REDUCING NON- REVENUE WATER TO IMPROVE PIPE BORNE WATER SUPPLY IN PANADURA - HORANA REGION

By

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Declaration

"I declare that this is my own work and this report does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Abbreviations

AWWA	American Water Works Association
CARL	Current Annual Real Losses
CI	Cast Iron
DI	Ductile Iron
DMA	District Meter Area
ILI	Infrastructure Leak Index
IWA	International Water Association
MIS	Management Information System
MNF	Minimum Night Flow
NRW	Non- Revenue Water
NWS&DB	National Water Supply & Drainage Board
PE	Poly Ethylene
PVC	Poly Vinyl Chloride
RSC(W-S)	Regional Support Centre (Western-South)
UARL	Unavoidable Annual Real Losses
UFW	Unaccounted for Water
WHO	World Health Organization

Abstract

Panadura -Horan water supply scheme is the second oldest water supply system in Sri Lanka and have many issues with old deteriorating pipes. Amongst them, Non-Revenue Water (NRW) is the most affecting problem as it shows a high value of 32%. In view of various reasons such as lack of resources, lack of knowledge and insufficient time etc., no proper management system had been introduced at Panadura -Horan water supply scheme to reduce NRW so far. Without proper NRW management the system is not able to sustain its services or cover all population with available water source.

The aim of the research is to propose strategies that would help to minimize the NRW quantities and improve pipe borne water supply in Panadura - Horana region. A sub zone from Panadura Region was selected for the purpose of this study, where the existing issues in the water supply system are identified and methodologies are proposed in reducing NRW component to a more manageable level.

Under field study, initially the main causes of NRW are identified while paying more attention to the most significant causes. After studying various strategies part to whole method was selected as the most appropriate strategy to reduce NRW in the selected sub-zone.

Further, this study on water loss management, shows that fixing of responsibility with proper directions and commitment interest with awareness of all staff members top to bottom is important to ensure positive results and to provide reliable and customer satisfactory service.

The methods adopted for water loss management are different from country to country city to city and place to place depending on factors such as the condition of infrastructure, maintenance practices, resource availability and institutional framework etc. The strategies developed for water loss management for Panadura – Horana region could be applied in similar systems of developing countries.

Chapter 1

1 INTRODUCTION

Water constitutes about two-thirds of the whole earth surface, but it is limited in its availability as freshwater to human. The emphasis is on freshwater resources since it is used for consumption, agricultural and industrial purposes. According to Wikipedia freshwater constitutes only about 2.5% - 2.75% of the total water available on earth. Nevertheless, only less than one per cent of water is readily available to be accessed and used by human. Table 1.1 shows, water in its various forms and their percentage of the total.

Table 1.1: Various forms of water

Water Existing Type	Volume (10^6 km^3)	%
Oceans	13730	94.2
Groundwater	60	4.13
Ice sheets/Glaciers	24	1.65
Surface water on land	0.28	0.019
Soil Moisture	0.08	0.0055
Rivers	0.0012	0.00008
Atmospheric Vapor	0.014	0.00096

(Source: Shaw, 1994)

It is already known that about one fifth of the world's population lack access to potable drinking water and that about eighty countries, which constitute about forty percent of the world's population are already in serious water crisis (Aswathanarayana, 2001).

Even though freshwater resource accounts for only 2.75% of the whole water resource on earth, this amount is quite huge enough to cater for the needs of the current population as well as future ones. What is needed is the ability to manage and protect the resources. It is of utmost importance that prudent and efficient measures are taken to ensure effective and efficient use of the available freshwater resources. It should be noted that water cannot be created or manufactured and therefore the option left to human is the efficient management of the available freshwater resources.

Water loss has been one of the major challenges in water utility management all over the world. Water losses in most cities of developing countries are at alarming proportions; about forty percent to sixty percent of the total water supply (Thornton, 2002).

1.1 Background to case study

Panadura-Horana water supply system is one of the growing urban water supply systems in Sri Lanka. It has many issues with old deteriorating pipes, lack of valves, lack of proper zoning etc. All these factors make the identification of the components of NRW and subsequent reduction a very difficult task.

Earlier when the system was fed from Ambatale reservoir, it faced a lot of difficulties due to low water pressure and lack of water quantity. However, at present the water pressure has increased after the source is changed to Kandana-Kalu Ganga Water Treatment Plant.

The old outdated pipe lines in the system results in frequent pipe bursts in the distribution system generating low pressure areas and the final result is unsatisfactory customers. Apart from the leakage losses, Panadura-Horana water distribution system is affected by several other factors such as illegal connections, commercial losses etc. that also increase the NRW value in the system.

NRW value in Panadura-Horana Region was 32% of total production. The reason for the high NRW and NRW reduction strategy will be found through the research.

Figure 1.1 shows the study area of water loss management in Panadura – Horana region.

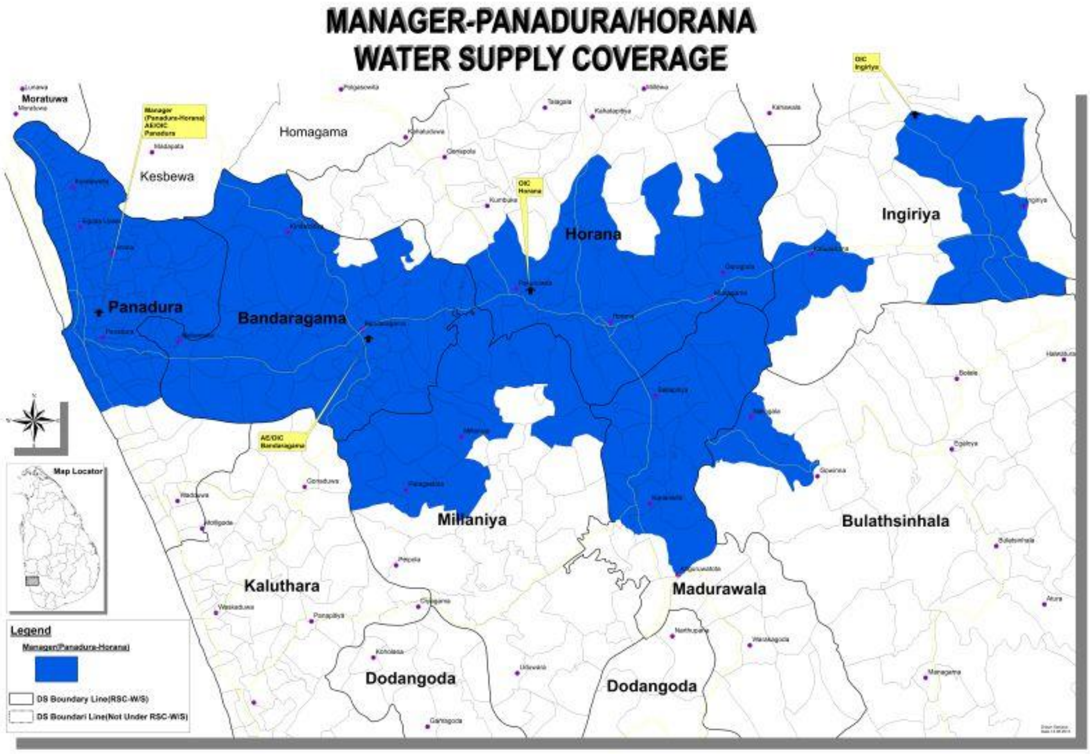


Figure 1.1 : Study area - Panadura – Horana region

(Source: Waterboard.lk/map Panadura-Horana)

1.2 Problem identification

Low pressure areas have been identified at many locations of the water supply system in Panadura- Horana region for a long period. The people in these locations have been suffering due to unreliable and poor services. Some studies have been carried out to find out the causes of these problems but, most of the studies have not progressed beyond the problem identification stage due to various reasons. As such, during the past few years, there are no significant improvements in water losses management in Panadura- Horana region.

