and dissolved using ArcGIS in order to create Kebele boundary. The process for integrating the spatial component of the kebeles with that of the consumption is shown in Appendix V.

4. Domestic Water Supply Coverage

4.1. Introduction

Problems in provision of adequate water supply to the rapidly growing urban population are increasing dramatically. Water demand in the domestic sector of developing cities including Addis Ababa increases through time that as a result demands for additional water sources and infrastructure. Despite to these, the financial capacity of the city is low to satisfy the growing demand. Financial constraint is one of the major factors for the low water coverage of the water supply but poor management of the existing water supply system also has a great impact for the low coverage. Beside to the overall low supply coverage, supply disparity exists among different localities. Therefore evaluating the intra-city distribution of the water supply is important in order to identify the problematic areas and intervene accordingly.

Water supply coverage is usually evaluated based on the quantity, quality, paying capacity of the people, distance, etc., but the intention of this research is not to evaluate all these but related to the quantity of supply and level of connection that are related to the water loss. In this part of the analysis, the number of domestic connections per family and the average daily per capita consumption is used to analyze the domestic water supply coverage for the entire city. The level of coverage has been also compared with other cities of developing countries. Beside to the statistical analysis for the entire city, the distribution of the average daily per capita consumption and connection per family has been evaluated using a map for some part of the city.

4.2. Level of Domestic water supply coverage

Access to water supply may be evaluated using the amount of water consumed and the level of connection. For evaluating the amount of water consumption, the annual water consumption is converted to average daily per capita consumption using the population data of each Kebele. The number of domestic connections per family has been also used for analysing the level of connection as elaborated below.

4.2.1. Average daily per capita consumption

The volume of water consumed for domestic purpose has been aggregated to all 303 kebeles of the city so as to analyse the distribution of the water coverage among different localities. Statistical analysis were used to evaluate the distribution of the supply coverage in all kebeles of the city while a supply coverage map is prepared that covers nearly 50 percent of the city (144 kebeles).

Evaluating the domestic water supply coverage using volume of consumption may not allow realizing the distribution comparison among the kebeles. For this reason 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 kebeles was derived using the following expressions,

$$\text{Per capita consumption (l/person/day)} = \frac{\text{Annual consumption } (m^3) * 1000\ l/m^3}{\text{Population number of each Kebele} * 365 \text{ days}}$$

The distribution of the domestic water coverage has been evaluated using the following statistical tools. The distribution of the consumption has been first reviewed using the descriptive statistics, a box plot and histogram as shown in Figure 4.1and Figure 4.2 below.

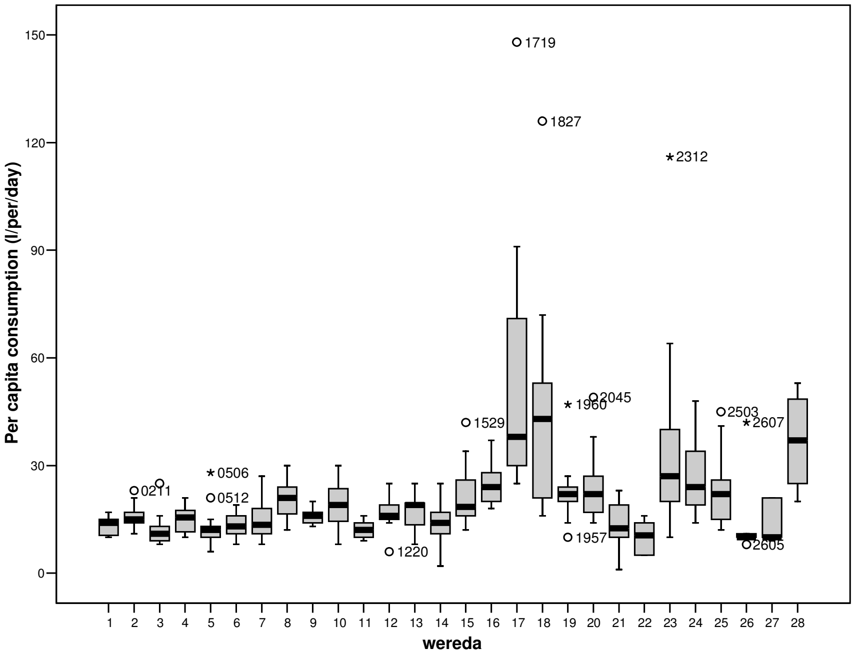
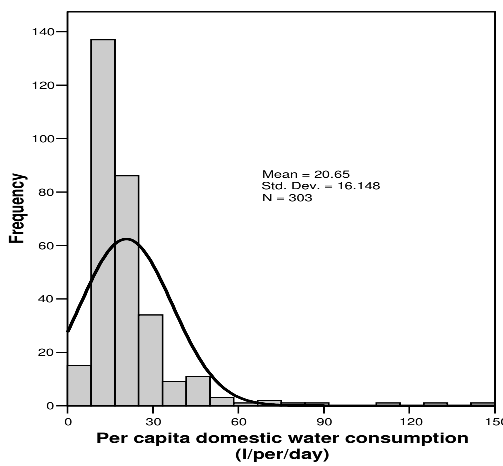


Figure 4-1 Box plot of average daily per capita domestic water consumption by Wereda



N	Valid	303
	Missing	0
Mean		20.65
Median		16.00
Mode		15
Std. Deviation		16.148
Minimum		1
Maximum		148
Percentiles	25	12.00
	50	16.00
	75	23.00

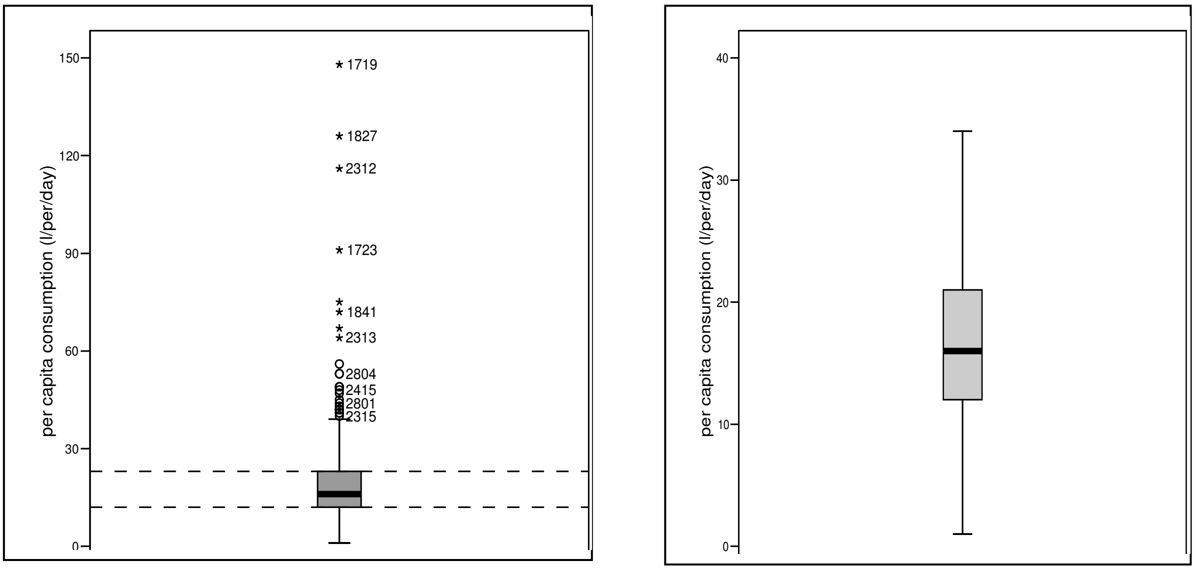
a) Histogram of per capita consumption **b) Descriptive of per capita consumption**

Figure 4-2 Histogram and descriptive of average daily per capita domestic consumption

As shown in the above box plot, the distribution of the water consumption varies among Weredas as well as among kebeles of each Wereda. More or less the variation is observed in all Weredas but particularly in Weredas 17, 18, 23 and 28, on the one hand these Weredas are having better average consumption while compared to the others on the other hand there is a great variation among the Kebeles with in the Wereda.. This variation is reflected in the skewed histogram shown on Figure 4.2 above.

Excluding the extreme cases (outliers) may help to get realistic average figures for comparison. Therefore, the kebeles which are having significant consumption differences while compared with the others should be excluded before computing the average daily per capita consumption of the city. A box plot is used to evaluate the distribution of the per capita consumption of all kebeles in order to identify the outlier kebeles and exclude them.

The box plots before and after excluding the outlier kebeles is shown Figure 4.3 below.



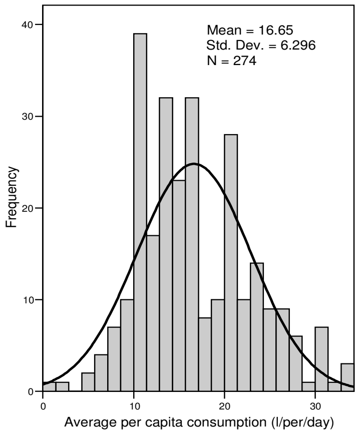
a) Box plot for all Kebeles b) Box plot after excluding outlier Kebeles

Figure 4-3 Box plot of average daily per capita water consumption (all Kebeles)

As shown in Figure 4-3 a) above, the outlier kebeles that greatly varies from the majority of other Kebeles are indicated by their ID number above the inter quartile range of each box plots.

The inter quartile range (IQR) is the difference between the quartiles. It is the spread of the centre half of the data. The 1.5 x IQR criteria flags observations more than 1.5 times beyond the quartiles as possible outliers (David and George, 2003). The inter quartile range is derived as 23 – 12 = 11 l/per/day. i.e. Kebeles having 12 minus 1.5 x 11 = -4.5 l/per/day (that means 0) and 23 plus 1.5 x 11 = 39.5 l/per/day may be excluded as they are outliers. 29 out of the total 303 Kebeles were excluded.

The descriptive statistical values and the histogram after excluding the outlier Kebeles are shown in below.



N	Valid	274
	Missing	0
Mean		16.65
Median		16.00
Mode		15
Std. Deviation		6.296
Minimum		1
Maximum		34
Percentiles	25	12.00
	50	16.00
	75	21.00

a) Histogram for per capita consumption **b) Descriptive of per capita consumption**

Figure 4-4 Distribution of the average daily per capita consumption after excluding outliers

Taking the mean consumption as shown in b) above, the average domestic water coverage of the city is found to be 16.65 l/per/day. The average daily per capita consumption of the city is very low while compared to other cities even in developing countries like the southern African larger cities. An overview of urban water supply for Southern African larger cities is shown in Table 2 1 of chapter 2.

According to some literatures, a minimum quantity of 25 l/per/day domestic water supply is categorized as basic level of service (Wallingford HR., 2003) which is higher than the average domestic consumption of the city of Addis. Out of the total 303 kebeles of the entire city, 247 with 2.4 million inhabitants (nearly 80%) are getting water less or equal to the this basic service.

On the other hand according to the UN-Habitat, that 20 l/per/day taken as the basic need to be provided, 204 Kebeles with a total population of 1.85 million (60% of the total inhabitants of the city) are still getting water below the standard set by the UN-Habitat as a basic service.

A map of average daily per capita consumption distribution was prepared for 144 Kebeles that covers nearly half of the entire city as shown in Figure 4.5 below.

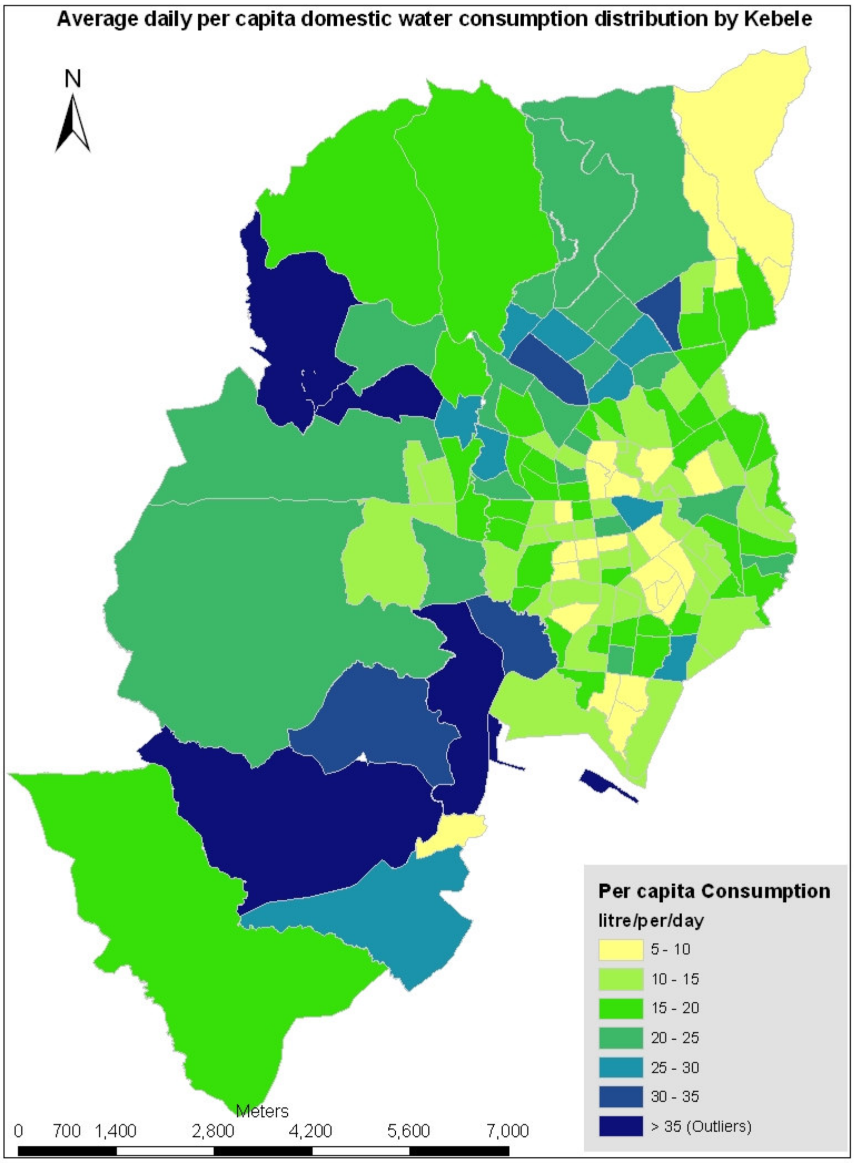


Figure 4-5 Distribution of average daily per capita consumption by Kebele

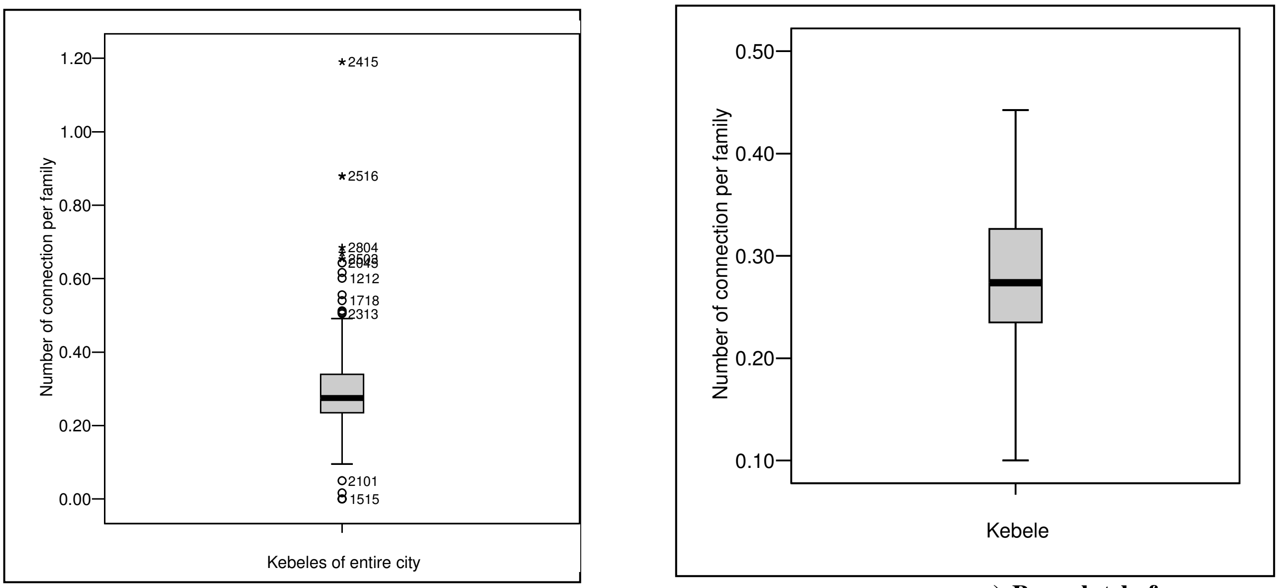
4.2.2. Level of connection per family

Level of water connection is an important element on the one hand for evaluating the level of water coverage that will be the focus of this section and on the other hand it has a direct impact on the water loss that will be dealt separately.

The total numbers of connections or water meters with in the city are about 202,000 that among these, 171880 are for domestic use. In order to compare the distribution of the water connection among the different Kebeles, the total numbers of connections per Kebele are converted to connection per family using the population data of each Kebele. According to the census of the 1994, average family size of 5.5 is used for calculating the average number of connection per family using the following expression.

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

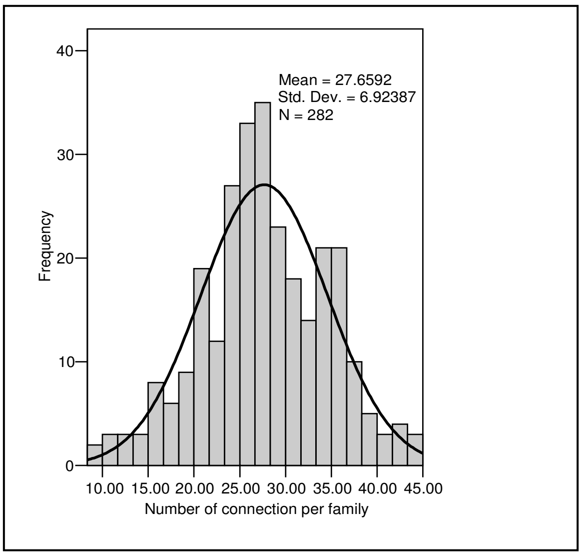
Similar to the per capita consumption, the distribution of the connection per family has been evaluated using a box plot as shown in Figure 4-6 below. As shown from the box plot below, some of the Kebeles are found to be having much higher level of connection per family while compared with the other majority Kebeles. The Kebeles having connection per family 1.5 times the inter-quartile range (i.e. number of connection < 0.235-1.5 x (0.33-0.235) = 0.095 and number of connection > 0.33 + 1.5 x (0.33-0.235) = 0.47) are excluded as outliers. The box plot after excluding outlier Kebeles is shown in Figure 4-6 b) below.



a) Box plot before excluding outliers **b) Box plot after excluding outliers**

Figure 4-6 Box Plot for number of connections per family

The distribution of the level of connection per family after excluding outliers is shown in the histogram and the descriptive values as shown in Figure 4-7 below.