The major cause of water loss is leakage and it is followed by illegal consumption. Another reason could be the practice of methodologies and techniques used in develop countries without analyzing them for the local condition. Therefore, it is essential to develop a suitable method for local conditions by formulating suitable water loss reduction strategies.

1.3 Objective of the Study

The main objective of this research is to propose strategies that would help to minimize the NRW quantities and improve pipe borne water supply in Panadura - Horana region.

The above objective of the study is achieved through the following specific objectives

- Identify the current NRW value in the Panadura – Horana region
- Analyze the water losses according to IWA format
- Evaluate current and alternative strategies to reduce NRW in the system.
- Propose the best strategies for reduction of NRW in Panadura- Horana region.

Chapter 2

2 LITERATURE REVIEW

2.1 Introduction

It is necessary to review available literature on the topic in order to better understand the concerns of NRW component in Panadura- Horana region. Although the focus on the NRW management the world over has only been recently given attention, there are several studies and literature available due to the impact that water has on the survival of man. The review of this literature was discussed under the ensuring heading.

2.2 Water Facts

It is well known fact that without water, life on the planet as we know it would not be possible. The human body itself consists of 60.70% of water and can only last four days without it. More than half of the earth's surface is covered in water, the total volume of water on the planet is apparently some 1,380,000,000 cubic kilometers that could cover the globe to a height of 2.7km if spread evenly over its surface. But more than 94% of that water is sea water. The amount of fresh water in the world is not evenly distributed and not readily available for human use leaving many areas in the world suffering from water and scarcity (Charalambous, 2010).

2.3 Water Stress and Scarcity

According to the World Business Council for Sustainable Development (2005) a country's renewable fresh water availability should be at least 1700 m^3 on an annual per capita basis for it to be sufficient. If this value falls between 1000 and 1700 m^3 the country experiences water stress, while if the value falls below 1000 m^3 the countries will experience water scarcity (Charalambous, 2010).

Water Scarcity can be defined as economic or physical. Economic scarcity may occur in a country where there is a lack of investment in infrastructure and unequal distribution of water. Physical scarcity is present where water supply cannot meet the demands of a country's population (Charalambous, 2010). Figure 2.1 indicates the areas of physical and economical scarcity over the world.

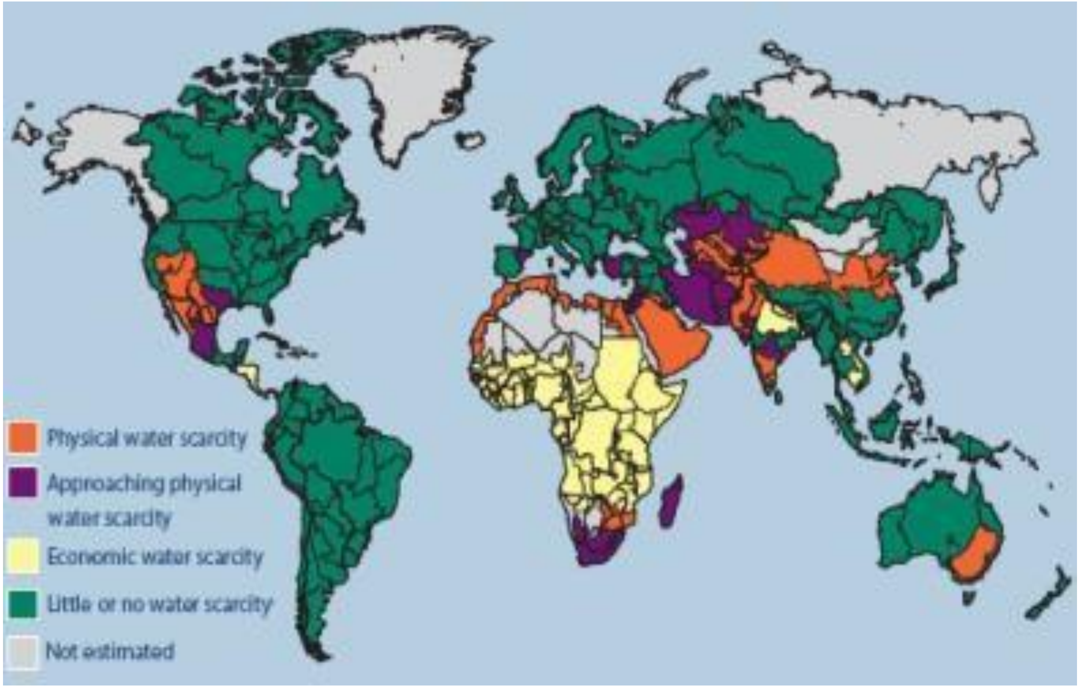


Figure 2.1 : Areas of physical and economical scarcity over the world

Globally, 1.1 billion people are without access to improved water supply and 2.4 billion are without access to improved sanitation. Figure 2.2 shows where the unserved population is found. For both water supply and sanitation, the vast majority of those without access are in Asia (WHO, 2000).

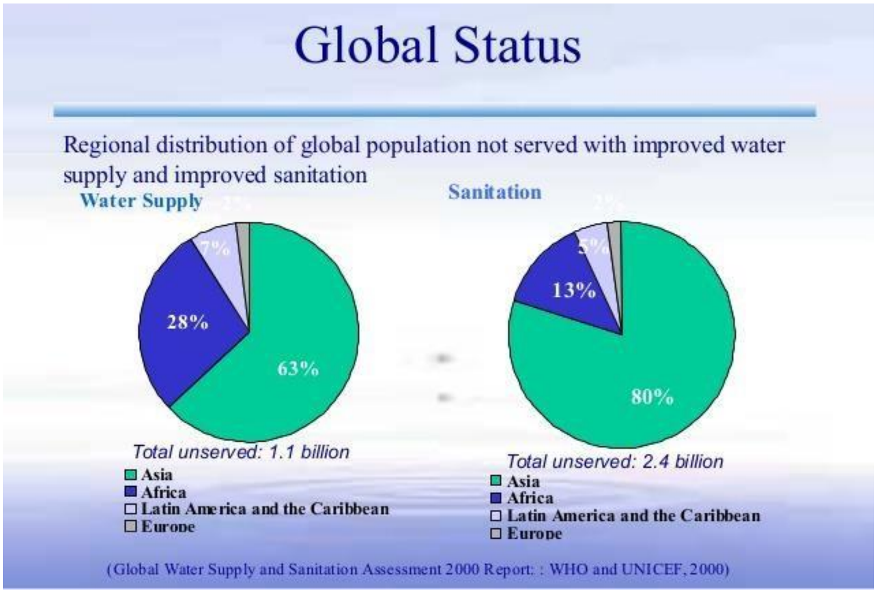


Figure 2.2 : Global status of unserved water

2.4 Water Loss Management

The water loss management is increasingly important as water losses from mains and service pipes in a global study amounted to 20-35% of the total flow in the system. One of the major constraints affecting the reliability of a sustainable water supply is water loss. All organizations in water management try to distribute whole water production to the consumers with minimum water loss in order to collect maximum amount of revenue and maximum utilization of water. Reliable operation and maintenance of water supply by using advance technology and appropriate management is vital to reduce the water loss at all the stages below (Figure 2.3), especially in areas where polluted ground water is significantly used. Many countries, particularly in Africa and middle east, must maintain reliable water service as water resources is limited. Further due to the geographical situation, infrastructure developments, different climate conditions, cultural behaviors and natural conditions water loss management is vital. Economic and Infrastructure developments and the population concentration mainly depend on availability of reliable water service.

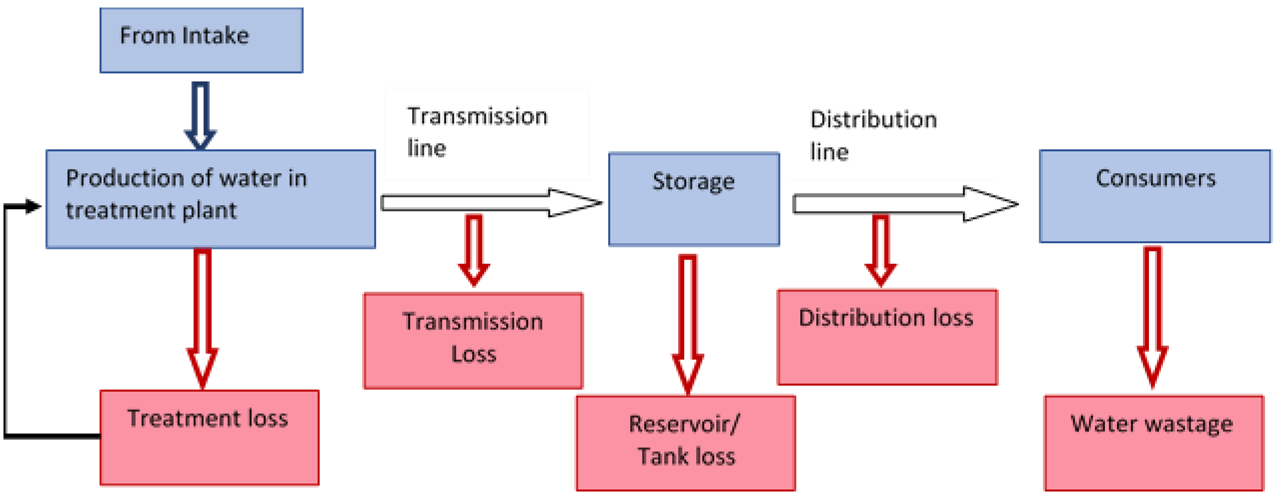


Figure 2.3 : Means of Water Losses in Water Distribution Processes

The characteristic of the pipe network, water utility's operational practice, the level of technology and the expertise applied to control them have impact on the amount of water loss in water distribution systems. The volume of losses and causes for each loss are not similar for all water supply schemes. It is situational and the strategies for controlling therefore differ from scheme to scheme. Hence, it has been revealed that the examination of relative significance of each of the components above and attending to the key areas by using proper technology and expertise is vital to reduce the water loss and maximize the water usage and revenue.

2.4.1 Components and Definitions of NRW and UFW

There are many terms that are used to reflect water losses, the most commonly used being Non-Revenue Water (NRW) and Unaccounted for water (UFW). Leakage is one of the main contributory factors in a water supply scheme according to the International Water Association (IWA) Task Force on Water Loss.

According to the International Water Association (IWA) Task Force on Water Loss, (IWA, 2003), the Non-Revenue Water (NRW) is defined as the difference between the volume of the input water to the System and the volume that is Billed Authorized Consumption. Percentage of NRW can be expressed as;

$$NRW = \left\{\frac{Q_{Supply} - Q_{Consume}}{Q_{Supply}}\right\} X\ 100$$

These definitions and others are shown in Figure 2.4 below.

System Input Volume	Authorized Consumption	Billed Authorized Consumption	Billed Metered Consumption (including water exported)	**Revenue Water**
			Billed Non-metered Consumption	
		Unbilled Authorized Consumption	Unbilled Metered Consumption	**Non-Revenue Water**
			Unbilled Non-metered Consumption	
	Water Losses	Apparent Losses	Unauthorized Consumption	
			Metering Inaccuracies	
		Real Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflows at Utility's Storage Tanks	
			Leakage on Service Connections up to Customers' Meters	

Figure 2.4 : The IWA best practice standard water balance

The unaccounted-for water (UFW) is defined as the difference between the volume of water delivered in a network and legitimate consumption, both metered and unmetered. Percentage of UFW can be expressed as

$$UFW = \left\{ \frac{Q_{Supply} - Q_{Consume} - Q_{legitimate\ unmetered\ consumption}}{Q_{Supply}} \right\} X\ 100$$

The main reasons for UFW and NRW are water leakage, illegal consumption and administrative losses and in addition to NRW legitimate free water uses such as unmetered supplies to the firefighting, stand post supplies etc.

In view of the above, these two terms describe the status of the water supply scheme. If UFW and NRW are high it may directly indicate high leakages existing in the distribution system. Leakage of water is a waste of resources while losing revenue.

If UFW is very high, performance of the water scheme is in a low level of operational condition. Therefore, it is not favorable for the utility as well as to the consumers.

Further considering the predicated scarcity of drinking water in the next millennium and development and improvement infrastructure of the cities, it is important to minimize the water leakages in distribution systems.

2.4.2 Water losses in developed countries

The water loss management scenarios in developed countries differ from those in developing countries in many ways. The main difference is in the response strategies and response sensitivity of the water utilities and governments of these countries. Utilities in developed countries have managed to reduce their water losses to acceptable and manageable ranges. Salient features of the low NRW are high degree of private sector participation, using concession and lease contracts and the existence of basin agencies that levy fees on utilities in order to finance environment.