N	Valid	282
	Missing	0
Mean		27.66
Median		27.36
Mode		9.55(a)
Std. Deviation		6.92
Minimum		9.55
Maximum		44.25
Percentiles	25	23.47
	50	27.36
	75	32.68

a Multiple modes exist. The smallest value is shown

a) Histogram of connection per family **b) Descriptive statistics of connection per family**

Figure 4-7 Distribution of connection per family after excluding outliers

Taking the mean which is equivalent to the median as shown in Figure 4-7 below the average connection per family for the entire city is found to be 0.28. This implies that at average more than three and half families or twenty persons are sharing one connection or water tap

4.3. Evaluating the distribution of the water supply coverage

As clarified earlier the water supply coverage of the city, both in quantity and level of connection is low while compared to other cities as well as the basic need. In this section the spatial distribution of the consumption in relation to number of population is discussed.

In areas where water supply coverage is sufficient, volume of domestic water consumption is expected to be linearly related to the level of connection. i.e. areas having better level of connection are expected to consume more water as they can easily get it with in their building or compound. At the same time better level of connection may imply for better paying capacity. i.e. families who can afford to have their connection (water meter) may have better capacity to consume and pay for more water.

A detailed demand study in Africa found that average water carried was about 22 l/cap/day over a long distance rising to about 27 l/cap/day where water was obtained from the consumers own stand pipe. Of course distance is not a big problem in urban areas while compared to rural areas (ADB, 1993).On the other hand in areas having insufficient supply like Addis Ababa, some areas may have better level of connection but may not necessarily mean they are consuming more volume of water as the possibility of getting the water does not depend only on the connection. This situation is reflected in the city. As per the feed back from the local experts, there are number of places that get low volume of water due to their topographic location. As the city mainly uses gravitational supply system, topography has a great impact on the per capita consumption.

To evaluate this situation, the average daily per capita consumption and the level of connection is compared using the map shown in figure 4.8 below.

As can be seen from the map in figure 4-8 below, low average per capita consumption that is indicated by the yellow colour was observed in the relatively old settlement areas that are also reflected in the map of connection per family. Nevertheless, some of the kebeles are still having higher per capita consumption while their level of connection per family is low or moderate. In order to evaluate the extent of variations of the water coverage among the different kebeles, the number of population living in each Kebele and the average yearly consumption has been compared using a correlation and scatter plot that is discussed in the next section.

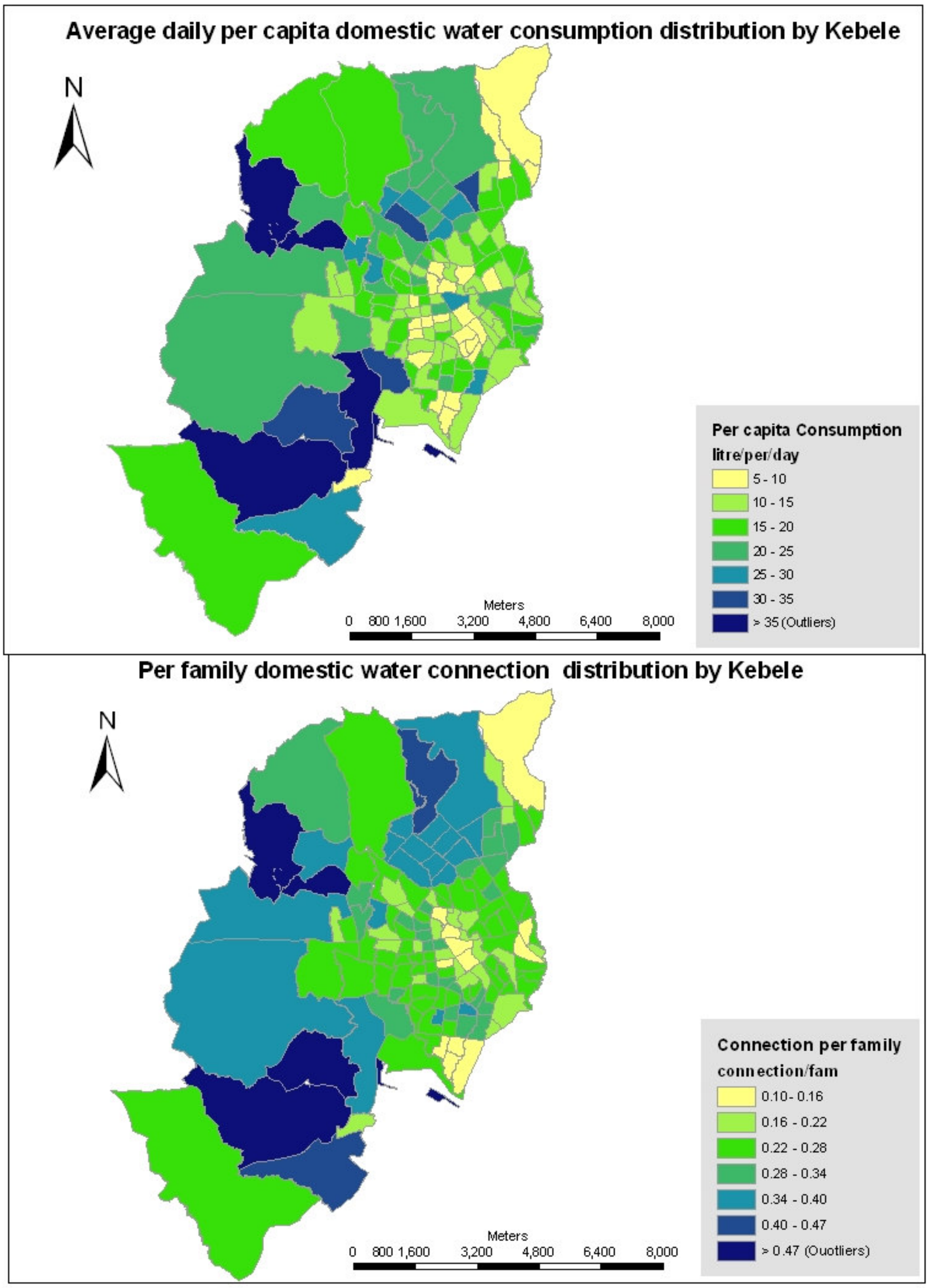


Figure 4-8 Distribution of average daily per capita consumption Vs connection per family

4.3.1. Correlation between population and water consumption

It is understood that settlements having more people consume more water than the settlements with low number of population as far as all the areas are having similar chance of getting water. This is also reflected with the above two maps (maps on per capita consumption and connection per family), that majority of the areas having higher level of connection are still having higher per capita consumption. But still there are some areas that their per capita consumption is high but the level of connection are still low or moderate and vice versa.

It is necessary to evaluate why some of the kebeles are consuming more water while they have low or moderate level of connection. This has been evaluated using the correlation between the water consumption and number of population as shown in Figure 4-9 and Figure 4-10 below.

		Yearly Consumption	Number of Population
Yearly Consumption	Pearson Correlation	1	.749(**)
	Sig. (2-tailed)		.000
	N	303	303
Number of Population	Pearson Correlation	.749(**)	1
	Sig. (2-tailed)	.000	
	N	303	303

Figure 4-9 Correlation between the domestic water consumption and number of population

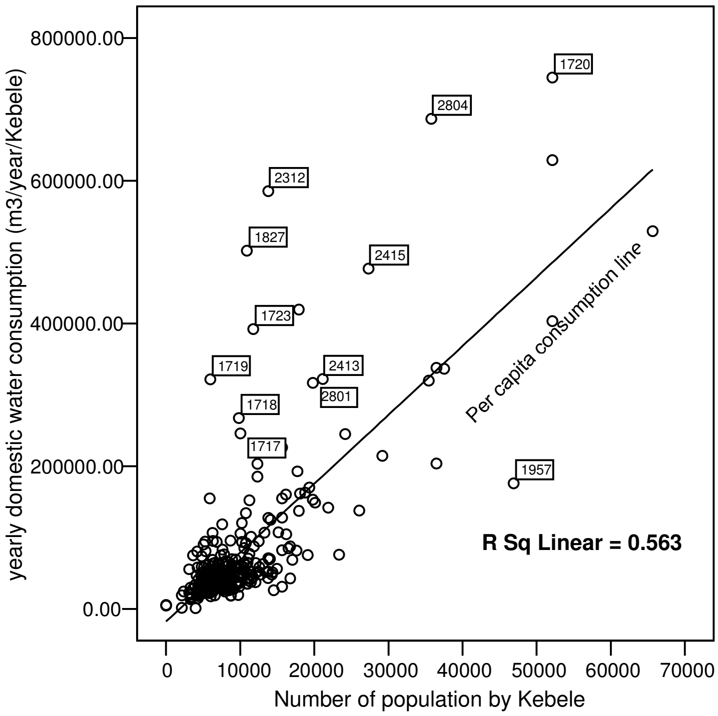


Figure 4-10 Scatter plot for volume of water consumption and number of population

Figure 4.9 explains that the correlation coefficient is 0.749. Thus, although the level of water coverage both in quantity and connection differ among different Kebeles, the number of population and volume of domestic consumption are found to have higher and positive correlation.

As shown in the above graph, the relatively higher correlation coefficient (0.749) may show that the number of population and total water consumption are linearly correlated to each other, but some Kebeles are still deviating from the correlation line or line of average per capita consumption.

Some kebeles having lower number of population but consume more water. This implies that either the people living in these kebeles are relatively rich and/or they have better chance of getting water due to their location or network condition.

On the other hand unlike the above situation, except one Kebele (Wereda 19 & Kebele 57), no kebeles are observed with extremely low consumption while they have higher number of population. This situation may give an indication that illegal water consumption is not a big problem. Had there been higher illegal consumption in specific kebeles, it might have been reflected in the above shown scatter plot. i.e. there might have been kebeles located extremely below the per capita consumption line.

In areas where enough water is supplied, the main possible cause for any differences in per capita consumption among different locations could be as a result of differences in income level and living condition of the people. Settlements that have better income level may have better paying capacity for the water they have consumed, but this might not be always true for areas that have shortage of water like Addis Ababa.

In the context of Addis Ababa where water is highly scarce, even though differences in income level (paying capacity) exist, the possibility of getting the water becomes difficult even for those who can afford to pay. On the other hand due to the heterogeneous nature of the city that people with different income level live together, the aggregated effect of the per capita consumption among kebeles should not differ much except is some areas where dominantly high income people are living.

The causes could also be resulted due to higher water loss in areas having aged network systems like in the old settlement areas and also due to low pressure in areas located at higher ground elevation as a result of topographic nature of the city.

In order to evaluate whether the differences is resulted due to the difference in paying capacity of the people or not, the consumption is evaluated using population density as explained here below.

4.3.2. Comparison of population density and consumption

Literatures show that on the one hand densely populated areas are mainly occupied by the low income people and on the other hand the low income people consume less amount of water as a result of their low paying capacity. Therefore, the highly populated areas are expected to have low per capita consumption, but as mentioned above this situation usually happen when there are enough water supplies. This is evaluated by comparing the per capita consumption and population density. A scatter plot and correlation is used as in shown in Figure 4.11 and Figure 4.12 below. Beside to the statistical comparisons, the distribution of the per capita consumption and the population density has been also evaluated using maps for the 144 Kebeles as shown in Figure 4.13 below. The population density is derived by dividing the number of population of each Kebele by the residential built up areas and its unit of measurement is population per hectare.

		Per capita consumption	Population density
Per capita consumption	Pearson Correlation	1	-.539(**)
	Sig. (2-tailed)		.000
	N	144	144
Population density	Pearson Correlation	-.539(**)	1
	Sig. (2-tailed)	.000	
	N	144	144

** Correlation is significant at the 0.01 level (2-tailed).

Figure 4-11Correlation between average daily per capita consumption and population density

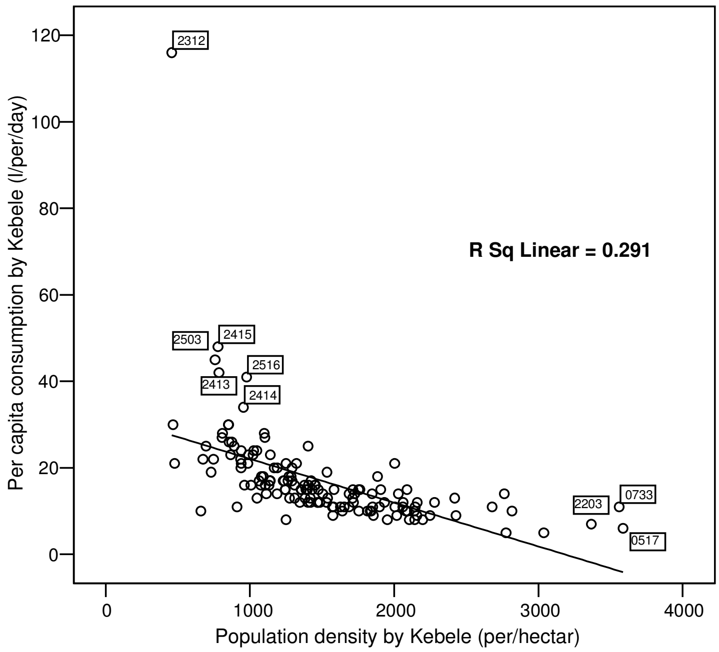


Figure 4-12 Scatter plot of average daily per capita consumption and population density

As can be seen from the above correlation and scatter plot, there is a negative but moderate correlation (-0.539) between the average daily per capita consumption and the population density. Some of the Kebeles like that of Kebele_ID 2503, 2415, 2516, 2413 and 2424 are having comparatively higher per capita consumption although they have low density and to the contrary Kebele_ID 2303, 0733 and 0517 are highly populated kebeles but their per capita consumption is comparatively very low. This is also shown in the map of the per capita consumption and population density distribution in Figure 4-13 below. As can be seen from the map on Figure 4-13 below, the kebeles that are highlighted are densely populated but their average daily per capita consumption is very low. These two highlighted kebeles (Kebele_ID 2303 and 0733) are not only highly populated areas but also majority of the people living in these areas are low income groups. Thus, one of the possibilities for the low per capita consumption could be resulted from the low living condition and low paying capacity of the residents. Moreover, these Kebeles are located in the higher ground elevation and older settlement part of the city. The higher ground elevation has an impact on the low consumption due to low pressure and the old network might as well have an impact due to loss of water with in the aged system. Therefore, the possible cause could be a combination of all the three and may be other possible factors.

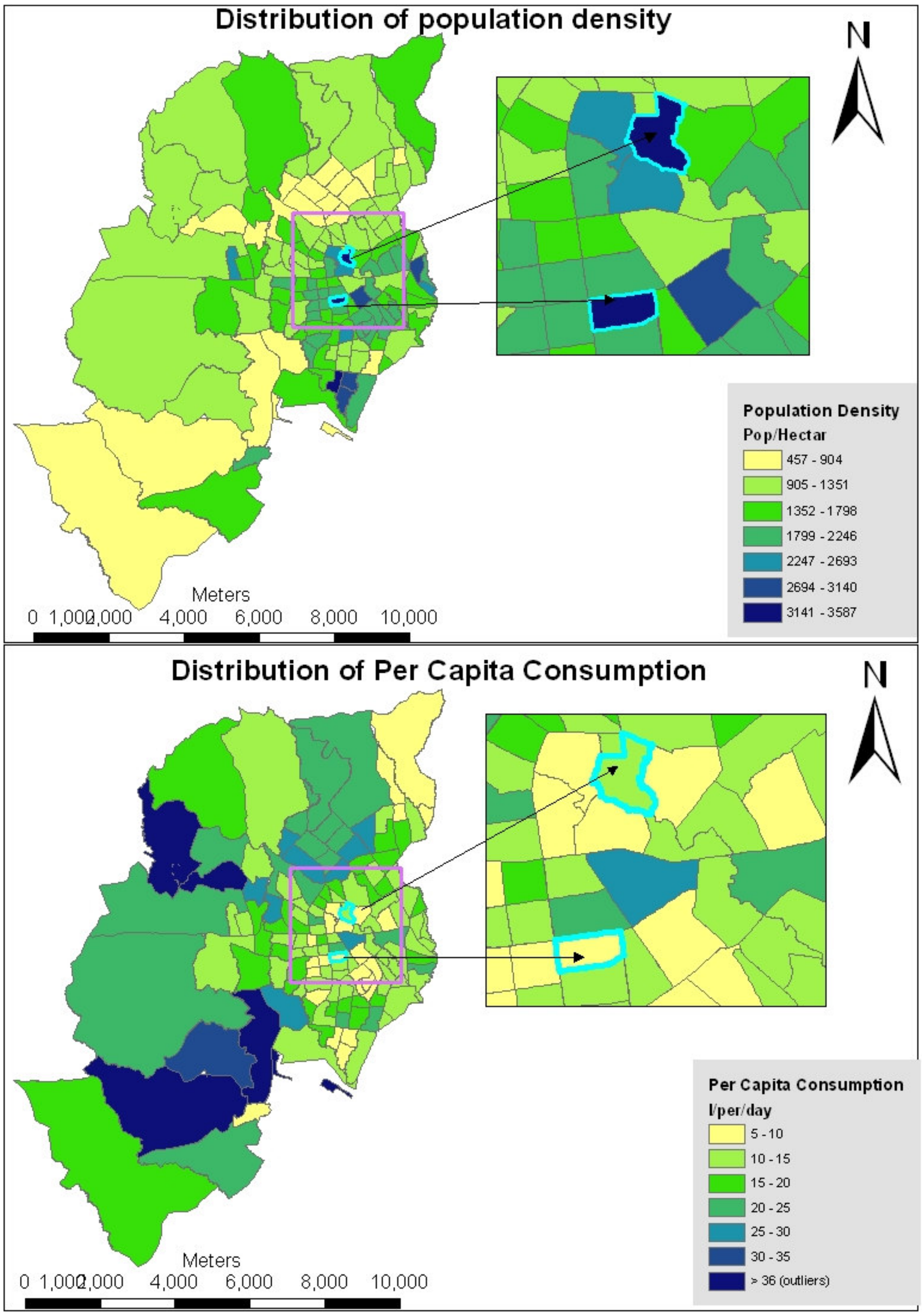


Figure 4-13 Distribution map of average daily per capita consumption and population density

4.4. Findings and conclusions

In order to get a realistic average daily per capita consumption of the city of Addis it was necessary to exclude both higher and lower extreme values both for the per capita consumption and connection per family. After excluding the outliers the average per capita consumption of the city is found to be 16.65 l/per/day. This average per capita consumption is lower while compared with other developing countries like the southern African cities and even it is lower than that of the minimum standard set by UN-Habitat as a basic need (20l/per/day). Except three Kebele having average per capita consumption greater than 100l/per/day, even the kebeles having relatively higher per capita consumption are getting water at an average of less than 100l/per/day which is still low while compared to other developing cities.

The other water coverage aspect evaluated was the level of connection per family. The average level of connection of the city is found to be 0.28 connections per family i.e. one water tap is at an average serving more than three and half family. In other words the average in-house or yard connection is about 28%. The level of connection is also far below the African cities' average of 43%.

The other issue than has been addressed was that negative correlation of the population density and the per capita consumption. This can show us on the one hand the highly populated areas where the low income people are living are having low per capita consumption on the other hand the moderate value of the negative correlation coefficient (-0.539) and that of the low R^2 value (0.291) indicates that even the less populated areas like the bole area (Kebele_ID=) 1719,1720 and 1721) and the old airport areas (Kebele_ID = 2312, 2313, and 2314) where predominantly rich people are living are still getting less water even though they have better capacity to pay.