However, water loss management is a dynamic equilibrium process, which depends on amount of resources pumped into the system. Water losses in Italy is 29%, is high compared to France

(26%), England(19%) , Germany(7%), Netherlands(6%) , Japan (7%) , Denmark(6%) and Singapore(5%).
In singapore and Tokyo galvanized iron (GI) poly vinyl chloride(PVC) service connections have been replaced with stainless steel service connectios and NRW levels has been remained very low due to the success of this approch. Singapore, Tokyo and other cities also have programes for replacing asbestors cement pipes in distribution systems, as pipe breaks have been reported very often (Lambert, 2005).

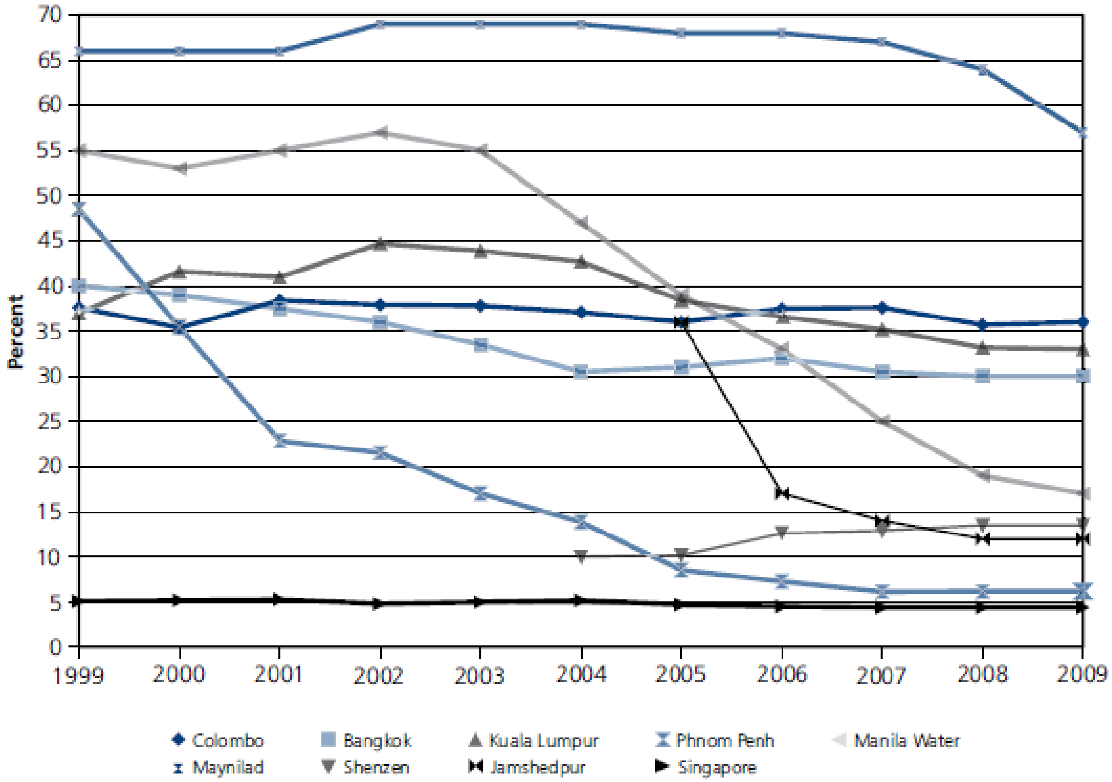
Benchmarking is one of the successful features in Dutch water sector water companies (first introduced in 1997). This has inspired smilier efforts in other Europen countries. Benchmarking NRW is useful, as water loss per kilometer of distribution and as water loss per connection, but this assumes that NRW does not have a high contribution of apperent losses. (Lambert, 2000)
Asset Management is another succesful feature developed in developed countries. This was mainly initiated in Australia and New Zealand and later followed by other developed countries as a concept to maintain distribution system in order to achieve reliable uninterrupted water supply with the reduction of NRW. Accordingly, the establishment of water Asset Management Philosophies, Information, Systems and Performance measures are required to be in sequence to establish financially sustainable programme for the reduction of NRW. Water Asset Management plan includes preparation of summary of asset conditions, a condition statue and risk management analysis of assets, preparation of optimized maintenance programme which will include a recommended approach and recommended annual expenditure of any programme for NRW reductions (Blakemore, 2007).

2.4.3 Water losses in some developing countries

In early days of the world, water was freely available but with the population growth and industrial development, safe water became a scarce commodity. Due to the scarcity, available fresh water must be properly managed. It is one of the major challenges faced by many water utilities in most of these countries due to lack of resources including expert knowledge. Most of the water utilities in developing countries record high NRW, some has recorded as more than 60 % (Asia Water Watch 2015). Current managements of most of the utilities in developing countries just maintain systems to provide water. Expenditure is being balanced with tariff increase without paying attention to active leakage controlling programmes.

The database maintained by the World Bank on water utility performance, “The International Benchmarking Network for Water and Sanitation Utilities (IBNET)”, includes data from more than 900 utilities operating in 44 developing countries. According to this database, the average percentage of NRW in the countries considered is around 35%. NRW in Colombo, Sri Lanka has been 46% in 2016. A high NRW level means that a large amount of water is being lost from the distribution system through leaks. The amount of NRW is the most accurate indicator of the income lost by the utility due to water losses. Most of the utilities in developing countries are interested in only earning revenue. They maintain their systems only to provide water and increased expenditure is incurred as a result of NRW being met by increasing water tariff and not by introducing leak controlling programmes.

In developing countries roughly 45 million cubic meters of water is lost daily with an economic value of over US$ 3 billion per year. A World Bank study puts the global estimate of physical water losses at 32 billion cubic meter each year, half of which occurs in developing countries. The average figure of NRW levels in developing countries is around 35%. Most of the developing countries do not have proper records of NRW because of lack of flow meters both domestic and bulk, and proper continuous monitoring system. Figure 2.5 shows the NRW levels of Asian cities, and clearly illustrates the situation of developed countries compared to developing countries.



(Source: Water in Asian cities, ADB (2004)

Figure 2.5 : NRW levels of Asian cities

It is necessary to pay more attention to reduce non-revenue water in the developing countries because treated water is costly to produce due to the cost of chemicals, energy, administration, high capital and maintenance etc. to maintain sustainable service these costs need to be recovered through water sale. If the utilities have high figures of NRW, due to the inefficiency of the institution, the consumer ends up with increased water tariff. This is a big burden especially in developing countries as the majority of the consumers are poor and as a result the service becomes unaffordable. Due to this majority of consumers either use water illegally or are forced to use alternatives such as common stand post or contaminated water sources like open wells, water streams etc. Hence the main objective of a country; a healthy nation cannot be achieved through this kind of inefficient services.