On the other hand extreme low consumption is not observed in the scatter plot of the consumption vs. population. This may reflect insignificance of illegal water consumptions. This has been also confirmed during discussion with the local experts. According to the opinion of the local experts, illegal consumption of water is not the main problem of the city; rather the main problem is getting continuous and enough supply of water. The issue of payment was not a major problem until recent times as the tariff for water was not as such higher, but due to the recently increased water tariff, illegal consumption might become as an issue to be addressed. Illegal consumption of water is one of the component of unaccounted for water (UFW) that in most cases is caused due to illegal connections and malpractice of meter readers. This illegal consumption issue does not include losses due to meter errors like under-recording of customer meters that is qualified as major problem of the city as per the feedback from the experts.

5. The Water loss Analysis

5.1. Introduction

The water loss analysis is done and compared both at city level and local level (sub-systems). Although the data has been collected for each customer meter or contract of the entire city, as water production was only available at city level, the water loss analysis has been done focusing at the entire city and some selected sub-systems that data is found. Three sub-systems that have their own isolated reservoirs have been selected to analyse and compare the spatial distribution of the water loss.

Beside to water loss experienced through out a distribution system, water is also lost as a result of customer meter errors. This issue is being addressed in the analysis using selected sample meters supplied from one sub-system and one reservoir and some how located in areas having relatively significant elevation difference. As all the meters are not geo-referenced to the land information system (LIS) of the city, it was not possible to analyse all meters that serve one specific Kebele or block that would have been realistic so as to compare with the demand or expected consumption.

The total water loss analysis at both the city and sub-system levels have been evaluated and compared using three approaches of measuring loss, the percentage, loss per length of mains and loss per connection.

5.2. City level water loss analysis

The total annual water produced and distributed to the distribution system and the water billed that was aggregated from the individual customer meter readings were used to quantify the total water loss for the entire city. All the water consumptions in the city were metered except very few like for fire fighting use and water used by the water authority itself. As per the 1996 Ethiopian Fiscal Year report of AAWSA (July 2003 to June 2004), the annual water consumed for fire fighting and that of consumed by the water authority itself was estimated to be 66,656 cubic meter which accounts only 0.1% of the total annual water production. As the authorised non-metered consumption are insignificant while compared with the total water production, the unaccounted for water (UFW) has been used as a synonymy of the total water loss in this analysis. The 12 months water production and consumption that the water loss calculation was based on is shown in Table 5-1 and Table 5-2 while the corresponding curve of the total water loss is shown in Figure 5-1 below.

$$\textit{Total water loss (\%)} = \frac{(\textit{Total water produced} - \textit{Total water billed}) * 100}{\textit{Total water produced}}$$

Table 5-1Monthly water bill of the 1996 Ethiopian Fiscal Year (July 2003 – June 2004) by branch

Months	Akaki branch	Central branch	East branch	North branch	South branch	West branch	Total Billed (M^3) (Consumption)
July 2003	141086	524882	959304	492712	1107774	355492	3581250
Aug. 2003	114328	682608	935835	463154	1101912	395680	3693517
Sept. 2003	127357	594042	828557	465083	1060366	538986	3614391
Oct. 2003	127538	735317	956894	503094	989190	476303	3788336
Nov. 2003	124395	903972	1285950	615029	1138566	623962	4691874
Dec. 2003	137474	771727	1180260	536457	1198778	530032	4354728
Jan. 2004	158607	618079	1139167	529421	1185622	483730	4114626
Feb. 2004	276993	602586	911918	489023	1128396	488309	3897225
Mar. 2004	144190	702538	1187550	535579	1268693	470880	4309430
Apr. 2004	174527	781776	1291036	568802	1285780	532015	4633936
May 2004	156400	1108015	1223048	531679	1425305	527473	4971920
June 2004	147771	811226	1084623	544064	1224023	431728	4243435

Table 5-2 Total monthly water production, consumption and loss

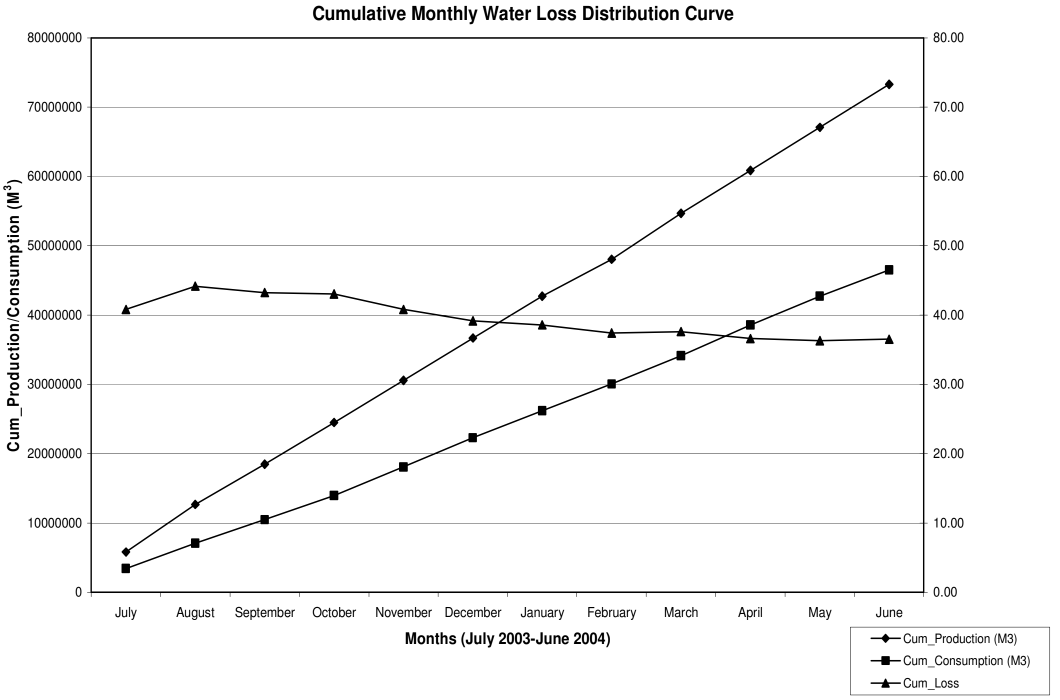
Months	Production (M^3)	Consumption (M^3)	Monthly Loss (%)	Cum. *Prod(M^3)	Cum. Cons (M^3)*	Cumulative♣ loss (%)
July 2003	5841174	3581250	38.69	5841174	3581250	38.69
Aug. 2003	6838219	3693517	45.99	12679393	7274767	42.63
Sept. 2003	5804696	3614391	37.73	18484089	10889158	41.09
Oct. 2003	6036524	3788336	37.24	24520613	14677494	40.14
Nov. 2003	6071828	4691874	22.73	30592441	19369368	36.69
Dec. 2003	6096720	4354728	28.57	36689161	23724096	35.34
Jan. 2004	6018917	4114626	31.64	42708078	27838722	34.82
Feb. 2004	5330214	3897225	26.88	48038292	31735947	33.94
Mar. 2004	6656367	4309430	35.26	54694659	36045377	34.10
Apr. 2004	6189234	4633936	25.13	60883893	40679313	33.19
May 2004	6203855	4971920	19.86	67087748	45651233	31.95
June 2004	6206035	4243435	31.62	73293783	49894668	31.93

The cumulative average water loss of the city is shown in the table above. Water loss is usually expressed in terms of percentage (UFW), loss per kilometre length of main pipes and loss per properties or number of connections. The total water loss has been evaluated based on the three measurement approaches as explained here under.

* Cum-Prod & Cum-Cons stands for cumulative production & consumption of the months taking July 2003 as a base

♣ Cumulative loss stands for the average loss of each month taking July 2003 as a base

Figure 5-1 Monthly total water loss distribution curve based on cumulative values



5.2.1. Total Water loss expressed as percentage (UFW)

The total annual water produced and distributed to the system with in the specified year has been 73,293,783 cubic meters and the annual total water loss as derived using the above expression was 23,399,115 cubic meter which accounts to 32% of the total water production. Taking the average tariff of water in the city as 1.95 Ethiopian birr (1 USD = 8.65 Ethiopian birr), the water loss is estimated to be 5.25 million USD every year. However, the real loss is beyond this as the water tariffs like other developing countries are usually subsidized.

5.2.2. Water loss expressed as per number of connection

Water loss expressed as a percentage could be an appropriate means to show the extent of the loss with in a given environment, but it is not a good indicator for comparing the losses from one area to another. According to some literatures comparison of water loss between different areas is recommended to be done using the water loss per service connection per day. Taking the total number of connections in the city as 202,000, the water loss per connection for the similar duration was derived as,

Water loss = 23,399,115 x 1000 / (202000*365) = 317.36 litre/connection/day.

5.2.3. Water loss expressed as per length of pipes

Water loss expressed as per kilometre length of main pipes is also used as indicator to compare water loss. This indicator is usually recommended for non-densely populated areas. The total length of pipes of size 50mm and above of the entire city is 1,681 kilometres out of which nearly 679 kilometres were categorized as main pipes according to the classification of AAWSA. Nevertheless, as there are some pipes that their diameter not clearly identified, all the pipes greater or equal to 50 mm in diameter have been used to evaluate the water loss per length of pipes. The length of pipes including their age for main pipes (pipe diameter >=

125mm) are shown in Figure 5.2 and the summary of lengths for all pipes greater or equal to 50mm is shown in Table 5 3 below.

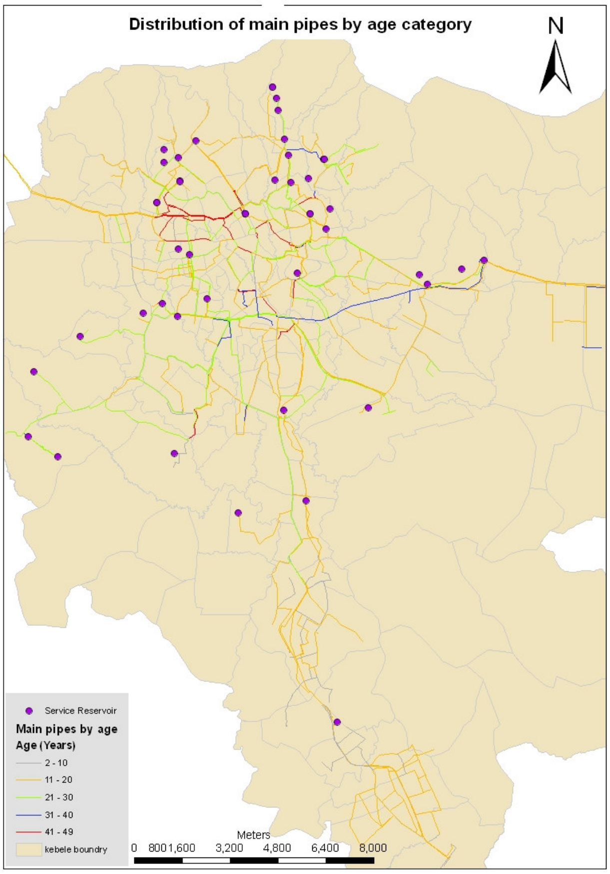


Figure 5-2 Distribution of main pipes by age category

Table 5-3 Summary of pipe lengths by age category

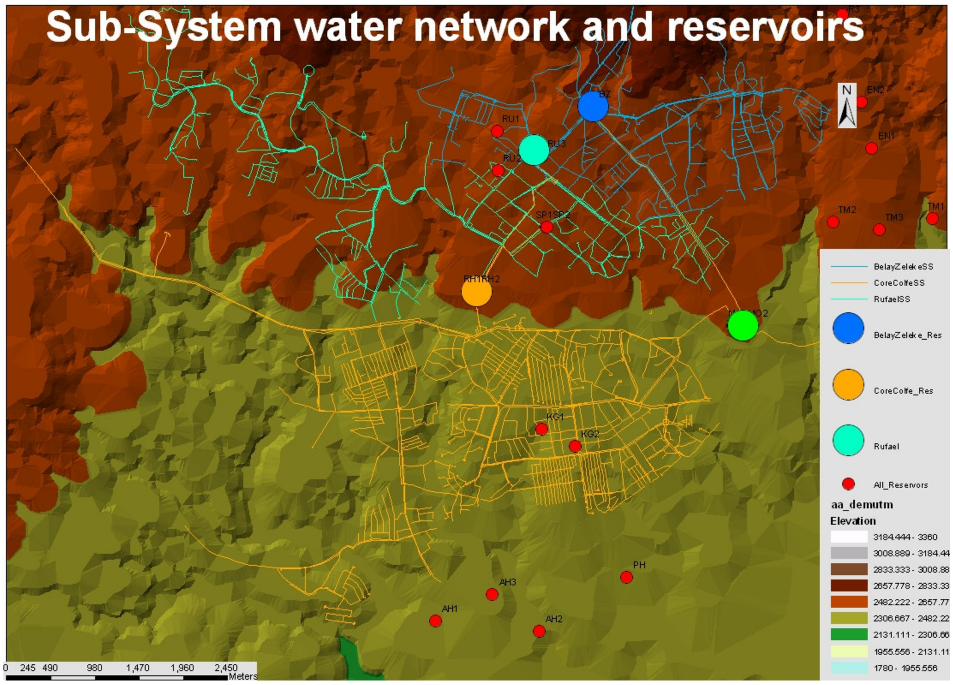
Age Category	All pipe category		Main pipes category		Secondary Pipes category	
	Total Length (M)	% from total	Pipe length	% from main total	Pipe length	% from secondary total
10 years & less	68303	4.06	52047	7.67	16256	1.62
10 - 20 years	414496	24.65	370675	54.61	43821	4.37
20 - 30 years	1111105	66.09	189911	27.98	921194	91.88
30 - 40 years	41130	2.45	31980	4.71	9150	0.91
40 years and more	40975	2.44	34096	5.02	6879	0.69
Not specified	5272	0.31	0	0.00	5272	0.53
Total Length of Main pipe	1681281	100.00	678709	100.00	1002572	100.00

Using the total pipe length of the entire city, the water loss per kilometre length of main pipes was derived to be 23,399,115/ (1681 km*365days) = 38.14 m3/ km/day.

5.3. Water loss analysis at sub-systems

Three sub-systems that have data on production and consumption of water have been selected for analyzing water losses at local level. The entire city is sub-divided in to a total of thirteen sub-systems, but data on production and consumption as well as a separate network in AutoCAD format was only found in the three sub-systems. The network plan of the three sub-systems is shown in Figure 5-3 below.

Figure 5-3 Sub-system water network and reservoir location



The total water loss of each sub-system has been evaluated using a similar expression to that of the city level analysis as shown here below.

5.3.1. Colfe Core Sub-system

The monthly water distributed to the sub-system and that of consumed from is sown in Table 5.4 below and the corresponding monthly total water loss curve is shown in below.

Table 5-4 Total monthly water distributed, consumed and loss in Colfe Core Sub-system

Months	Production (M^3)	Consumption (M^3)	Loss	Cumulative Production (M^3)	Cum.* Consumption (M^3)	Cum-Loss* (%)
7/8/1999	1092816.4	535057.14	51.04	1092816.4	535057.14	51.04
9/10/1999	927606.6	593334.47	36.04	2020423	1128391.61	44.15
11/12/1999	990326.7	570731.9	42.37	3010749.7	1699123.51	43.56
1/2/2000	1013034.9	572879.77	43.45	4023784.6	2272003.28	43.54
3/4/2000	952550.6	594452.4	37.59	4976335.2	2866455.68	42.40
5/6/2000	1037002.7	591984.75	42.91	6013337.9	3458440.43	42.49
7/8/2000	1018546.2	591162.33	41.96	7031884.1	4049602.76	42.41
9/10/2000	1137960.2	576462.53	49.34	8169844.26	4626065.29	43.38
11/12/2000	931684.34	584787.56	37.23	9101528.6	5210852.85	42.75
1/2/2001	729213.19	591218.49	18.92	9830741.79	5802071.34	40.98
3/4/2001	1081136.3	702296.04	35.04	10911878.1	6504367.38	40.39
5/6/2001	949580.38	657139.39	30.80	11861458.48	7161506.77	39.62
7/8/2001	969331.1	797844.31	17.69	12830789.58	7959351.08	37.97
9/10/2001	1007842.1	693079.49	31.23	13838631.67	8652430.57	37.48
11/12/2001	937792.29	713925.19	23.87	14776423.96	9366355.76	36.61
1/2/2002	904678.24	713925.19	21.09	15681102.2	10080280.95	35.72
3/4/2002	915633.2	630015.84	31.19	16596735.4	10710296.79	35.47
5/6/2002	980117.2	642291.16	34.47	17576852.6	11352587.95	35.41

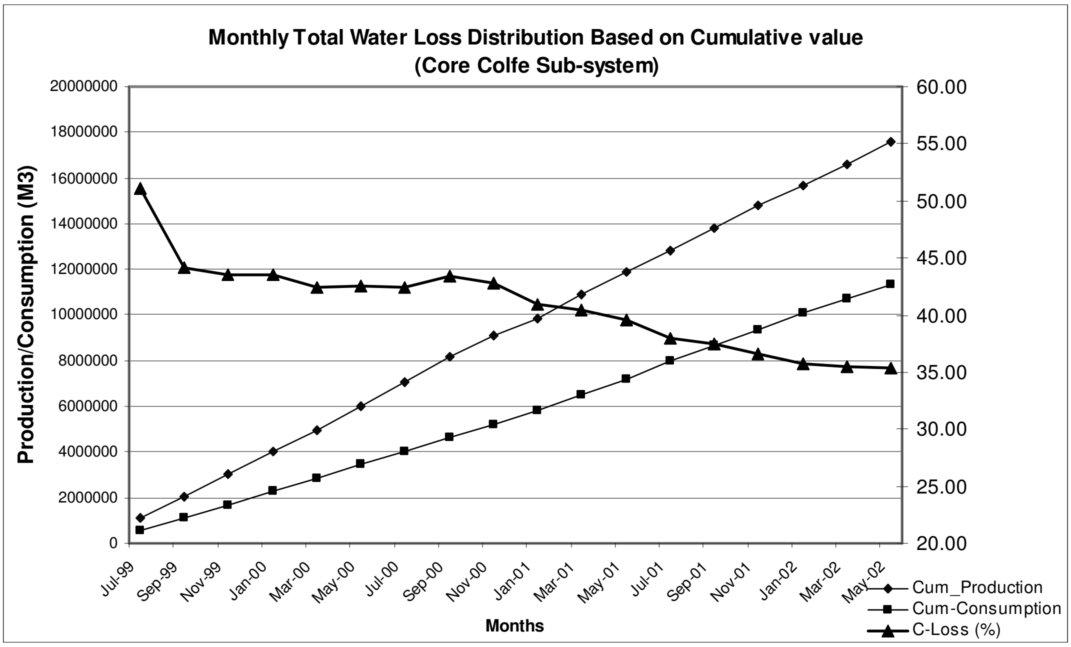


Figure 5-4Colfe Core sub-system total monthly water loss distribution curve based on cumulative values

* Cum. Consumption = cumulative consumption & cum. Loss = cumulative loss

5.3.2. Rufael sub-system

The monthly water distributed to the sub-system and that of consumed from is sown in Table 5-5 below and the corresponding monthly total water loss curve is shown in below.

Table 5-5 Total monthly Water distributed, consumed and loss in Rufael sub-system

Months	Production (M^3)	Consumption (M^3)	Monthly Loss (%)	Cumulative Production (M^3)	Cum. Consumption (M^3)	Cum. Loss (%)
7/8/1999	329153.5	210359.67	36.09	329153.5	210359.67	36.09
9/10/1999	356690.2	200247.61	43.86	685843.7	410607.28	40.13
11/12/1999	367810.3	227941.9	38.03	1053654	638549.18	39.40
1/2/2000	383499.5	236956.79	38.21	1437153.5	875505.97	39.08
3/4/2000	362334.9	230746.35	36.32	1799488.4	1106252.32	38.52
5/6/2000	349531.7	219162.7	37.30	2149020.1	1325415.02	38.32
7/8/2000	331440.9	203115.2	38.72	2480461	1528530.22	38.38
9/10/2000	353362.5	202273.42	42.76	2833823.5	1730803.64	38.92
11/12/2000	351939.1	214112.67	39.16	3185762.6	1944916.31	38.95
1/2/2001	400335.2	274995.61	31.31	3586097.8	2219911.92	38.10
3/4/2001	315064.1	221673.2	29.64	3901161.9	2441585.12	37.41
5/6/2001	369590.2	253185.32	31.50	4270752.1	2694770.44	36.90
7/8/2001	394473.8	328318.06	16.77	4665225.9	3023088.5	35.20
9/10/2001	380907.2	299824.12	21.29	5046133.1	3322912.62	34.15
11/12/2001	368591.42	251014.2	31.90	5414724.52	3573926.82	34.00
1/2/2002	372539.48	251014.2	32.62	5787264	3824941.02	33.91
3/4/2002	377644.3	273581.45	27.56	6164908.3	4098522.47	33.52
5/6/2002	389093.2	299460.6	23.04	6554001.5	4397983.07	32.90

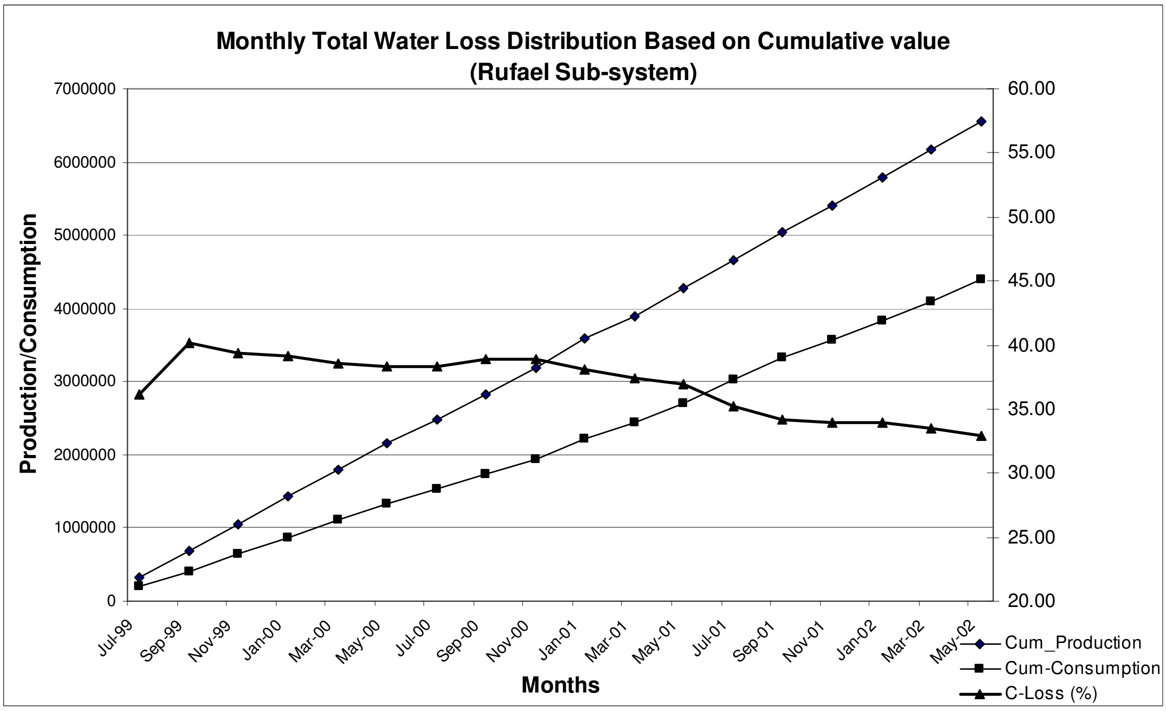


Figure 5-5 Rufael sub-system total monthly water loss distribution curve based on cumulative values

5.3.3. Belay Zeleke sub-system

The monthly water distributed to the sub-system and that of consumed from is sown in Table 5-6 below and the corresponding monthly total water loss curve is shown in table 5-6 below.

Table 5-6 Total monthly Water distributed, consumed and loss in Belay Zeleke sub-system

Months	Production (M^3)	Consumption (M^3)	Monthly Loss (%)	Cumulative Production (M^3)	Cum. Consumption (M^3)	Cum. Loss (%)
7/8/1999	272032.4	147310.63	45.85	272032.4	147310.63	45.85
9/10/1999	305385.9	151300.17	50.46	577418.3	298610.8	48.29
11/12/1999	288375.8	195245.47	32.29	865794.1	493856.27	42.96
1/2/2000	330379.4	165376.62	49.94	1196173.5	659232.89	44.89
3/4/2000	304678.4	192635.68	36.77	1500851.9	851868.57	43.24
5/6/2000	295783	151816.47	48.67	1796634.9	1003685.04	44.14
7/8/2000	316988.4	180778.22	42.97	2113623.3	1184463.26	43.96
9/10/2000	255344.7	167092.22	34.56	2368968	1351555.48	42.95
11/12/2000	310885	164076.98	47.22	2679853	1515632.46	43.44
1/2/2001	332147.5	170716.6	48.60	3012000.5	1686349.06	44.01
3/4/2001	263383.3	177168.45	32.73	3275383.8	1863517.51	43.11
5/6/2001	271905	195327.83	28.16	3547288.8	2058845.34	41.96
7/8/2001	289573.8	162312.63	43.95	3836862.6	2221157.97	42.11
9/10/2001	309872.4	196033.16	36.74	4146735	2417191.13	41.71
11/12/2001	356653.9	228141.7	36.03	4503388.9	2645332.83	41.26
1/2/2002	343990.2	228141.7	33.68	4847379.1	2873474.53	40.72
3/4/2002	321923.5	169310.2	47.41	5169302.6	3042784.73	41.14
5/6/2002	355458.5	191419.34	46.15	5524761.1	3234204.07	41.46

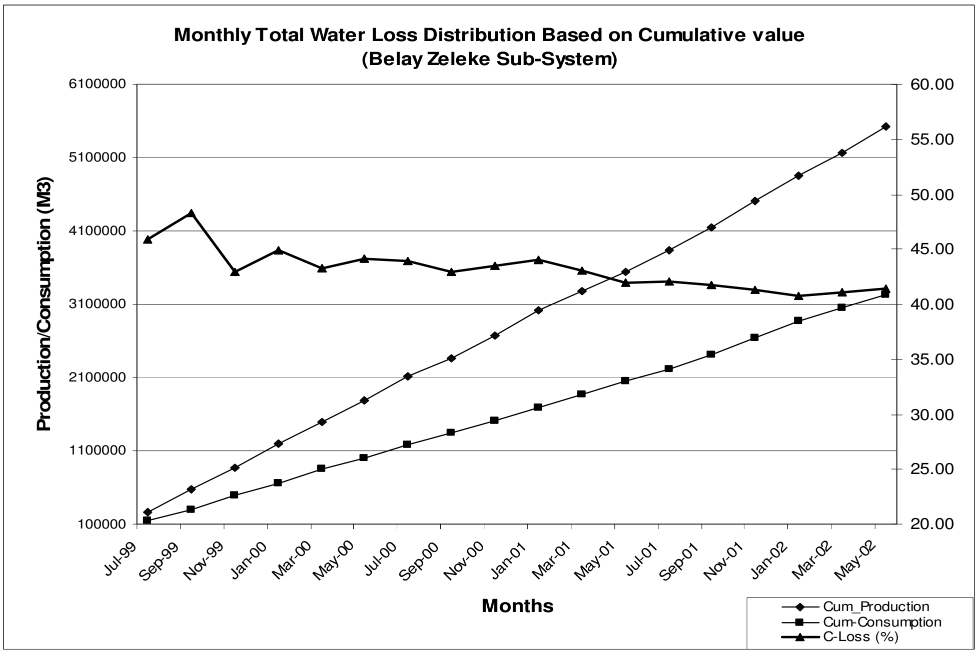


Figure 5-6 Belay Zeleke sub-system monthly water loss distribution curve based on cumulative values

5.4. Comparison of water losses

Using the percentage and quantitative figures found from the above tables and curves, a comparison is made among the three sub-systems based on three approaches, the percentage of total loss (UFW), loss per length of pipe and loss per number of connections.

5.4.1. Comparison among sub-systems

5.4.1.1. Comparison based on percentage of loss (UFW)

The average water losses expressed as percentage of the total volume of water supplied to the sub-systems were first used to compare the losses in each of the sub-systems. As can be seen from the loss tables of each subsystems shown above , higher percentage of losses were recorded in Belay Zeleke sub-system, 41.46%, while compared with the others.

5.4.1.2. Comparison based on loss per length of pipes

The water loss has been also evaluated based on the lengths of pipes in each sub-system. The total water loss expressed as percentages of the total volume of water supplied to each sub-systems and loss per km length of pipes is summarized in Figure 5-7 below. According to AWWSA pipes of size greater or equal to 125mm in diameter are classified as main but as some of the pipes in the sub-systems are not clearly identified, all pipes greater or equal to 50mm in diameter were taken for comparison purpose.

Figure 5-7 Total Water loss per kilometre length of pipes per day

Sub-system	Total percent of Loss (%)	Total water loss (m^3)	Total pipe length (km)	Loss per length (m^3/km/day)
Belay Zeleke	41.46	2290566	74.37	56.25
Rufael	35.41	2156266	90.75	43.40
Colfe Core	32.90	6223864	154.54	73.56

Unlike the UFW expressed as percentage of the water production, the water loss expressed as per kilometre length of pipes per day was higher in Colfe Core sub-system.

5.4.1.3. Comparison based on loss per number of connection

The number of connections (customer meters) of each Kebele that are served by each of the sub-systems has been used to evaluate the loss per number of connection. For Kebeles that are only partially served by the sub-system, the total number of connections (customer meters) of the kebeles has been proportionally adjusted based on the building areas that their centre is located with in the specific sub-system. The spatial selection of the ArcGIS operation has been used. After identifying the number of connections (customer meters) in each Kebele, the water loss per number of connection was evaluated as shown in Table 5-7 below. Both the domestic and non-domestic connections have been used.

Table 5-7 Total water loss per number of connection per day

Sub-system	Total UFW (%)	Total loss (M^3)	Num of Connection	Duration (days)	Loss per connection (l/con/day)
Belay Zeleke	41.46	2290557	8806	1095	237.55
Rufael	35.41	2156018	11153	1095	176.54
Core Colfe	32.90	6224264	23126	1095	245.80

Similar to the loss per length of pipes, the total loss per number of connections was also higher in Colfe Core sub-system and the lower losses were found in sub-system Rufael.

5.4.2. Comparison of the loss between sub-systems and entire city

One of the limitations in comparing the total water losses in the entire city and that of the sub-systems was the duration of the data. Both the production and consumption data for the entire city was from July 2003 to June 2004 while that of the sub-systems' is from July 1999 to May 2002. Although there is around one year timing difference with in the duration of the two data, no major change is expected as can also be seen from the monthly distribution curves of the losses. i.e. The cumulative percentage of losses not differ much with in one or two years time. Keeping this in mind, the comparison of the loss between the city level and the sub-systems is evaluated. The percentage of loss, loss per meter length and loss per connection is summarized as shown in Table 5-8 below.

Table 5-8 Summary of water loss for entire city and sub-system

Network place	Percent of loss (%)	Loss per length (m3/km/day)	Loss per connection (l/connection/day
Entire city	31.93	38.14	317.36
Belay Zeleke	41.46	56.25	237.55
Rufael	35.41	43.4	176.54
Colfe Core	32.9	73.56	245.8

While the water loss is evaluated based on the three approaches, the loss in the entire city is found to be less than the three sub-systems based on the percentage and loss per kilometre length of pipes, but it is bigger while the comparison is made based on the loss per connection.

As clarified earlier, comparing based on the percentage of loss could be misleading as it can be greatly affected by the huge volume of water produced at the entire city. This can be clearly seen from the figures of production for the three sub-systems as well as for the entire city. The percentage of water loss is higher in Belay Zeleke sub-system that is having low water production in comparison to the other two sub-systems. .

Unlike the comparison among the sub-systems, comparison between sub-systems and entire city based on the loss per length of pipes and that of loss per number of connection has given conflicting results. As measuring the loss per length of main pipes is highly affected by the density of connections, literatures recommend using a performance indicator of loss per connection (litters/connection/day) instead of loss per kilometre length of pipes for cities with dense connections.

For density of connections ranging from 45 to 100, 'litters/service connection/day' was found a more robust simple performance indicator for real losses than 'm^3/km mains/day' (Farley & Stuart).

Taking the total number of connection in the entire city as 202,000 and approximate length of main pipes (diameter greater or equal to 125mm) as 679 kilometres, the density of connection per length of main pipes become 297. Therefore in the Addis Ababa context, evaluating and comparing the distribution of the loss using an indicator of loss per connection is more appropriate than the other indicators or approaches. But the loss expressed as per kilometre

length of main pipes may be a useful indicator too for evaluating the loss in transmission or main distribution lines that do not have many branch outs.
Taking the indicator of 'loss per connection', the losses in three of the sub-systems is found to be less than that of the city. This gives an indication that either there are other sub-systems that their magnitude of loss is higher than these three sub-systems or as there is a timing differences between the data used for the entire city analysis and the sub-systems, the situation of water loss in the city is becoming worsen rather than improving. This needs further study using data from same duration and considering all the sub-systems.

5.5. Evaluating possible causes of the water loss

Due to limited data, the analysis of the water losses made so far both at city and at the sub-systems level is that of the total water loss. As it would be difficult to directly identify and characterize the causes of the losses from the results of the total loss, this has been attempted to evaluate by comparing the losses based on other factors that have an impact to the magnitude of the water loss. The pipe age, ground elevation differences and comparison of meter records has been used for evaluating the distribution of the total water loss.

5.5.1. Evaluating the loss based on ages of pipes

Pipe age is one of the factors that affect the magnitude of losses especially that of physical losses. Aged pipes are more likely having more water loss through leakage than newly installed pipes The ages of pipes in each of the sub-systems and the corresponding loss per length of pipes is summarized as shown in Table 5 10 and the corresponding chart.
As indicated in Table 5 9 and the corresponding chart below, more than 94% of the pipes in sub-system Rufael were having an age of less than 30 years while for Colfe Core and Belay Zeleke were 76 % and 85% respectively. Only considering the age factor, Rufael sub-system were expected to have lower percentage of losses than the other two which has also been reflected in the results of the total water loss analysis in both loss per length and per number of connection. i.e. The loss is found to be higher in the Colfe Core sub-system relatively having older pipe systems. This gives an indication for the loss to be predominantly caused from leakages through the pipe system. The pipe network for the three sub-systems by their age category is also shown on a map in Figure 5.8 below.

Table 5-9 Distribution of pipe network by age

a) Pipe lengths by age category

Age Category	Rufael		Core Colfe		Belay Zeleke	
	Length (M)	Length (%)	Length (M)	Length (%)	Length (M)	Length (%)
10 years & less	99	0.11	3652	2.08	1579	2.03
10 - 20 years	16054	17.31	19535	11.10	10092	12.97
20 - 30 years	71284	76.86	111664	63.47	54594	70.17
30 - 40 years	387	0.42	7955	4.52	1630	2.09
40 years and more	633	0.68	19222	10.93	2124	2.73
Unspecified	4290	4.63	13912	7.91	7788	10.01
Total	92747	100.00	175940	100.00	77807	100.00
Loss per length	176.54 m3/km/day		245.80 m3/km/day		237.55 m3/km/day	

b) Pie chart for percentage of pipes by age category

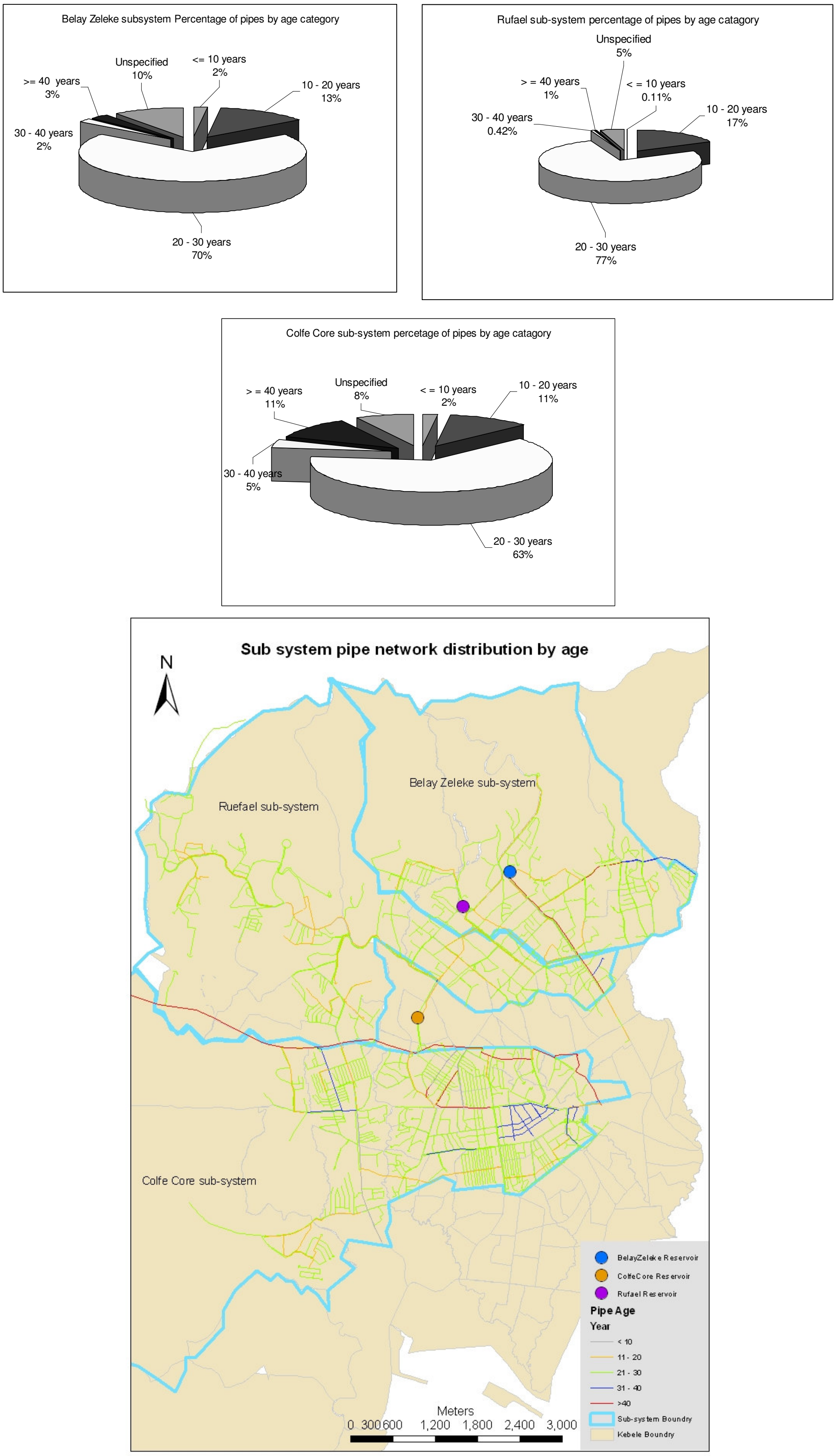


Figure 5-8 Distribution of pipe networks by age in thee sub-systems

5.5.2. Evaluating the loss based on ground elevation differences

As indicated in the network plan in Figure 5.8 above, each sub-systems are having their specific service reservoirs that are located upstream of the sub-systems that water is supplied through gravity. Due to the topographic nature of the city, significant elevation differences are observed among different settlement areas that are getting water from the same service reservoir. The elevation differences might have a great impact on the magnitude of loss through leakage. Higher loss is expected in lower settlement areas than settlements located in elevated areas. Nevertheless, distance from the reservoir also has an impact due to head loss.
The critical point is generally either the highest point in the system or the point most distant from the service although it may be a combination of the two depending upon local topography and various other factors (McKenzie and Wegelin).
The impact of the distance was evaluated using correlation and scatter plot between the distance and the average per capita consumption of the kebeles as shown in Figure 5.9 below. The very small correlation coefficient (-0.138) indicates that the effect of distance on the per capita consumption is almost nearly zero. Had the effect been large enough the coefficient would be negative and large. This is also reflected in the scatter plots shown in Figure 5.9 b) below. The network distance of the Kebele centres from the reservoir were calculated using the work station in ArcGIS environment. Therefore, the impact of the head loss for this particular case is assumed to be equivalent for all the sub-systems as they have comparable pipe types and distance from each reservoir.