2.5 Causes of Water Losses

Major causes for water losses are treatment losses, leaks in pipe line (transmission mains, distribution system and service lines), illegal water consumption, administrative losses and free water supply. These causes are mainly divided into two groups namely

- Real Losses (Physical)
- Apparent losses (Commercials)

2.5.1 Real Losses (Physical Losses)

This is the water that is physically lost after production, in the water distribution process between the treatment plant and the end user, without being used in the distribution system. Real losses may be attributed to causes such as

- Treatment losses
- Leakage from transmission mains and Distribution systems
- Leakage and overflows from reservoirs
- Leakage from service line and connections, before the consumers' meter

The volume of lost will depend largely on the characteristic of the pipe network, the leak detection and repair policy practiced by the utility and other local factors such as;

- Pressure in the network
- Frequency and typical flow rates of new leaks and bursts
- Proportions of new leaks that are reported
- The level of background leakage (undetectable small leaks)

2.5.1.1 Treatment losses

Treatment losses could be minimized but cannot be eliminated as it is needed for the process of the treatment plant. However, this water could be re-circulated to minimize intake pumping. In treatment plants, water losses occur mainly due to treatment process requirement such as filter back washing etc.

2.5.1.2 Leakage from Transmission mains and Distribution systems

This is the main contributory factor for the NRW and UFW in most of the water supply schemes. This also cannot be completely eliminated, but it is possible to minimize them to certain extent. Leaks will occur due to age of the pipe network, soil condition, pipe materia , inadequate cover to pipe line, inactive CI lines in the distribution system, heavy moving loads, availability of leak repair materials and resources, quality of material used and workmanship and status of distribution valves.

Transmission mains generally consist of 2%-3% of volume water leakage mainly from sluice valve and pipe joints. This kind of losses could be eliminated by implementing proper preventive maintenance programme.

Leakage from distribution systems is frequently found to be the single largest component of NRW. Factors contributing to this are large number of pipe joints, pipe damages due to development work, extensive network of small diameter pipes with unnecessary pipe lines, usual pipe bursts and leaks due to vehicle loading.

2.5.2 Apparent Losses (Nonphysical losses)

Apparent losses are those that are caused by faulty or badly read meters and meter under – registration and water that is taken from the network without permission.

Apparent losses consist of two main components;

- Customer metering inaccuracies and data handling errors
- Unauthorized consumption

The main causes of unauthorized consumption are;

- Illegal connections
- Misuse of fire hydrants and firefighting systems
- By passed consumption meter
- Unbilled consumption
- Disconnected and illegally connected premises

2.6 Strategy for Dealing with Water Losses

The two most important components of NRW are the real losses and the apparent losses. The third component, unbilled authorized consumption can be controlled fairly well without much resources. It is therefore important to develop the appropriate strategies for controlling water losses especially through real and apparent losses, if meaningful achievements are to be made and the outcome would justify the efforts put in (Yeboah, 2008). According to Butler and

Mamon (2006), The starting point to deal with water losses in any water utility, is to understand the network system of the utility.

Butler and Mamon (2006), suggest that certain questions should be posed about the water utility with regard to the characteristics, the production process, and the operating practices, and using the available tools and mechanisms within the water utility to answer these questions, form the first step in the right direction to deal with the prevailing situation. In the process of trying to answer these questions, better understanding of the network system of the water utility would now be obtained, which would then form the basis for the formulation of strategies for dealing with water losses. Butler and Mamon (2006) suggest the following questions:

- How much water is being lost?
- Where is it being lost from?
- Why is it being lost?
- What strategies can be introduced to reduce losses and improve performance?
- How can we maintain the strategy and sustain the achievements gained?

The Table 2.1 gives a summary of the tasks required to address the above questions.

Table 2.1 : Tasks and tools for developing a strategy

QUESTION	TASK
1. HOW MUCH WATER IS BEING LOST? - Measure components	- WATER BALANCEImproved estimation/measurement techniques - Meter calibration policy - Meter checks - Identify improvements to recording procedures
2. WHERE IS IT BEING LOST FROM? - Quantify leakage - Quantify apparent losses	NETWORK AUDIT - Leakage studies (reservoirs, transmission mains, distribution network)Operational/customer investigations
3. WHY IS IT BEING LOST? - Conduct network and operational audit	REVIEW OF NETWORK OPERATING PRACTICES - Investigate: historical reasons poor practices quality management procedures poor materials/infrastructure local/political influences cultural/social/financial factors
4. HOW TO IMPROVE PERFORMANCE? - Design a strategy and action plans	UPGRADING AND STRATEGY DEVELOPMENT - Update records systems - Introduce zoning - Introduce leakage monitoring - Address causes of apparent losses - Initiate leak detection/repair policy - design short/medium/long term action plans
5. HOW TO MAINTAIN THE STRATEGY?	POLICY CHANGE, TRAINING AND O&M Training: improve awareness increase motivation transfer skills introduce best practice/technology O&M: Community involvement Water conservation and demand management programmes Action plan recommendations, O&M procedures

Source: Butler and Mamon (2006)

This diagnostic approach, followed by the implementation of solutions that are practicable and achievable, can be applied to any water company to develop a strategy for NRW management.

This approach will also provide a systematic basis for developing and monitoring any performance based NRW reduction arrangement (Taha, 2011).

In practice, a tailor-made NRW reduction strategy might address only physical losses or only commercial losses, but in most cases, it will be required to deal with both. A wide array of activities must typically be carried out (Taha, 2011).

It is often thought that dealing with physical losses mainly involves pipe repairs, but in reality, a sustainable physical loss control strategy must be comprised of four main elements (Taha, 2011).

- **Active leakage control:**
  Monitoring network flows on a regular basis to identify the occurrence of new leaks earlier so that they can be detected and repaired as soon as possible (Taha, 2011).

- **Pipeline and asset management:**
  Managing network rehabilitation in an economical manner to reduce the need for corrective maintenance (Taha, 2011).

- **Speed and quality of repairs**:
  Repairing leaks in a timely and efficient manner (often requiring a thorough shakeup of working practices, organization, and stock keeping of repair materials) (Taha, 2011).

- **Pressure management:**
  Regulating network pressure through the judicious use of pressure-reducing valves (often an underestimated option for leakage reduction) (Taha, 2011).

Figure 2.3 displays the leakage types that will have a direct impact to the physical losses.