a) Correlation

		distance of Kebele centers from reservoir	per capita consumption
distance of Kebele centers from reservoir	Pearson Correlation	1	-.138
	Sig. (2-tailed)		.344
	N	49	49
per capita consumption	Pearson Correlation	-.138	1
	Sig. (2-tailed)	.344	
	N	49	49

b) Scatter plot

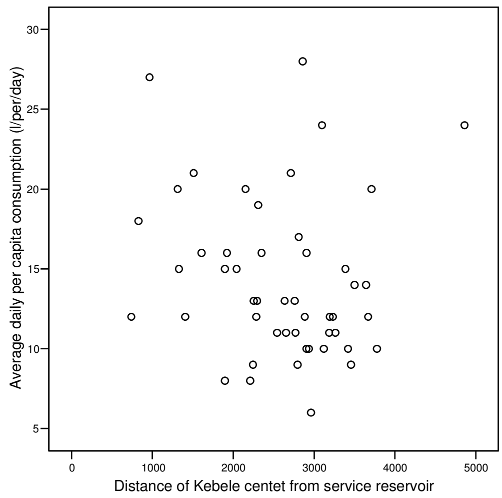


Figure 5-9 Correlation and scatter plot of per capita consumption and distance of Kebele centres

To evaluate the effect of ground elevation, elevation differences among the settlements (buildings) in each sub-system has been analysed with respect to the elevation of the service reservoirs where the sub-systems are getting water from. As all the meters are not geo-referenced to each of the buildings all the buildings whether they have water meter or not have been considered for the evaluation. The building layer (shape file) located in each sub-systems were converted to raster in ILWIS format for further comparison using histogram of the pixels. The histogram of each sub-system is shown in Figure 5.10 below.

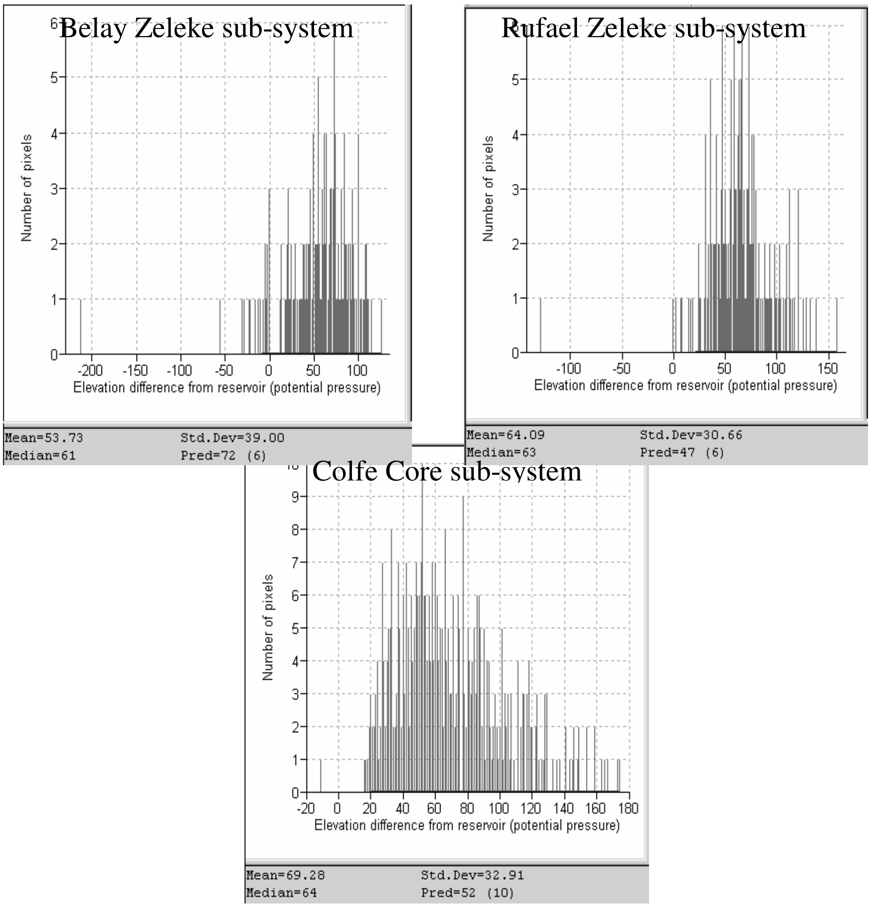


Figure 5-10 Histogram for elevation differences (Potential pressure) of buildings

As shown in Figure 5.10 above, the elevation differences among the settlements and the respective reservoirs that water is supplied from and between the settlements (buildings) themselves is higher in Colfe Core sub-system. The average elevation difference of the Core Colfe sub-system is 69.20 meters while that of the Belay Zeleke and Rufael is 53.73 and 64.09 respectively. To this effect pressure is expected to be higher in Colfe Core sub-system than the other two sub-systems.

Moreover, from the water loss analysis of the sub-systems, the total water loss is also found to be higher in Colfe Core sub-system. This gives an indication that pressure caused due to ground elevation differences (potential pressure) has great impact on the water loss. The ground elevation differences (potential pressure) distribution of each sub-system as derived from their corresponding reservoirs is mapped as shown in below

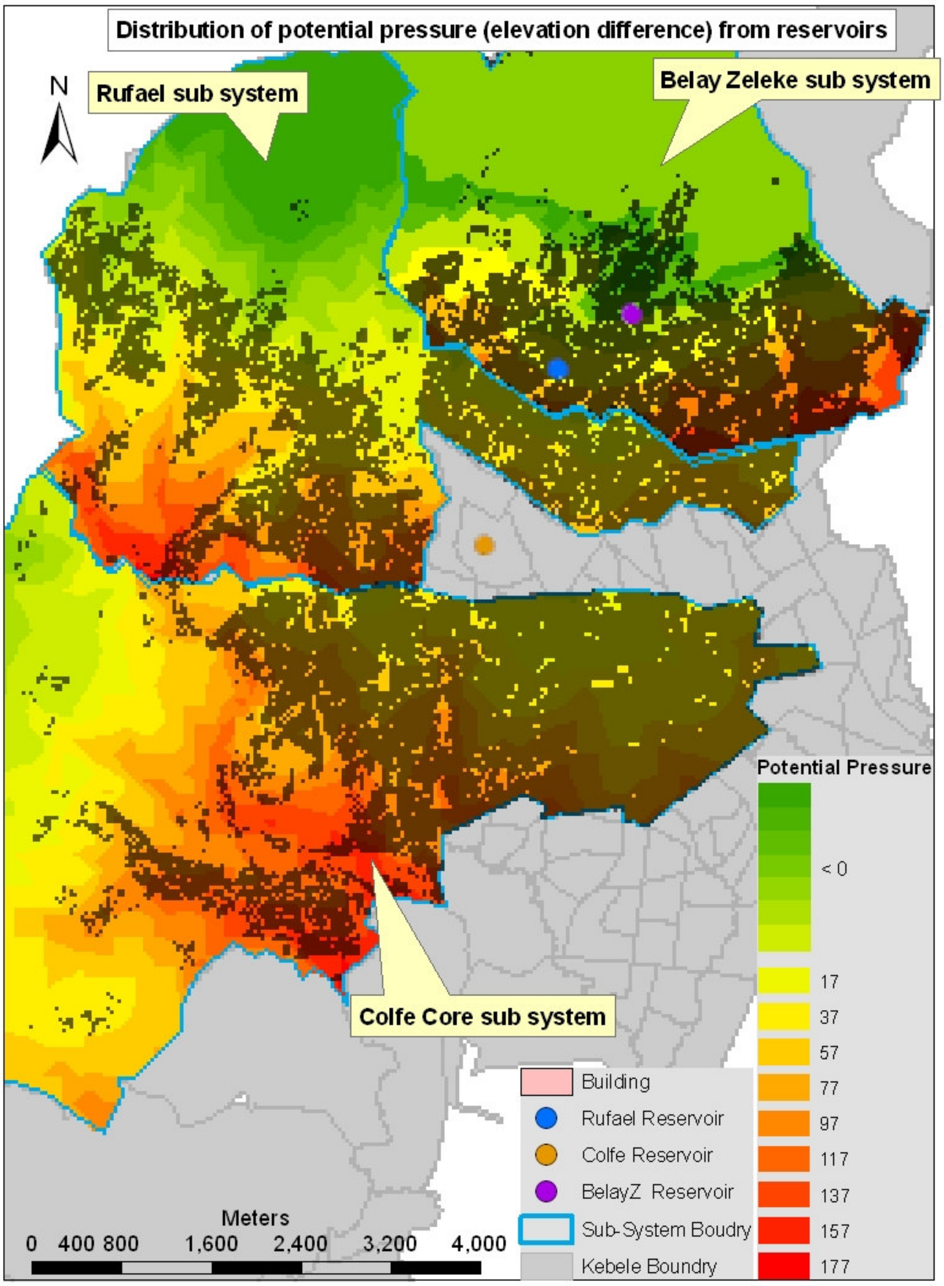


Figure 5-11 Distribution of buildings and their elevation differences (potential pressure) from respective reservoir

5.5.3. Evaluating the loss based on customer meter records

Many water institutions do not give enough attention for water losses caused as a result of metering errors but it has a considerable impact unless due attention is give like to that of the pipe networks. As per the feedback from the local experts, until recently the water authority was not checking the customer meters by itself unless the customers apply for check up. However, customers apply most probably when the problem were over-registration rather than under registration.

According to a leak detection study by AAWSA, the UFW volume due to the under registration of the consumption of domestic consumers of Addis Ababa was about 6% of the total production of the city (AAWSA, 1997).

Water loss in customer meters may be evaluated by analysis of domestic water draw-off patterns by means of electronic instantaneous flow recorders (loggers) ((Hopkins, Savage & Foxt, 1995). Nonetheless, such analysis might be expensive as well as technically difficult to be used in developing countries.

Other alternative way of testing customer meters is to meter the flow through a single main supplying a group of properties (Twort, Law, Crowley & Ratnayaka). In such cases, the total domestic water consumption recorded by individual property meters with in selected areas are compared with the bulk flow into each area as registered by a calibrated meter standard (Hopkins, Savage & Foxt, 1995). This method does not reveal individual results so that exceptionally high or low consumptions are not revealed for investigation. Also the consumption may include some undiscovered leakage from the main or service pipe connections downstream of the supply metering point (Twort A.C. et al., 1994). In networks sub-divided into smaller manageable areas, such method might be more feasible from the developing countries point of view.

So far the water loss evaluated both for the entire city as well as the sub-systems was that of the total loss, but in reality the total water loss is a combination of different types of losses that loss at the level of customer meters is among the others. It would have been more feasible if groups of customer meters located at different representative geographic locations had been compared from the demand or expected consumption of a specific area, but as the customer meters are not fully geo-referenced it was not possible to compare the actual consumption with that of the expected. Moreover, the customer meters do not serve only a specific family. Due to data limitation, only sample meters that can be geo-referenced to specific buildings has been taken for further analysis only to compare the average daily consumption records of groups of meters located at different locations, regardless of their demand or expected consumption.

5.5.3.1. Selection of sample customer meters

Records of customer meters readings (consumption) were evaluated by selecting two kebeles that are located in the Colfe Core sub-system that relatively has higher water loss. The following criteria have been used to select representative sample meters for further analysis.

- ❖ Meters that get water from same reservoir
- ❖ Groups of customer meters located at relatively different ground elevations while compared to the reservoir.
- ❖ Meters that was not changed for the past two and half years that data was available (January 2002 to June 2004).
- ❖ Meters of domestic use, in order to compare one from the other

Based on the above criteria, Wereda 25 & Kebele 06 (W25K06) and Wereda 24 & Kebele 17 (W24K17) have been selected.

In order to identify the meters that were not changed during the specified duration, meters that their previous readings are less than the latest readings have been selected using the SQL query in ArcGIS. Based on these criteria, 33 meters from W25K06 and 61 from W24K17 were taken as sample meters for further analysis. The total consumption for the two and half year's duration was converted to average daily consumption. The distribution of the sample meters and their average daily consumption together with the pipe network is shown in Figure 5.12 below.

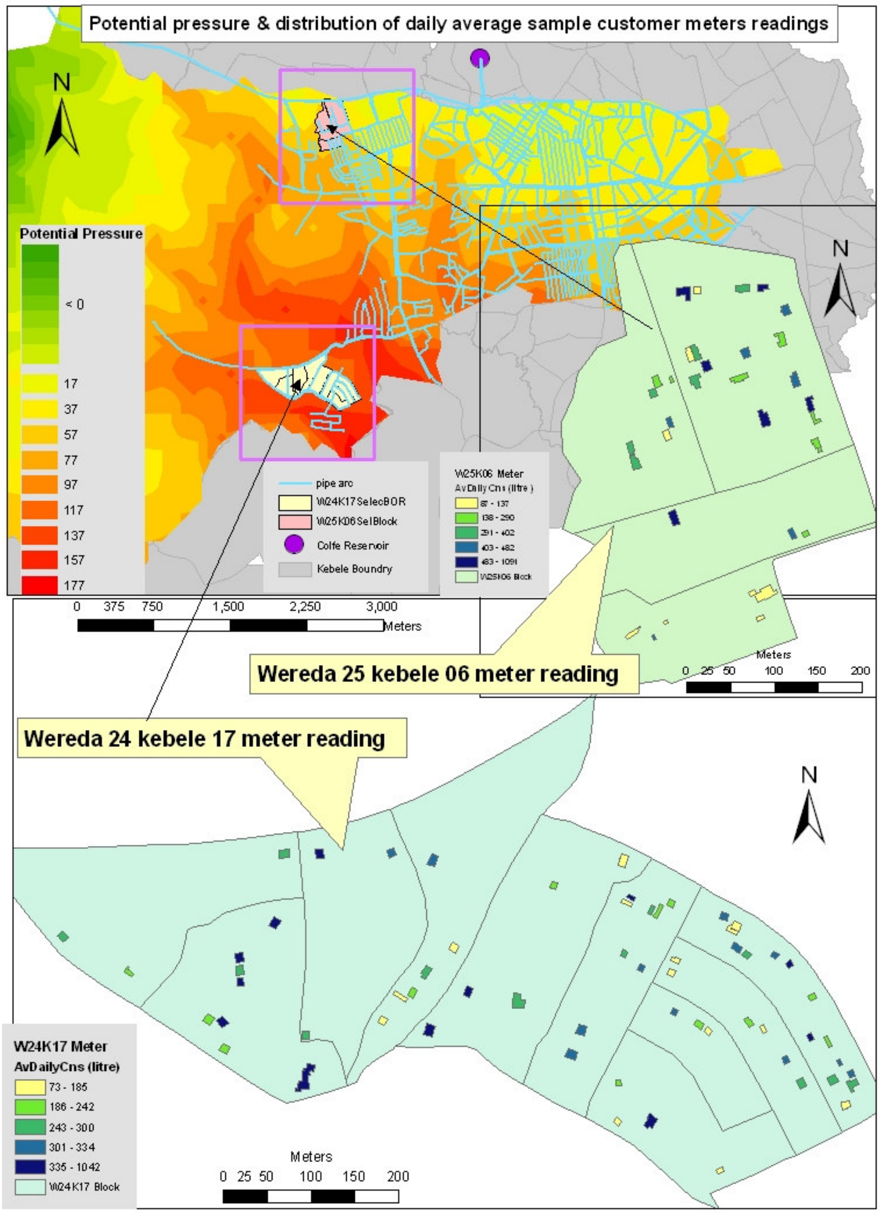


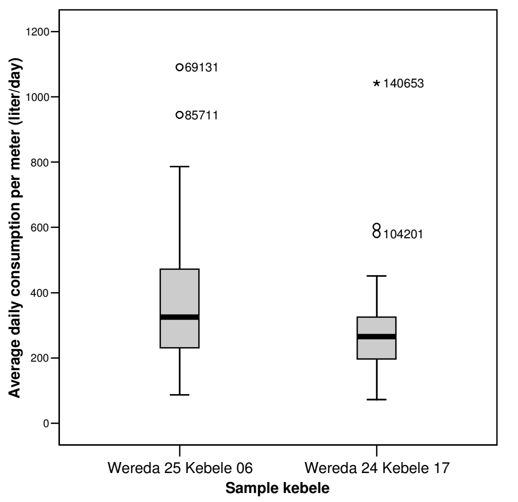
Figure 5-12 Distribution of sample customer meters and their average daily consumption

5.5.3.2. Comparison of meter readings

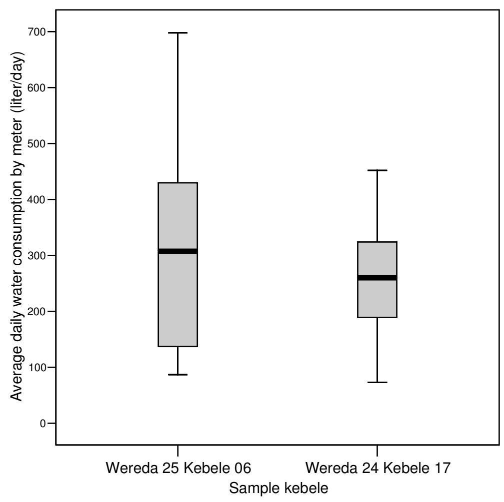
In order to compare the meter readings in the two sample kebeles the distribution of the readings need to be evaluated. As mentioned above, the readings of the two and half year's duration have been converted to average daily consumption.

It is important to evaluate and exclude outlier meter readings before making any comparison. A box plot was used to evaluate and identify the outlier meters in the two kebeles. As shown in a) below, the outlier meters were indicated by their contract number above the inter quartile range of each box plots. Taking the upper inter quartile range from the box plot as 380 l/day, meters having consumption above 1.5 x 380 = 570 l/day were excluded as they were outliers. The box plot after excluding the outlier meters is shown b) below.

a) Box plot before excluding outlier meters



b) Box plot after excluding outlier meters



c) Wereda 25 Kebele 06 (higher elevation)

N	Valid	30
	Missing	0
Mean		320.37
Median		307.50
Std. Deviation		166.499
Minimum		87
Maximum		698
Percentiles	25	137.00
	50	307.50
	75	432.50

d) Wereda 24 Kebele 17 (Lower elevation)

N	Valid	58
	Missing	0
Mean		260.78
Median		260.00
Std. Deviation		79.853
Minimum		73
Maximum		452
Percentiles	25	188.50
	50	260.00
	75	324.00

Figure 5-13 Box plot and descriptive of average consumption per meter per day (l/day)

As can be seen from the box plots in b) above, on one hand higher average readings (daily consumption) on the other hand larger variation among the meter readings is observed in the groups of meters located at higher ground elevation (W25K06).

One of the expected outputs from the analysis on these sample customer meters were to evaluate if the meters have a problem of under recording comparing with the per capita demand or expected consumption. However, the average daily consumption of the meters was much higher than the average daily per capita consumption of the city as well as the two kebeles where the sample meters are located. Thus, the meters are not serving single family due to the low level water connection. This is compared as shown in Table 5 10 and the corresponding graph in Figure 5.14 below.

Table 5-10 Average daily per capita consumption Vs average daily records of sample meters

Location	Average daily consumption or meter readings (litre/day)	Remarks
W25K06 Sample meters	320.37	Average daily consumption
W24K17 sample meters	260.78	Average daily consumption
W25K06 entire Kebele	66	Daily consumption per family
W24K17 entire Kebele	93.5	Daily consumption per family
Entire city	91.58	Daily consumption per family

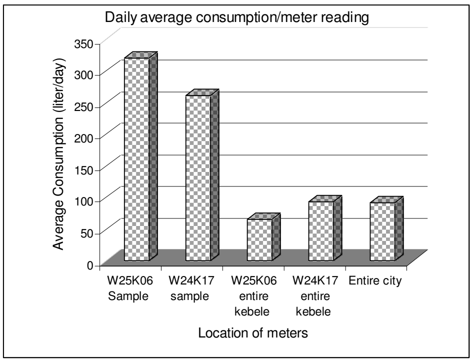


Figure 5-14 Comparison of average consumption per family and sample meter readings

Despite higher average consumption of the sample meters located at higher elevation (W25K06), as shown in c) above, the 25 percentile of the sample meters located at higher elevation are having much lower records than the meters located at lower elevation. The higher average consumption and the extreme lower records are contradicting to each other. From this the following conclusions can be given:

- Although it is difficult to achieve realistic conclusion about under recording of meters from such analysis, the relatively higher consumption and bigger variation among the readings of meters located in the elevated areas may give an indication that customers residing in the elevated areas are relatively using roof tankers compared to the lower locations. This is also reflected in reality through out the city. Moreover, literatures indicate that customer meters with roof tanker are expected to under record readings that might be the possible cause for the low consumption in the similar groups of meters too.
- The other possible cause might be due to the pressure decreasing in the sample meters located at lower elevation due to pressure head loss as they are nearly three times far away than the other groups of sample meters from the reservoir. The average network lengths of the groups of meters located in lower ground elevation (W24K17) is 6245 meters while that of the upper elevation (W25K06) is 2440 meters.

5.6. Findings and conclusions

Measuring and analysing water loss and leakage needs a detail data due to its complex nature. These data are usually scarce in developing countries that the case of Addis Ababa is also similar. Therefore, due to the limited data the analysis was focussing on evaluating the total water loss both at the entire city and the sub-systems. The topographic nature of the city as well as ages of pipes was used to some how evaluate the possible causes of the water losses. Average customer metre records has been also investigated taking sample meters located some how at different elevation and getting water from the same reservoir in order to evaluate for any possible losses by comparing the past records with regard to their location taking ground elevation difference (potential pressure) as a base for comparison. Based on the results of the analysis the following conclusions are drawn;

- During the comparison of water losses among the sub-systems, comparing losses based on percentage of water losses (UFW) is found to be reversed while the comparison has been done using the loss per meter length of pipes and loss per connection. Therefore, comparison of losses from one location to another using the percentage has a limitation as the percentage of loss highly depends on the amount of water produced.
- From the water loss analysis of the sub-systems, higher water loss is found in Colfe Core sub-system which is located relatively at lower elevation in comparison to other sub-systems and having higher elevation differences with in the sub-system itself. From this it can be concluded that pressure resulted due to significant ground elevation differences have an impact on water losses that as a result needs proper management.
- The other issue addressed in the analysis was that of the impact of pipe age on water loss. As can be seen from the total age category of the main pipes with in the city, 62% and 90% of the main pipes are aged below 20 and 30 years respectively while 98% of the secondary pipes are aged less than 30 years. From this, it can be concluded that although all the primary and secondary pipes seem to have relatively younger ages, on the other hand the total percentage of yearly water loss seem very high. This can give an indication that the impact of non-physical water loss also seem to have a great impact that as a result needs great attention instead of only focussing on the physical loss (leakage). But still the impact of the pipe age is reflected while comparing the losses with in the sub-systems that relatively higher loss is recorded in Colfe Core sub-system which has relatively older pipe ages.
- From the analysis of the sample customer meters, on the one hand greater variation has been observed among the consumption records of the sample meters located in the higher elevation on the other hand although the average consumption of the sample meters is higher, the 25 percentiles of the meters located at the higher ground elevation are found as having low average daily consumption (137l/day) while compared with similar percentiles of those located at lower elevation (188.5l/day). From this, it can be concluded that the possibility of meters to have under recording is higher in meters located at higher elevation as a result of low pressure, but on the other hand meters with relatively higher consumption records are also observed in the metres located at the higher elevation that might be caused due to many families of the city use roof water tank to collect water during the night.
- Although the causes of water losses has been tried to be identified based on the available data, in order to better identify and characterise the causes of water losses and develop solution to minimize the loss, an appropriate methodology is necessary considering the local conditions.

6. Synthesis in identification and reduction of water losses

6.1. Introduction

From the previous analysis, the present level of water coverage in the entire city is found very low while the water loss is high. The extent of the water loss is expected to be higher, if additional water supply sources are constructed without managing the loss properly. Therefore establishing an appropriate methodology to identify and reduce the loss considering the local conditions is vital. In the previous chapters, both at the city and the sub-system levels, the analysis was focussing to the total water loss. Identifying the total water loss is one step forward, but unless the types and particular locations of the losses are identified, it will be very difficult to intervene for the reduction of water loss. Due to its complex nature, identifying and charactering the causes of water losses in a particular location is not an easy task and it needs an appropriate methodology that is the focus of this chapter. After brief overview of the current practice of the water authority related to the issue of water loss, methods of evaluating and measuring water loss from literature point of view is discussed. The findings of the previous analysis with regard to these are discussed as well. Finally methods that support for better identification and reduction of water loss considering the local condition has been suggested.

6.2. Current practice of AAWSA on water loss management

As shortage of water is a crucial problem in the city, great attention is given to the issue of water loss by the water authority. A water leakage detection study has been conducted by a consultant in collaboration with the Addis Ababa Water and Sewerage Authority (AAWSA) during the years 1995 and 1997. During the study, a minimum night flow monitoring was used to identify the loss. According to the draft report, an average 2 m^3/km/hr loss through leakage was registered before maintained through the crash programme during the same period. Thus a reference linear leakage index of 0.5 m3/hour/km was set in order to take action accordingly.

While this leakage index is compared with the results of the total loss per kilometre length of the present study (1.91 m3/km/hr), the present loss is found nearly equal to the figure before the crash programme. This shows us that although much works might have been done during the crash programme, the loss becomes nearly the same as before that of the crash programme.

Furthermore, a new department of research and water demand has been established that one of its responsibilities is to reduce water loss. As per the information found from the experts of the department, the newly established department is at its start of the work organizing data from different sections. The establishment of this new department might be a good opportunity to strengthen the research activities in the water demand management in general and the water loss in particular. Its activity can be easily integrated with the newly established GIS unit that currently updating the city water network.

As perceived during the field work, there is also a great effort especially with the young professionals towards new investigations and improvements. The other achievement that has been observed in the water authority is, there is a clear demarcation in the responsibility of the head office and the branches that can allow the experts of the head office to focus on strategic issues instead of the routine activities.

Beside to these, much works has been done recently to improve service delivery activities with a great support from the city administration. Big water consumers have been identified to help the authority focusing on these as the loss is expected to be higher with in these premises. AAWSA also has a free telephone service that can support to get information from the community in case of leakage and breakage of pipes.

Testing of customer water meters that has been centralized until recently has been decentralized to the braches and this can enhance possibility of checking and testing more meters. The authority has also planned to start systematic checking of meters and illegal connection that were not made before. Taking the above achievements as a great opportunity, the major constraints still observed in the authority is lack of information and integration among different activities with in the authority itself as well as other utility providing institutions like Power, Road and Telecommunication Authorities.

6.3. Methodology to evaluate and monitor water loss and leakage

6.3.1. Updating network data

Availability of correct and current data is an important step for evaluating a water loss and take measure accordingly to reduce the loss. Unless appropriate data is available at different hierarchies of the network system, it will be difficult to identify and locate the areas that are in a bad condition.

Record-keeping is an essential part of water network management, and is also the base for GIS. Supply zone and district meter areas (DMAs) records should relate to both physical records and records for leakage analysis. If network records are poor, a network survey is essential before zoning and DMA design can take place, and for accurate leak detection and location to be carried out.

AAWSA has done a lot with this aspect that most of the network records like the pipe sizes, material types and years of installation are collected and stored in AutoCAD format. This is an important step for managing the network as well as monitoring the water loss, but other records like maintenance and pressure records need also integrated with the network. Integration of the network data with the cadastral information of the city is also important. Although AWWSA has done lots of updating works, the network data seems lacking integration with the cadastral information of the city. For instance, some of the pipe networks are seen laid beneath parcels and buildings of individual owners. The reason might be, either the data is captured wrongly or they have been installed before the construction of the buildings. Therefore, parallel to updating the data on the network, introducing GIS system is timely, as the data in AutoCAD and other formats can easily be converted to GIS for further spatial and network analysis. Where a well maintained and updated GIS data is available, it provides a base to construct a network model.

6.3.2. Measuring and evaluating water loss and leakage

Calculating and evaluating the water balance of the city is important as it can support for development of a methodology and establishing a water loss strategy. A water balance is the measurement of distribution input and water consumed that can be measured using different techniques. Ideally, all components of a water balance should be quantified over the same designated period, and expressed in Mega litters per day (WHO, 2001).

The International Water Association (IWA) recommends detailed performance indicators for real losses, the infrastructure leakage index (ILI). This is the ratio of current annual real losses (CARL) divided by unavoidable annual real losses (UARL) (Farley and Trow, 2003). The unavoidable real losses depend on the economic level of leakage that greatly varies from country to country. The infrastructure leakage index helps to prioritize areas of intervention to reduce the water loss. Monitoring the flow by introducing zoning and district meters is important in order to measure the loss and leakage and prioritize for leak detection activities. Unless the existing sub-systems are further sub-divided in to smaller and manageable areas it will be difficult to identify and characterize the spatial distribution of the water loss and leakage. Once the spatial distribution of the loss is identified, it will support to characterize the types of the losses taking in to consideration the network condition of the specific area like the pipe ages, type of material, soil or ground condition, pressure condition, etc. Sub-dividing the network into smaller and manageable areas not only supports to identify the loss but also to prioritize further operational and maintenance activities based on available resources.

The IWA international standards of calculating the water balance (Farley and Trow, 2003), may still be recommended to be adopted for calculating the loss of the city considering the local conditions as explained here below.

6.3.2.1. Distribution input

Identifying and quantifying all the water inputs and sources is important in order to compare it with the consumption. At present this data is recorded only at the main water sources (the treatment plants and well fields). This data might be useful to evaluate the total water loss of the entire city, but it does not help to identify and characterize the causes of the losses.

Therefore, beside to the records of the production from the water sources it is also important to have records at the inlet and outlet of all the reservoirs. At present many of the flow metres of the reservoirs are not working at all or are not well functioning. Beside to this, the flows need to be sub-divided into different zones that the volume of water supplied to each zone will be used as an input for evaluating the water balance and water loss by comparing with the records of district meters or consumption records.

6.3.2.2. Consumption

Billing records are usually used to quantify water consumption that will be used to evaluate the water balance together with any authorized but unbilled consumption and the difference is considered as a total loss. With regard to Addis Ababa, as most of the customers of the city are metered, the billing records is equivalent to the consumption that can be used for the water balance calculation. Even though they are very few while compared to the total consumption, the un-metered authorized consumption need also be included either by introducing a meter or estimating the demand.

6.3.2.3. Calculating the water loss

The total water loss can be calculated by subtracting the total consumption including the un-metered authorized consumptions from the supplied water. Depending on available records on the distribution input and the consumptions, the total water loss can be derived both for the entire city and for the zones or sub-systems. The total loss at the sub-systems level can be derived by subtracting the consumption records of all the customers (including un-metered authorized consumption) from the total volume of water recorded by the flow meters at the entry of the specific zone or sub-system. Although the total water loss may be calculated using the water balance at different levels, it is still difficult to characterize the type of loss from such analysis. Therefore the water loss needs to be further broken down to different components in order to identify and characterize the loss. According to some literatures, water loss is sub-divided in to real (physical losses) and apparent (none physical losses).
The main components of real loss comprise, (Farley and Trow, 2003):

- Leakage and overflow from reservoirs
- Leakage from transmission lines
- Leakage from distribution network (from the mains, service connections and fittings)

The leakage on transmission lines may be included in the distribution system measurement.

a) Reservoir water loss

Leakage on a reservoir can be measured using a reservoir drop test by closing the inlet and outlet valves and measuring the rate of fall of water level over the duration of the test. On the other hand overflow from reservoirs can be evaluated by inspecting the float valves, if any, but in case when there are no float valves, they can be closed manually. Guards are usually assigned to take care of the activities there. Due to overall shortage of water in the city, problems related to overflowing from reservoirs is not considered as a major problem but the problem of leakage needs great attention as the problem is expected to be worst as a result of poor construction techniques and usage of poor construction materials.
The rate of the fall of water which represents the leakage rate can be estimated using the following expression (Farley and Trow, 2003).

$$\text{Rate of leakage } (m^3/hour) = \frac{(D1 - D2) \times A}{T}$$

Where,

D1	= Initial depth of the water (m)
D2	= Final depth of the water (m)
A	= Surface area of the reservoir (m^2)
T	=Test duration (hours)

An appropriate measuring instrument is essential as the rate of fall of the water might be small especially when the surface area of the reservoir is large,

b) Leakage in a distribution network

Depending on different factors like ages of the pipe system, pressure variations, etc., the loss in a distribution system varies from one location to another. This has also been observed from the sub-system level analysis of this study. The result of the sub-system water loss analysis indicates that the water loss in the Colfe Core sub-system (one of the three sub-systems) is bigger than the other sub-systems. As it is difficult to quantify and evaluate the spatial distribution of water loss in an interconnected distribution system, literatures recommend to divide the entire system into smaller and manageable areas.

Because of the size and complexity of the pipe work in the distribution network, it is not always possible to measure leakage directly, except in small networks fed by a single metered feed. Therefore leakage in the distribution network is derived from measurement of night flows into the system or part of the system. Measurement is made by conducting a drop test (in a reservoir supply zone) or by selecting a representative area within the distribution system, and isolating the zone by closing the valves around the boundary. A meter is installed on the main supplying the zone and the night flow rate is recorded. Consumption of large metered consumers is monitored over the same period and deducted from the total night flow to give the net night flow (WHO, 2001).

There are two methods that that ca be used to express the leakage in a supply system; the night flow method and the total integrated flow method. The night flow method expresses the leakage in a system in terms of litre per property per hour. The total integrated flow method calculates the leakage in a system from total flows & not for a limited time period. This method is the preferred method of calculating leakage (Jastin, 1993).

Moreover, in countries where all customers are metered, regular monthly water balances can be undertaken to assess the difference between monthly inflow and monthly consumption. This calculated difference will obviously include any errors in the continuous metering of sector inflows and any errors in consumer metering. Short period measurements of inflows to well-defined demand management areas when consumer use is at a minimum allows for good evaluation of leakage in this area. The total leakage flow is obtained from the following mass balance:

$$q_l = q_n - q_d - q_{cm} - q_{cn} - q_{op}$$

where ql is the estimated leakage flow, qn the nightline, i.e. the minimum recorded inflow to the area, qd the estimated legitimate domestic use, qcm the metered legitimate commercial metered use, qcn the estimated legitimate commercial non-metered use, and qop is the operational use by a water company (Ulanicki and Bounds, 2000).

As all the customers of Addis Ababa are metered, this can help to evaluate the water balance with the support of night flow monitoring, but the interconnected nature of the networks and the overall shortage of water may hamper to get realistic figures. Many customers are also using roof tanks that also create difficulty to estimate the minimum night use. Regardless of these difficulties, evaluating the water loss using nigh flow monitoring especially for the transmission and main network line is an important solution for the city provided the network system is updated and sub-divided in to manageable hydraulic zones and district meter areas (DMAs). Nevertheless, evaluating loss using night flow monitoring for the network beyond the district meter areas might be difficult. This would be very expensive as the network covers large areas that are interconnected to each other. The water loss beyond the district meter areas may be better evaluated using the water balance by subtracting the aggregated records of the customer meters from the readings of the particular district meters where water is supplied from, but this also needs an up-to-date recording system and due allowance for the time lags between the readings of supply meters and customer meters.

In systems where supply is intermittent that usually is practiced in the case of Addis Ababa, supply arrangements may be changed temporarily to ensure that the zone under test receives a continuous supply. Flows into zones selected for test can be monitored using either existing zone meters or temporarily installed meters during the test period.

c) Performance indicators of water loss and leakage

In order to compare the extent of the water loss among networks of different zones and take action accordingly, availability of standard performance indicator is important.

The following technical performance indicators are most widely used in different part of the world to make comparison of annual volume of real losses (IWA, 2000).

- As a % of Input Volume
- As a figure per length of mains per day or hour
- As a figure per service connection per day or hour
- As a figure per property per day or hour
- As a figure per length of system per day or hour (where length of system = length of mains + length of service connections up to point of customer metering).

As stated in the previous chapters, the UFW expressed as a percentage of the production has limitation to be used for comparison purpose as it is highly affected by the volume of water produced.

Taking the advantage of the all metered customers of Addis Ababa; either the loss per length of main pipes or loss per properties may be useful indicators to compare the spatial distribution of the loss. Loss per length of main pipes is more suitable for network areas comprising few pipe branch outs like the transmission lines and main distribution lines while loss per property or number of connections is more suitable for the networks having more branch pipes.

Literatures recommend using number of connections instead of number of properties due to the possibility of the service connections to split into several separate pipes serving individual properties at or after the first metering point. Nevertheless from the context of Addis Ababa this possibility is not usual as most of the water connections are yard types except very little high rising apartment type of houses. Therefore in this study the number of properties and number of connections are synonymously used.

A night flow monitoring or water balance calculations by subtracting the aggregated readings of customer meters from the water supplied (records of bulk or flow meter to an isolated zone or district) may be used to evaluate the water loss.