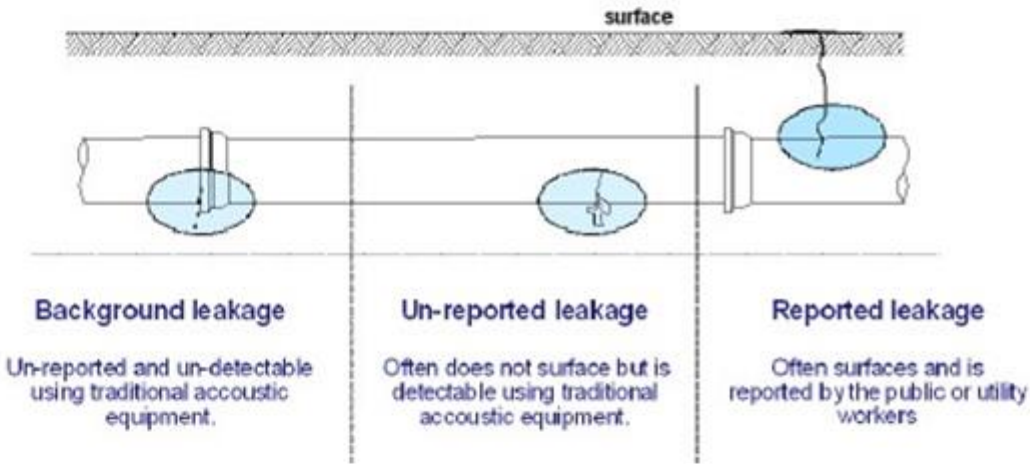


Figure 2.6 : Leakage types
(Source: Yeboah, 2008)

According to Taha (2011), the design of a commercial loss reduction strategy will very much depend on local circumstances, but is likely to comprise:

- **Improving customer meter accuracy**
  Ensuring that customer meters are in proper working condition and duly replaced at the end of their useful lives, reduces under-metering and recourse to estimated billing (Taha, 2011).

- **Improving meter reading and billing**
  A significant portion of commercial losses comes from mistakes in the meter reading and billing chains, not only because of poor technology and data handling errors in the office but also because of fraudulent practices on the part of utility staff (Taha, 2011).

- **Detection of illegal connections**
  Contrary to common belief, a large portion of water stolen from public utilities does not come from poor, marginal urban areas, but rather from large industrial customers and those with political clout and enough resources to bribe utility staff and management. Allowing illegal connections and such fraudulent behavior is unfair for those in the population who do pay their bills, especially the poor, and works against promoting a culture of good governance (Taha, 2011).

2.7 Leak Monitoring

According to Farley and Trow (2003), leak monitoring is flow monitoring into zones to measure leakage and to prioritize leak detection activities. This is normally done by the installation of flow meters at strategic points throughout the distribution networks, with each measuring the flow in to a specific zone which has a well-defined and permanent boundary (Butler and Mamon, 2006). Such a metered area or zone is called District Meter Area (DMA). The use of DMAs has become one of the most cost effective and most widely used techniques for leakage management. This methodology can be used even in systems which has supply deficiencies (Farley and Trow, 2003). Zones can be created one at a time and leaks detected and repaired before moving on to another zone. Eventually this system approach would improve the hydraulic characteristics of the network and improve supply (Farley and Trow, 2003). In Figure 2.7, creation of a DMA can be clearly identified. The creation of DMAs in itself does not reduce leakage. Its purpose is to facilitate the identification of the areas of leakages and by so enable to locate leakages easier and efficiently (Farley and Trow, 20

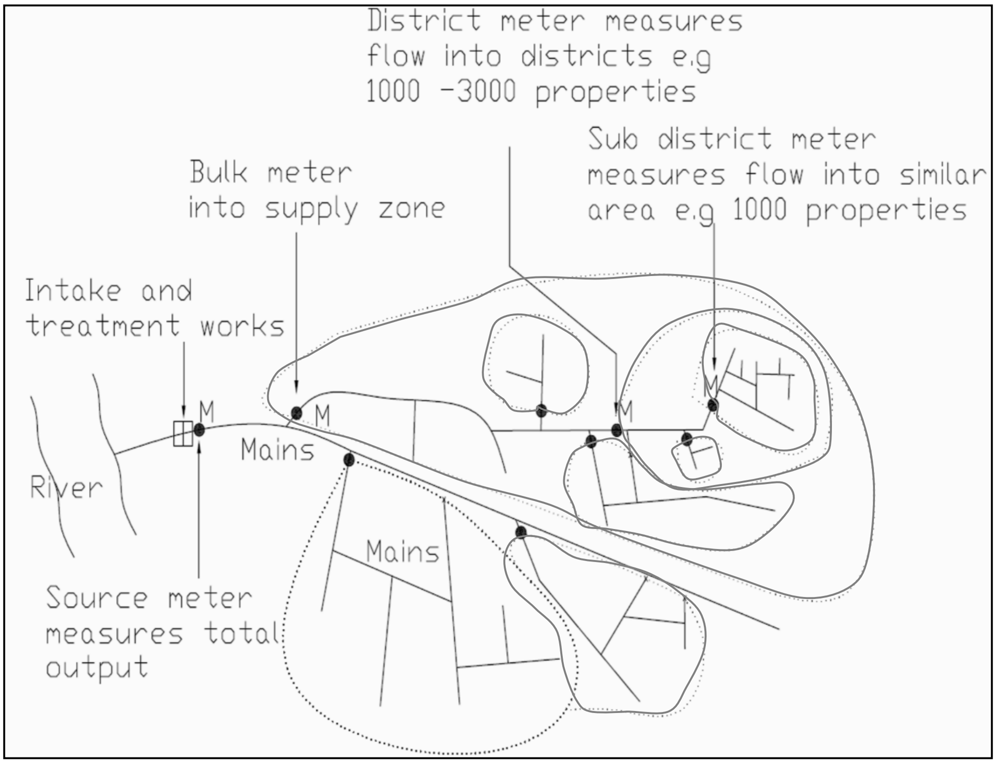


Figure 2.7 : DMA design options

(Source: Farley and Trow, 2003)

According to Farley and Trow (2003), for effective monitoring and control of the distribution system, the measurement system must be in hierarchical order, beginning at system input through zones and district levels to the customer's meter.

This system is composed of;

- Measurement of supply at the source or treatment works
- Measurement of flow into supply zones with defined boundaries (about 10,000 to 50,000 properties)
- Flow monitoring into DMAs of up to 3,000 properties with permanently closed boundary valves
- Small leak location areas within each DMA, of around 500-1,000 connections, where boundary valves remained opened except during leak location (step test) exercise; and
- Individual consumer meters, both domestic and commercial

Pressure reducing valves could be incorporated in the installation of the flow meters. Caution should be taken to ensure that the cost of leakage management does not exceed the savings that could be made. In order to ensure the accuracy of data from DMA, it is crucial to ensure the proper maintenance of DMAs. This maintenance includes the clear maintenance of the DMA boundary, the integrity of plant and equipment (Farley and Trow, 2003).

The design of leakage monitoring system apart from the creation of DMAs for the monitoring of night flows on regular basis, also enables pressure management of the individual DMA or group of DMAs for the network to operate at the optimum pressure (Farley and Trow, 2003).

2.8 Non-Revenue Water assessment

Non-Revenue Water assessment is the first step towards its management, and essential stage when preparing a baseline for NRW strategy (Kingdom, et al., 2006 and Liemberger and Farley, 2004).

The objective of NRW assessment is to quantify NRW amount in the subject system without considering where the losses are located (Puust, et al., 2010). Three and half decades ago, water loss assessment was more an estimation process than meticulous science (Liemberger and Farley, 2004). During the last twenty years, a large effort has been made by IWA and other organizations to promote new concepts and methods for improving the assessment and management of Non-Revenue Water (Vermersch and Rizzo, 2008).

Puust, et al. (2010), in their review paper, concluded that the current leakage, or water loss assessment methods can be classified into two main groups; (1) top-down assessment methods; using water balance, and (2) bottom-up assessment methods; Mainly by using 24 Hour Zone Measurement (HZM), or Minimum Night Flow (MNF) analysis.

2.8.1 Top-Down Approach

The top-down approach, the water balance, was first suggested by IWA Water Loss Task Force as an international "best practice" standard approach for NRW calculations. All definitions of the terms involved in the water balance have been provided clearly with the suggested water balance (Farley and Trow, 2007). The IWA water balance has rapidly gained international acceptance, and has already been promoted by many International agencies; Including AWWA and the World Bank. It has been also adopted by national water utilities, associations, and consultants in the developed, and developing countries (EPA, 2009 and Radivojevic, et al., 2008).

According to the NRW handbook sponsored by Ranhill and USAID (2008), four basic steps have to be made to conduct a water balance:

(1) Determining system input volume

(2) Determining authorized consumption:

- Billed: total volume of water billed by the water utility
- Unbilled: total volume of water provided at no charge; (metered and not metered)

(3) Estimating the apparent (commercial) losses:

- Theft of water and fraud
- Meter under-registration; since the tendency of the customer meters tend to be under-registration than over-registration (AWWA, 2009)
- Data handling errors

(4) Calculating the real (physical) losses:

- Leakage on transmission mains
- Leakage on distribution mains
- Leakage from reservoirs and overflows
- Leakage on customer service connections

According to these steps, system input volume, billed consumption, and unbilled metered authorized consumption are usually metered. In contrast, unbilled authorized unmetered consumption and the apparent losses are estimated.

The unbilled authorized consumption (metered and unmetered) is usually a small component, and thus typically assumed in the range from 0.5% (Lambert and Taylor, 2010) to 1.25% (AWWA, 2009) of the system input volume or estimated by the utility as it is site specific.

On the other hand, the apparent losses estimation starts with assuming the unauthorized consumption at 0.25% as in (AWWA, 2009) or 1% as in (Lambert and Taylor, 2010). Alternatively, it could also be estimated via the utility's experience with validated data (AWWA, 2009). Afterwards, the customer meter inaccuracies should be estimated according to meter tests at different flow rates representing typical customer water use and meter guidance manuals as well (Mutikanga, et al., 2010; Ranhill and USAID, 2008; and AWWA, 2009). The next step is to estimate systematic data handling errors by exporting and analyzing historic billing data trends for a certain period (Mutikanga, et al., 2010 and Ranhill and USAID, 2008). Thenceforth, the apparent losses component is estimated by summing its subcomponents.

Eventually, the real (physical) losses are calculated by subtracting the apparent losses and authorized unbilled consumption from the volume of NRW. Hence, NRW components are quantified by the water balance; top-down approach.

2.8.1.1 Unauthorized Consumption Estimation

Tackling the unauthorized consumption is rather difficult and challenging to estimate the unauthorized consumption (Mutikanga, et al., 2010) due to its hidden nature. The NRW handbook (Ranhill and USAID, 2008) confines this point by recommending that the unauthorized estimation should be a transparent component- based process (Ranhill and USAID, 2008). The guidance manual of Control and Mitigation of Drinking Water Losses in Distribution Systems published by the Environmental Protection Agency (2009) emphasized the difficulty of estimating unauthorized consumption but has only recommended that it must be accounted (EPA, 2009).

Mutikanga, et al. (2010) has attempted to estimate unauthorized consumption through long awareness and rewarding program. Advertisements were placed in the local newspapers requesting anyone with information on illegal use to report it to the utility and a cash reward was offered (Mutikanga, et al., 2010). This process, however, is considered bottom--up auditing rather than top down approach (Mutikanga, et al., 2010). Besides, there still might be potential significant illegal connections that are not reported.

To sum up this matter, yet, there is still lack of scientific methods attempts to quantifying the unauthorized consumption through top down approach apart from assuming it from 0.25% - 1% of the system input volume.

2.8.1.2 Bottom--Up Approach

Bottom--up approach estimates the physical losses by analyzing 24 Hour Zone Measurement (HZM) or Minimum Night Flow (MNF) analysis. Minimum Night Flow analysis is more common since the HZM in principle is used eventually to apply MNF analysis approach (Puust, et al., 2010).

Minimum Night Flow analysis is the lowest flow into the District Metered Area (DMA) over a 24-hour period, which generally occurs at night when most consumers are inactive as shown in Figure 2.8 (Farley and Trow, 2007). Minimum Night Flow analysis requires DMA, and to perform field tests between 02: 00 am and 04: 00 am in which most users do not use water (Cheung, et al., 2010; Farley and Trow, 2007). Besides, Minimum Night Flow analysis entails identifying in advance the potential large nightly water consumers within the DMA, and further, the medium water pressure in the DMA network (Cheung, et al., 2010; Puust, et al., 2010)

Accordingly, estimating the leakages in the MNF period is carried out by subtracting legitimate night uses from the MNF (Farley and Trow, 2007).

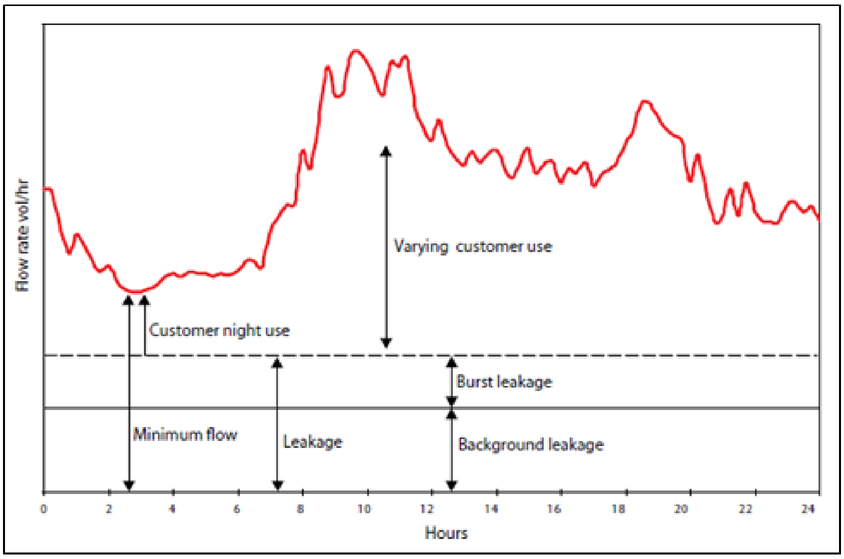


Figure 2.8 : Typical 24-hour DMA flow profile indicating MNF.