The following expressions may be used to evaluate the water loss in a distribution network of an isolated sub-system.

Main transmission or distribution loss (m^3/hr/Km) $= \dfrac{MNF - ENDC - HCNC}{\text{Test period (hour) x pipe length}}$

Or

Main and secondary network loss (m^3/hr/connection) $= \dfrac{MNF - ENDC - HCNC}{\text{Test period (hour) x number of connection}}$

Or

$= \dfrac{ISMR - ACMR}{\text{Duration (days)* number of connection}}$

Where, *MNF* = *Minimum Night flow recorded at the inlet meter to isolated sub-system (m^3/hr)*
ENDC = *Estimated night domestic consumption (m^3/hr)*
HCNC = *High consumers night consumption (m^3/hr)*
ISSMR = *Meter readings at inlet of isolated sub-system (m^3)*
ACMR = *Aggregated customer meter readings including estimated non-metered consumption (m^3)*

In doing so, a standard infrastructure leakage index (ILI) that would be used as a base for comparing the losses from one area to the other for further intervention need to be fixed based on the current practice and economic level of leakage. Infrastructure leakage index (ILI) is a useful non-dimensional Index of the overall condition and management of infrastructure, under the current operating system.

Since zero leakage is not plausible goal, the concept of an economic level of leakage (ELL) was developed to determine an economically acceptable level of water loss. Significant initial reductions in leakage can usually be achieved relatively easily, but subsequent reductions will become increasingly difficult and expensive because the remaining, unfixed leaks will tend to be those that are small or hard to detect or access (Ashton and Hope, 2000).

6.3.3. Need for Zoning and district metering

The first and foremost that helps to identify and evaluate the spatial distribution of water loss is availability of up-to-date network with its required information. In order to well manage the available information within the network of the city, all the network system of the entire city has to be sub-divided into different zones and sub-zones. The principle of zoning is a hierarchical way of evaluating losses that covers a number of levels beginning with measurement at the production and ends at the customers meter for an estimate of consumption.

Although the problem of interconnectivity exists among many of the sub-systems, the existing city network is sub-divided in to 13 sub-systems. Among these 13 sub-systems, three of them have been used for the present study.

Implementation of a zoning scheme whereby the complete water distribution network is broken down into manageable segments that can be easily metered, monitored and analysed creates better ground for further operations related to loss analysis and control. The implementation of different zoning levels facilitates the development of hierarchical

comparisons of flow that leads to the building of an effective water balance (Farley and Trow, 2003).
According to some literatures, district metered areas (DMAs) are increasingly being introduced into water distribution networks for improved demand management and the potential for leakage detection. It is generally accepted that efforts to reduce water losses and maintain them at acceptable levels will be more successful if water losses within small discrete areas are continuously monitored using district metering.
A flow measuring system in a water distribution network should include flows from source or treatment works (production) but also zone and district flows as shown in below (Farley and Trow, 2003).

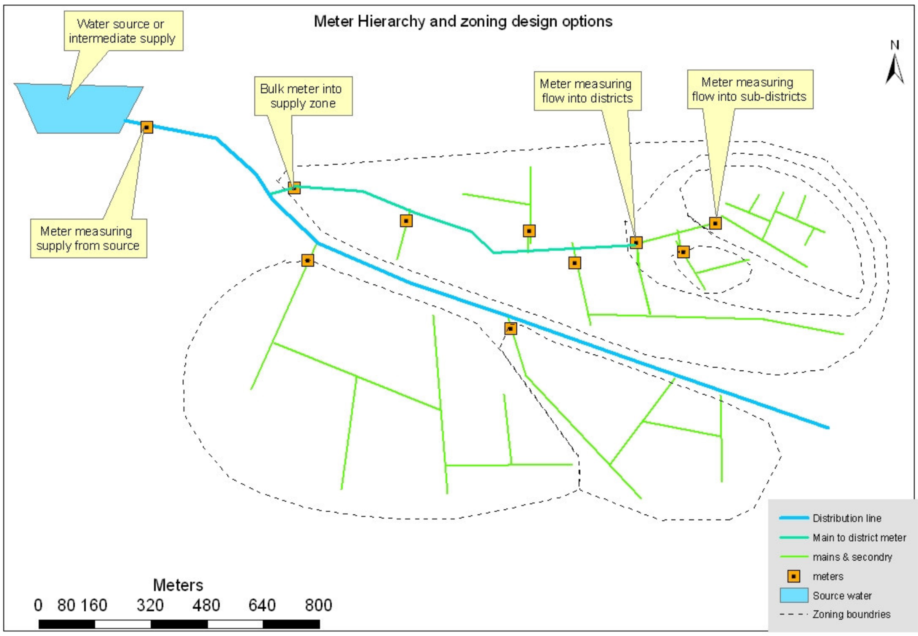


Figure 6-1 Metering hierarchy and DMA design options
(Adopted from (Farley & Stuart)
The system shown in the above figure comprises,

- Measurement of supply at the source or treatment works
- Measurement of flow in to supply zones, with geographic or hydraulic boundaries, usually with 10,000 to 50,000 properties
- Flow monitoring into district meter areas (DMA) of around 500 – 1000. Literatures recommend permanently closed boundary, but in the Addis Ababa context, as there is a need to supply water by shift system due to overall shortage, permanently closing the DMA might have a disadvantage.
- Individual customer meters, both domestic and commercial. The water balance from sub-district meter and the sum of individual customer meters leads to average loss usually measured in litres/property/day or m^3/km/day.

The potential of Geographic Information System (GIS) may be used to integrate the data on the network with the land information system (LIS) of the city by geo-referencing the customer meters with the building layer of the LIS.

While establishing zoning and district meter areas, the areas have to be investigated based on the ground elevation difference and distance from the respective service reservoirs. Some of the buildings in the sub-systems used for this study are located at ground elevations above the reservoirs where water is supplied from. Nevertheless, these areas are still getting comparable water to the others. Unless the distribution is supported by pumps, these areas are not supposed to get water only through gravity distribution. Therefore, the existing sub-systems of the city need to be evaluated while establishing zoning and district meter areas. The recently prepared digital elevation model (DEM) of the city may help to investigate the existing sub-systems and to establish further district and sub-district meter areas.

Number of connections or properties of 10,000 to 50,000 are usually recommended to be supplied by a single supply zone with its hydraulic boundaries that is further sub-divided into districts and sub-districts (Farley and Trow, 2003).

6.4. Improving billing system and meter readings

Improving a billing system is one step forward for improving the overall demand management of the city and helps to a great extent to better evaluate the water balance and water loss.

The most important part of determining how much water is being lost in a system is to accurately quantify the volume of water which is entering that system. Metering of input volumes and inflows into zone distribution systems is essential for water balance calculations. But Customer meters also require careful management if representative and significant results are to be obtained.

Billing system can be reviewed and updated for the integrity and quality of the data. The location and the historical records like ages of the meter, periods of calibration, etc. need also be integrated with the billing systems.

Geographic information system (GIS) may allow the water authority to map consumers on to points on a map layer that the total billed consumption for each zone could be computed using dedicated software (Farley and Trow, 2003).

While the meter readings of the city has been reviewed for the purpose of this study, many non-active contracts with negative consumptions and repeated contracts were found included in the records. On the other hand, numbers of meters were having similar previous and last readings (zero consumption) for some continuous months which seem unpractical. Unless these problems are alleviated, it would be very difficult to get a realistic water balance. The time duration of taking meter readings might be extended to three months in order to minimize the manpower need and customers might be asked to pay the three months average until adjusted based on next meter reading.

During the meter readings, cross checking between some previous duration is important and those meters having significant differences need to be reported for further investigation.

Geo-referencing the customer meters with the cadastral information of the city are the first step that needs to be done in order to integrate to the existing sub-systems and proposed district meter areas. Although the cadastral information that is prepared some 10 years ago is some how old that might not be updated, it can be easily integrated as they have similar hierarchy and administrative boundary arrangements. Integrating the network system and the customer meters with the LIS creates a good ground to treat the water loss calculation spatially as it would be easily integrated with the district meter areas. One of the constraints in integrating the billing system with the LIS is, creating a common attribute to link the two. The LIS has a unique code to identify each building, but the water authority use contract number as a unique identifier but the address (combination of Wereda, Kebele and house number) that doesn't directly mach to the code of the LIS may be used to transfer the contract number to each of the buildings. SQL query operation of MS-Access may be used to resolve this problem. Ones the contract number is matched with the LIS it is possible to map each of the existing customer meters that their house number matched with the LIS by converting the building polygon feature in to point feature in ArcGIS environment. The other problem is that there are houses with no specific addresses especially the buildings constructed in the past 10 years. But as location of the houses are already known by the meter readers of the authority and layout plans are usually prepared while installing new water expansion, this problem may be solved through time.

6.5. Remedial mesures to reduce water loss and leakage

Knowing the magnitude and the spatial distribution of the loss greatly helps to intervene giving priority to those areas with higher magnitude of loss with regard to the leakage index usually fixed based on local condition. Nevertheless identification is not by itself an end in reducing the water loss. Identifying the causes of the losses might help where to focus with probably limited resources that the city is having. This study some how gave an indication that the predominant causes of the water loss in the city is leakage and losses due to meter errors. Ones the spatial distribution and the characteristics of the loss are identified; it is possible to see alternative solutions to reduce the water loss. Therefore, an appropriate long and short term strategy is necessary.

Due to time limitation all the strategy issues are not addressed, rather some of the remedial measures to be taken are discussed in this section. The following may be considered to be remedial actions to be taken to reduce water loss and leakage in a distribution system but not limited:

6.5.1. Setting leakage index

The most important aspect of any leakage strategy is setting a leakage target. Ones the spatial distribution and characteristics of the losses is identified, what level of leakage should the water authority aim for and what level should be maintained in the long term should be well addressed. There will always be a level of leakage which has to be tolerated, and which has to be managed and it depends on the economic level of the leakage reduction activities specific to that area.

The estimation of the economic level of leakage (ELL) must use data, information and policy rules specific to that area and the water supply organization. Moreover, until significant works has been conducted to reduce leakage and so collect the necessary data, it is not possible to make an accurate assumption of ELL. Therefore, the calculation of ELL will follow a staged approach & could take several years to determine accurately (Farley and Trow, 2003).

6.5.2. Improving organizational management and provision of training

For an effective management of water supply service in general and water loss and leakage in particular, water supply providing institutions must have an appropriate organizational management. The organizational aspect related to the water loss management is well addressed in the organizational structure of AAWSA, but shortage of qualified and experienced personnel is the major problem of the country in general and AAWSA in particular. Capable management and technical staff are paramount in order to achieve better performance. Offering a continuous theoretical and practical training based on the need is also important. Due to the complex nature of water loss and leakage commitment of staffs at all level is also very important.

Effective leakage management requires an input from a number of different personnel and unless, they are all committed, the implementation of any water loss reduction programme will not be efficient, it may then be difficult to maintain the infrastructure which has lead to lower leakage levels (Farley and Trow, 2003).

6.5.3. Establishing Pressure management

Pressure management is related to the establishment of zoning and district meter areas. In the previous sections, this has been discussed in detail with the perspective of identifying and quantifying losses. While establishing zoning and district meter areas, the scope for pressure management should be evaluated in all cases. The relationship between pressure and leakage is explained in detail in the previous chapters.

6.5.4. Proper maintenance and renewal

One of the major causes for the increase of water loss is the usage of poor quality materials and poor workmanship. In spite of the many pipe networks in the city seem to have younger ages, the loss found from the analysis reaches up to 40% of the production. The main reason for this might be the usage of poor quality of material and poor workmanship. Therefore care should be taken while maintaining existing networks and installation of new ones. While rehabilitation of any mains is planned, due attention should be given to maintain as well the service connections fed from the mains.

Replacing an old water main with a new installation will undoubtedly reduce on the main. Most leakage occurs on service connections and, unless the service connections are also renewed, the benefit may not be a great as the first estimated (Farley and Trow, 2003).

6.5.5. Regular inspection of the water network

Ones the locations of highly suspected leaking networks are identified due attention should be given to inspect for these areas and any leaks should be well recorded as it will be a good base for further maintenance or replacement. Regular inspection supports to find the problematic areas and take action immediately before much water is wasted. Regular inspection should not be limited only to the network systems and supply meters but also to the customer meters.

6.5.6. Calibration and replacement of customer meters

One of the main causes for the water loss is the under-recording of customer meters. The usage of poor material quality also holds true for the customer meters. Unless meters are regularly calibrated and those not functioning well are either maintained or replaced the water loss reduction programme will not be effective. Until recently, the water authority was checking the customer meters only if it is requested by the customers themselves, but this might only help the customer not to pay more as such requests are usually for over registration. Therefore systematic check up of the customer meters is important not only to identify the magnitude of the loss but also to maintain and replace when necessary.

6.6. Summary and Proposed Methodology

As clarified in the above sections of this chapter, a method for evaluating the water loss of the city is proposed as shown in the Figure 6.2 below. The method of evaluation is divided into different hierarchies based on the existing situation of the sub-system and recommendations from literatures. After evaluating the spatial distribution of the water losses using the proposed methods, it is possible to characterise the causes of the loss based on the specific characteristics of the areas like the ages of pipes, ground condition, ground elevation (pressure condition), soil condition, etc. This data can also be integrated using GIS and through time it is also possible to integrate this with hydraulic models.

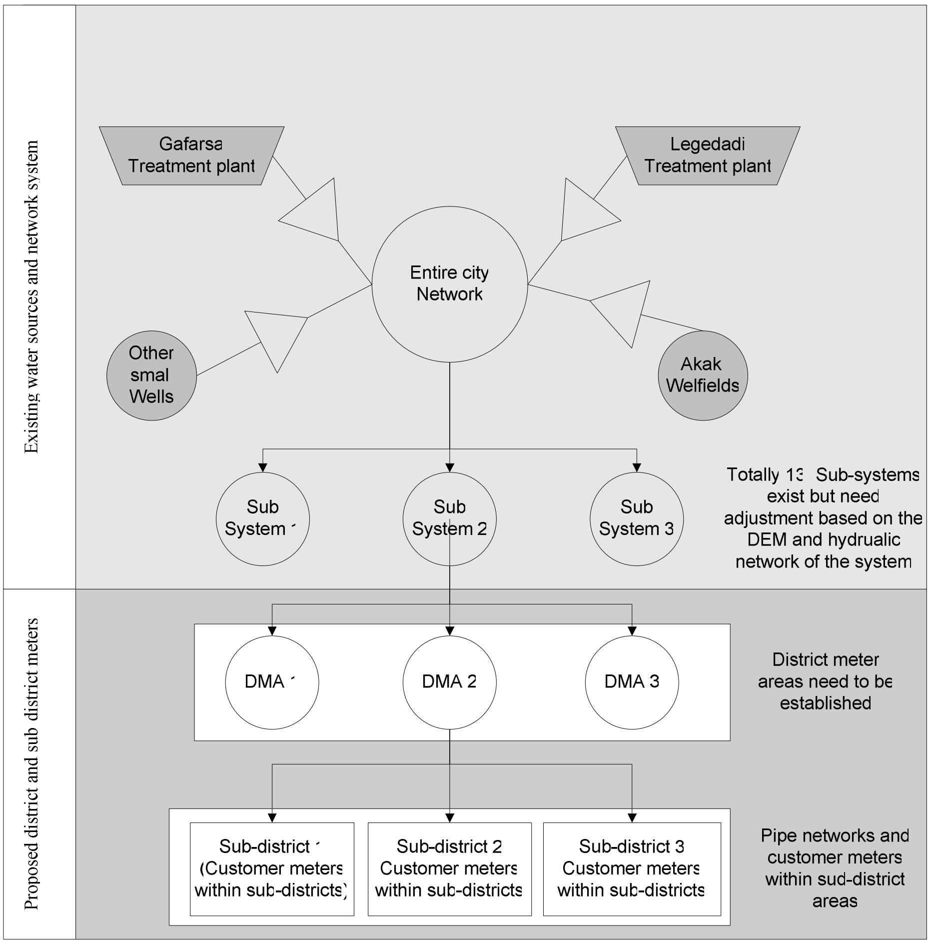


Figure 6-2 Existing network hierarchy and proposed district meter area systems

Both network distance and elevation differences from the location of the service reservoirs in conjunction with the hydraulic and physical foundries of the networks may be used to adjust the existing sub-systems. The network distance helps to determine the pressure head loss while the elevation differences represent the potential pressure.

Literatures recommend limiting the number of properties up to 3000 for district meter areas and 1000 for sub-district meter areas (Farley and Trow, 2003), but this needs further study considering the local condition, using sample areas before implementing it in larger areas. A method for quantifying water losses at different hierarchies of the network system is suggested as shown in Figure 6.3 below.

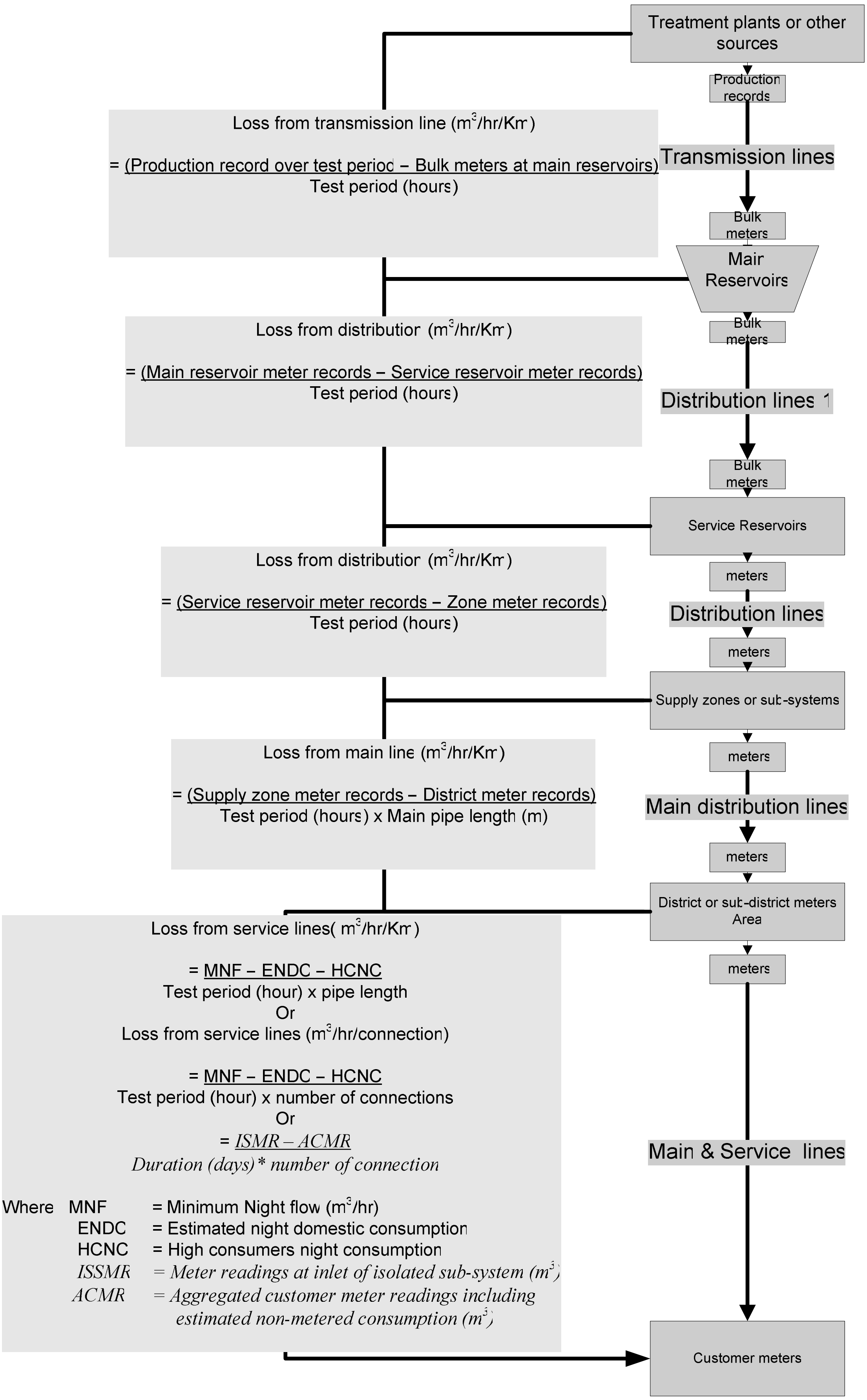


Figure 6-3 Supply network hierarchy and suggested method of calculating water loss

7. Conclusions & recomendations

7.1. Introduction

The main objective of the research was to evaluate the water supply coverage and explore the water loss in the water supply distribution system of the city of Addis Ababa. The analysis was divided into two parts. The first part focussed on the evaluation of the water supply coverage distribution among different localities of the city. The second part focussed on evaluating the total water loss and exploring the possible causes of the water loss. Finally, a methodology was prepared for better evaluating and reducing the water loss in the system. The water loss analysis was designed to be carried out at two levels, the city level and the sub-system level. For exploring the possible causes of the water loss, the magnitude of the water loss among the sub-systems was compared with regard to the ages of pipes and ground elevation difference (potential pressure) of each sub-system as these factors have an impact on the magnitude of the water loss. An average consumption of some two and half years (customer meter readings) of some sample customer meters was also evaluated with regard to their location so as to get some notion loss at customer meters.

7.2. Findings and conclusions

- Both the average water supply coverage and the intra city distribution were evaluated based on the daily per capita consumption and level of connection using the population data of the city. The average water supply coverage of the city is found to be 16.65 litre/person/day. This average per capita consumption is found much lower compared with other developing cities like the southern African cities and even is lower than that of the standard set by UN-Habitat as a basic need (20l/per/day). The average number of connections per family of the city which is equivalent to 28% in-house or yard connection, is also far below the African cities' average of 43%.
- The intra city distribution of the water supply coverage was also using a correlation between number of population and yearly consumption of each Kebele and the correlation coefficient is found to be positive and strong (+0.749). This positive and strong correlation on the one hand shows that although there is overall shortage of water in the city, predominantly the existing amount of water is fairly distributed among the different localities except few kebeles that consumed much water although their number of population is either low or moderate. On the other hand, except one Kebele (Wereda 19 & Kebele57), no Kebele is found consuming extreme low amount of water while compared to its number of population. This can also give an indication that the water loss varies directly with the amount of consumption. In other words we can conclude that unaccounted for water (UFW) due to illegal use of water

may not be a problem as it has been also confirmed during discussion with local experts. This illegal consumption does not reflect that of losses due to meter errors as this problem can be observed in many of the kebeles especially in the old settlement areas.

- Despite the low water supply coverage of the city, the total water loss is found to be high enough (up to 41%). The total water loss was computed by subtracting the consumption from the water supplied. Three approaches were used to compare the loss among the sub-systems, (i) the UFW expressed as a percentage, (ii) loss per length of pipes and (iii) loss per connection. Comparison using the percentage has reversed the results of the comparison using the loss per length of mains and loss per number of connection. Therefore even though the total water loss expressed as percentage is an important tool to know the extent of the loss within a given environment, comparison of losses from one location to another using the percentage has limitations as the percentage of loss highly depends on the amount of water produced. This is also the experience of many international comparisons as explained by the international water association (IWA) task forces. Depending on the hierarchy of the network system, both the loss per kilometre length of main pipes (m3/km/day) and loss per connection (litres/connection/day) may be appropriate to measure the loss in the Addis Ababa context.
- From the water loss analysis of the sub-systems, higher water loss has been found in Colfe Core sub-system which is located relatively at lower elevation in comparison to other sub-systems and has higher elevation differences with in the sub-system itself. From this it can be concluded that pressure resulting from significant ground elevation differences (potential pressure) have an impact on the rising of water loss due to leakage. These also give an indication that the predominant cause of the loss might be that of leakage.
- The seasonal water loss comparison that was intended to be included in the analysis was only done for one year duration due to data limitation. Although the total water loss of the city level analysis show a relatively higher percentage of loss during the rainy season, it might be difficult to reach this conclusion only from one year’s data. At leas two to three years data is necessary to observe the trend if the higher percentage of loss in the rainy season is repeating itself in the next rainy seasons. Yet, from the local experts’ point of view, due to the difficulty of tracing leaking pipes, water loss is expected to be higher in the rainy season.
- The other issue addressed in the analysis was that of the impact of pipe age on water loss. On the one hand the loss was found to be higher in the sub-system where pipes of relatively older age are located. On the other hand despite the fact that overall pipe network seems to be of a young age, the total water loss is higher. This signifies that besides to the loss caused as a result of leakage, other non-physical losses may also be expected to be higher. To this effect, as illegal connection is not noticed as major problem, loss due to meter errors especially under recording of meters is expected to be higher.
- From the above explanations, the main causes of the water loss may be characterized as being caused by leakage and customer meter errors (under recording of meters).

However, from the quality of the available data and the complex nature of the water loss and leakage, this conclusion could only be taken as suggestive findings to be a base for further studies. For better identification and characterization of the water losses and evaluation of its spatial distribution, a methodology is suggested in chapter six of this study.

7.3. Recommendations

- While the higher magnitude of the loss is evaluated in conjunction with the amount of water which is extremely low, the magnitude of the loss is expected to be much higher had there been enough water supply and pressure in all areas. 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.
- One of the major limitations of this study was the quality of the consumption data especially the customer meter readings. The contract number of the customer meters which is supposed to be the unique identifier has been found to be repeated for some of the contacts. As the data set is very large it may even difficult to know which contracts are active at present. The other problem observed was, as each of the twelve months data of the customer meters are not linked together it will be very difficult to compare for any significant reading differences among consecutive period's meter readings. Therefore for better management of the billing system in general and better evaluation of water losses comparing with the billed water consumption, the problem stated in 3.3.3.2 of the Methodology chapter need a further study.
- Updating of the network which is undergoing by the GIS unit of AAWSA is appreciated, but this need to be integrated with the land information system (LIS) of the city as well as information on hydraulic flow of the water network. Operation and maintenance data including pressure records need also be integrated spatially with the network Therefore, introducing geographic information system (GIS) is timely as it may facilitate the updating of the networks and support to perform related spatial analysis. The recently prepared digital elevation model (DEM) of the city may support to divide the network in to manageable smaller hydraulic zones or district meter areas.

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Appendix

Appendix I Checklist for discussion with local experts

	Checklist for discussion with local experts
1	What are the main sources of water in the city? Are there any water sources that are not included to the distribution system? Where and how much?
2	Is there any difference in level of water distribution among different localities? If yes, how do you manage to balance the supply?
3	Is there any seasonal difference in amount (volume) of water supplied particularly in rainy season and dry season? If yes to what extent?
4	Are there any non-metered water consumptions? If so for what purpose and how do you estimate the volume of water consumed?
5	How do you estimate the residential water demand? Do you have any standard?
6	How do you identify leakage or breakage of water pipes? How do the residents/communities support in reporting leakage or breakage of pipes?
7	How frequent do water meters become defective? Do the customers report on time in case of defective water meter? If yes, do they report equally for both in case of the defect causing over readings and under readings? In case they didn't report how do you monitor it?
8	Have you encountered with illegal water connections? If yes how frequent? Do you think that all customers pay for all water they have consumed? If not why?
9	From your experience, does leakage and breakage of pipes have significant relation with age of pipes?
10	From your experience does the ground elevation difference of the city have a significant impact on pressure and distribution of water? How do you manage the pressure with the big elevation difference of the city?
11	Do you have a plan to replace aged pipes and water meters? What major criteria do you use for prioritization of replacement?
12	Do you have any plan regarding operation and management in general and leakage reduction in particular? If so what are the main components?
13	Do you use GIS in your operational management of the water supply network? If yes, which GIS software do you use?

Appendix II Number of repeated contracts and their consumption V/s total consumption

Akaki Branch

Months	Total No of contracts	No of repeated Contracts	Total Consumption	Repeated Contracts Consumption (M3)	% of repeated Consumption
July	9102	35	142892	1806	1.26
August	9140	42	118883	4555	3.83
September	9156	27	130757	3400	2.60
October	9187	42	128276	738	0.58
November	9209	112	126039	1644	1.30
December	9264	70	139800	2326	1.66
January	9300	54	164707	6100	3.70
February	9410	48	278605	1612	0.58
March	9473	17	144318	128	0.09
April	9534	98	206797	32270	15.60
May	9592	37	157501	1101	0.70
June	9650	17	148172	401	0.27
Total	**112017**	**599**	**1886747**	**56081**	**2.97**

Central Branch

Months	Total No of contracts	No of repeated Contracts	Total Consumption	Repeated Contracts Consumption (M3)	% of repeated Consumption
July	32073	70	528566	3603	0.68
August	32191	87	749419	66811	8.92
September	32298	100	640240	23198	3.62
October	32394	149	796653	61335.5	7.70
November	32563	111	1150717	246744.5	21.44
December	32714	336	833709	61981.5	7.43
January	32829	56	618481	401.5	0.06
February	32929	119	617964	15377.5	2.49
March	33130	58	703833	1294.5	0.18
April	33280	116	805560	23784	2.95
May	33412	108	1140096	10595	0.93
June	33546	213	821821	32081	3.90
Total			**9407059**	**547207**	**5.82**

Northern Branch

Months	Total No of contracts	No of repeated Contracts	Total Consumption	Repeated Contracts Consumption (M3)	% of repeated Consumption
July	35649	97	494918	2206	0.45
August	35731	87	467474	4320	0.92
September	35840	110	468279	3195.5	0.68
October	35964	120	538587	35492.5	6.59
November	36100	173	629112	14083	2.24
December	36241	203	541379	4921.5	0.91
January	36434	124	532346	2924.5	0.55
February	35582	187	491306	2283	0.46
March	36782	296	564320	28740.5	5.09
April	36981	282	578762	9960	1.72
May	37126	170	540849	9170	1.70
June	32238	146	546416	2352	0.43
Total			**6393748**	**119648.5**	**1.87**

Eastern Branch

Months	Total No of contracts	No of repeated Contracts	Total Consumption	Repeated Contracts Consumption (M3)	% of repeated Consumption
July	45415	510	1006699	47394.5	4.71
August	45953	362	960268	24433	2.54
September	46076	269	844135	15757.5	1.87
October	46119	227	960058	3163.5	0.33
November	46219	300	1296912	10961.5	0.85
December	46271	328	1192249	11989	1.01
January	46332	239	1153817	14650	1.27
February	47085	370	921861	9943	1.08
March	47383	351	1217274	29724	2.44
April	48016	339	1308638	27601.5	2.11
May	48508	457	1237686	14637.5	1.18
June	48730	374	1192896	108273	9.08
	Total		**13292493**	**318528**	**2.40**

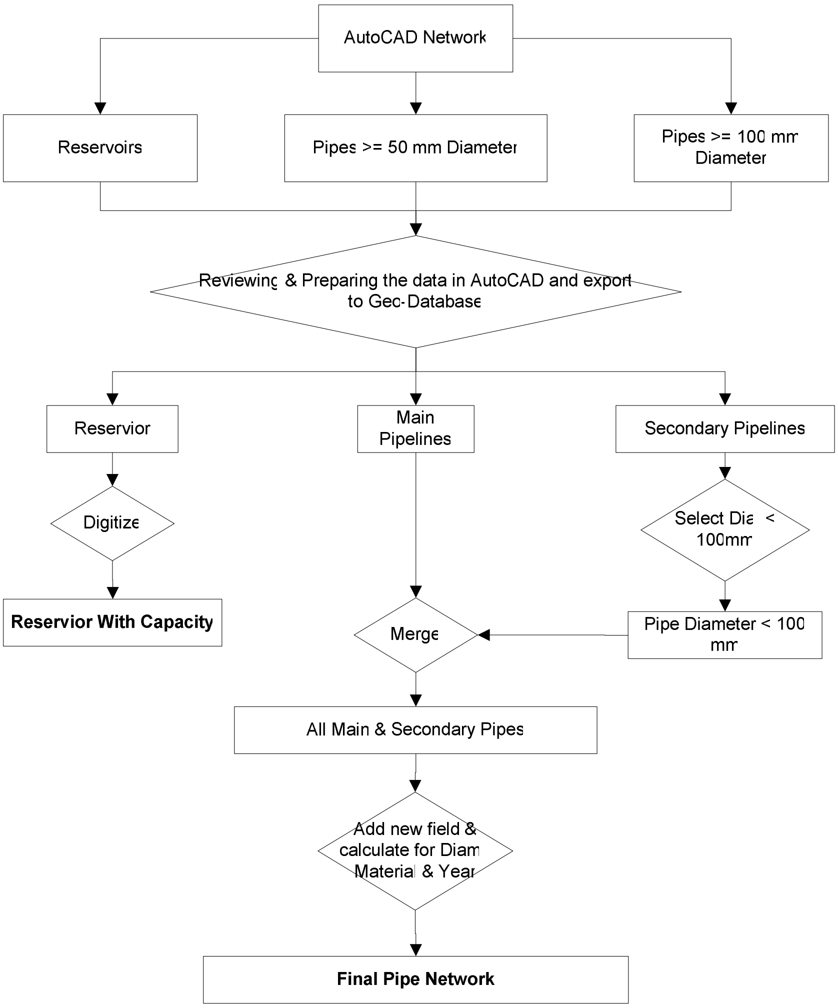
Southern Branch

Months	Total No of contracts	No of repeated Contracts	Total Consumption	Repeated Contracts Consumption (M3)	% of repeated Consumption
July	52539	736	1186596	78822	6.64
August	52685	321	1122142	20230	1.80
September	52766	373	1118668	58302	5.21
October	52927	305	1000347	11157	1.11
November	53170	340	1163504	24938	2.14
December	53369	404	1208856	10078	0.83
January	53569	349	1199648	14026	1.17
February	53723	485	1135058	6662	0.59
March	54035	4768	1317636	48943	3.71
April	54313	**564**	1297384	11604	0.89
May	54543	981	1444746	19441	1.34
June	54655	1243	1243191	19168	1.54
			14437776	**323371**	**1.54**

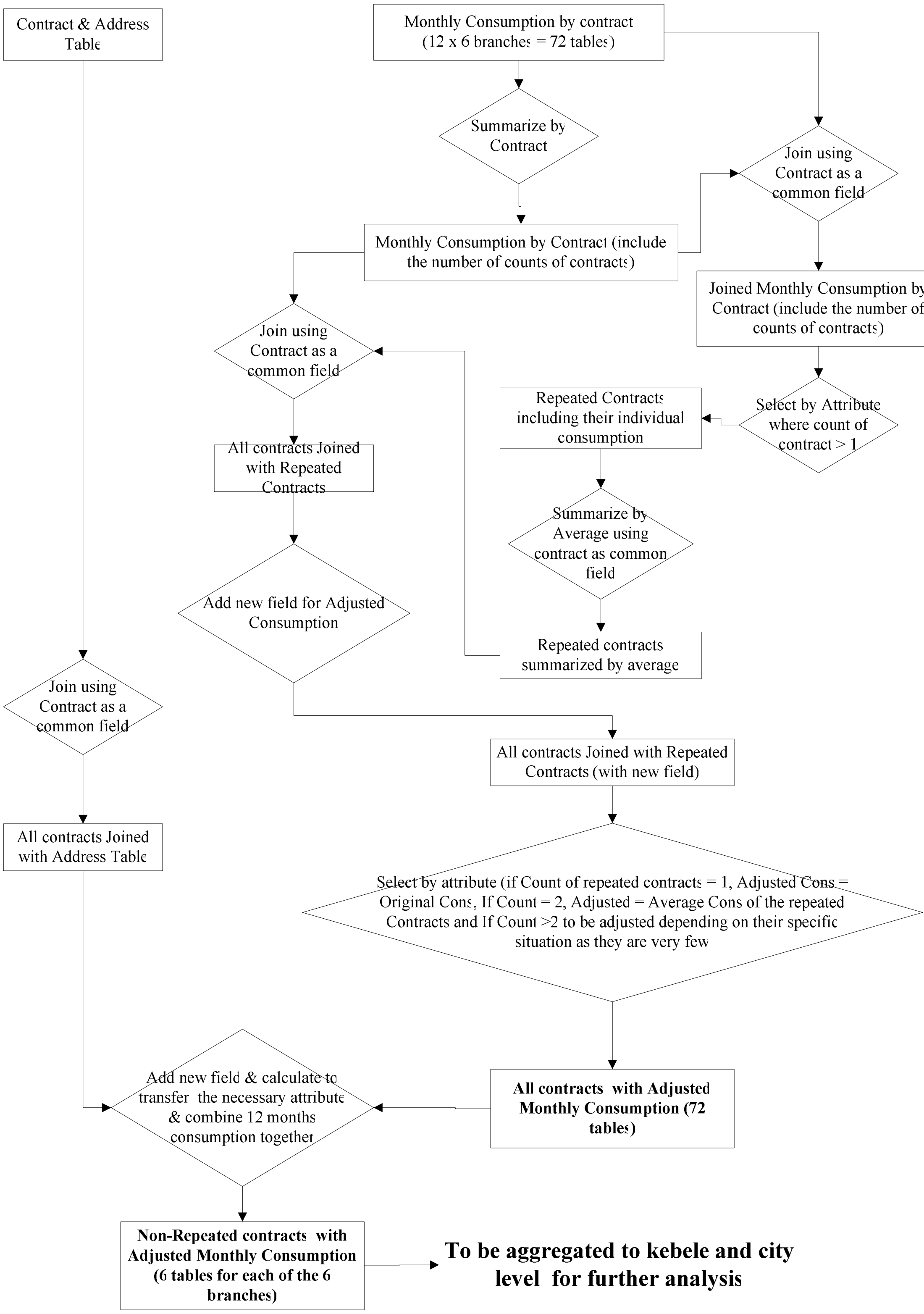
Western Branch

Months	Total No of contracts	No of repeated Contracts	Total Consumption	Repeated Contracts Consumption (M3)	% of repeated Consumption
July	35649	97	494918	2206	0.45
August	35731	87	467474	4320	0.92
September	35840	110	468279	3196	0.68
October	35964	120	538587	35493	6.59
November	36100	173	629112	14083	2.24
December	36241	203	541379	4922	0.91
January	36434	124	532346	2925	0.55
February	35582	187	491306	2283	0.46
March	36782	296	564320	28741	5.09
April	36981	282	578762	9960	1.72
May	37126	170	540849	9170	1.70
June	32238	146	546416	2352	0.43
Total			**6393748**	**119651**	**1.87**

Appendix III Converting Network Data from AutoCAD to ArcGIS



Appendix IV Identifying Repeated Contracts, Adjusting their values & combining together (6 branches)



Appendix V Aggregation of consumption Data to Kebele and City level

Appendix VI Network Distribution and Contour Plan of Addis Ababa