2.8.1.3 A component Base Analysis

This approach uses the concept of Burst and Background Estimates (BABE) that was developed by Lambert in the 1990s (EPA, 2009). The underlying principle of BABE concept is that real losses consist of numerous leakage events. Loss volume for each event is a function of the average flow rates and average run-times for different types of leakages (Thornton, et al., 2008) (Figure 2.9). Therefore, to conduct such analysis, real losses in the network is categorized into four categories

(1) Background leakage at joints and fittings
(2) Reported leaks and bursts (high flow rates with short duration)
(3) Unreported leaks and bursts (moderate flow rates with duration depending on the method of active leakage control)
(4) Hidden loss or excess losses; flow rates too low to be detected by sonic detection devices (EPA, 2009).

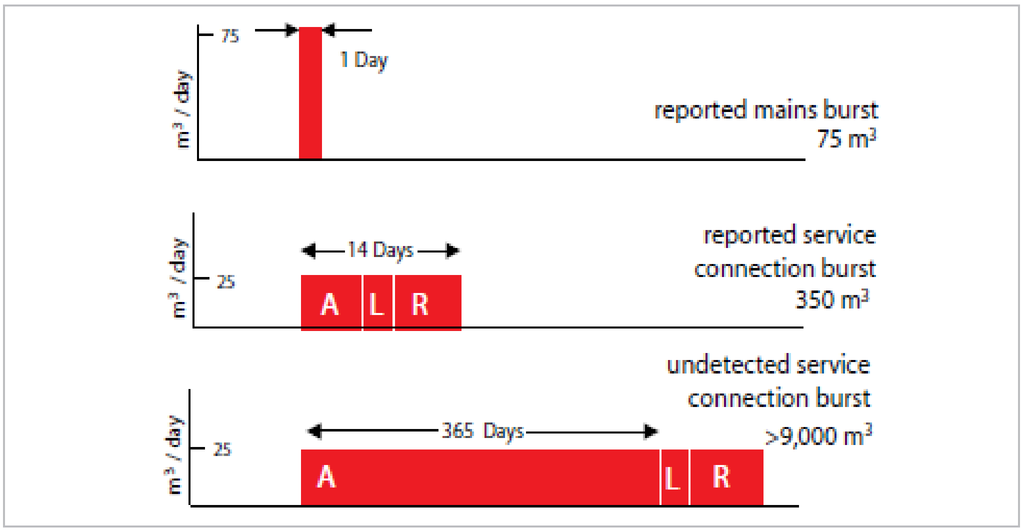


Figure 2.9 : Leak run time and volume of water loss

Where:

A: Awareness Time

L: Locating Time

R: Repairing Time

In using BABE model, typical burst flow rates are already set at a standard pressure, and then are adjusted to actual pressure using appropriate assumptions for FAVAD principle (EPA, 2009). Table 2.2 provides the standard approximate flow rates for the reported, unreported and background losses.

Table 2.2 : Standard Flow Rates for the BABE Method Source

Reported and Unreported Bursts Flow Rates		
Location of Burst	**Flow Rate for Reported Bursts [l/hour/m pressure]**	**Flow Rate for Unreported Bursts [l/hour/m pressure]**
Mains	240	120
Service Connection	32	32
Background Losses Flow Rates		
Location of Background Loss	**Flow Rate of Background Loss [Liter]**	**Unit of Measure**
Mains	9.6	Liters per km of mains per day per meter of pressure
Service Connection – main to property boundary	0.6	Liters per service connection per day per meter of pressure
Service Connection – property boundary to customer meter	16	Liters per km of service connection per day per meter of pressure

Although this concept is the first one to model physical losses objectively rather than empirically (Ranhill and USAID, 2008), Puust, et al. (2010) did not go through this concept in their recent review paper of real losses assessment methods. This might be due to its excessively estimation-oriented approach. Thornton, et al. (2008) has also recommended not using the component analysis, BABE, on its own to estimate the real losses because of significant level of uncertainty in much of the data used in the analysis. Although BABE approach has significant level of uncertainty in much of the data used, it provides valuable data for further breaking down the real losses into subcomponents, and thus, these data could be utilized for designing the appropriate leakage reduction policy (Thornton, et al., 2008).

2.9 Performance Measures for Water Loss and Leakage

Water loss from a distribution system is a direct measure of how well a system is performing and being maintained. The measurement of efficiency of the system would be at a point in time or over a long period. High and increasing water losses are an indicator of ineffective planning and construction. and of low operational maintenance activities. (Lambert 2000).

The IWA's task force on water losses recommended a standard international terminology for calculating of real and apparent losses from the water audit and performance indicators (PIs) to enable comparisons between different water distribution systems worldwide. These are discussed below.

2.9.1 Measuring and Evaluating the Water Loss and leakages

There are several methods available to evaluate water losses and leakages in water distribution networks. Each method has its own limitations. The most popular methods are the total quantity method (water audit) and minimum night flow method.

In the total quantity method, (Lambert, 2005) the quantity of water loss is determined by calculating the difference between the total amount of water delivered to the network and the summation of the water quantities consumed by customers. This method gives the total NRW rather than the amount of leakage. The minimum night flow rate method assumes that the minimum flow rate that occurs during late night hours (1 am to 3 am) will represent the rate of leakage upon reducing legitimate night flow (actual consumption at night). This method can be improved by calculating the net minimum flow. Which is the difference between the total night flow and legitimate night flow. Further, quantity of leakage get by multiplying net minimum night flow rate by appropriate factor (Called T factor corresponding to minimum and maximum pressure) which apply to correct pressure fluctuation during day and night. This method cannot be applied to intermittent supply systems.

After measuring the water loss, a technical audit can be carried out for the water distribution network using a number of indicators to express the level of water losses. For evaluating the technical condition of the water distribution network the following indicators are recommended by Lambert (2005) of IWA water loss task force; the Infrastructure Leakage Index (ILI) and the Economical Leakage Index (ELI). These are determined from the unavoidable real losses and current real losses and the various costs required to carry out a water loss reduction programme.

2.9.2 Current Annual Real Losses (CARL)

The CARL is the total loss from the system as calculated using water audit excluding the apparent losses and authorized consumption. There are physical water losses from the system. Up to the point of measurement of customer use. It is expressed in m^3/day. It is given by the formula:

CARL = System Input – (Authorized consumption + Apparent losses)

Where:

System input is the volume input to that part of the water supply system to which the water audit calculation relates, allowing from known errors.

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.

Apparent losses are unauthorized consumption and all types of metering inaccuracies.

Where it is difficult to get reliable data on the real losses, it can be estimated that the CARL are equal to the NRW as normally the apparent losses take up a smaller percentage of the total losses.

2.9.3 Unavoidable Annual Real Losses (UARL)

According to IWA (2003), real losses cannot be eliminated completely. The lowest technically and practically achievable annual real losses value is known as Unavoidable Annual Real Losses (UARL). This is demonstrated by the Figure 2.10.

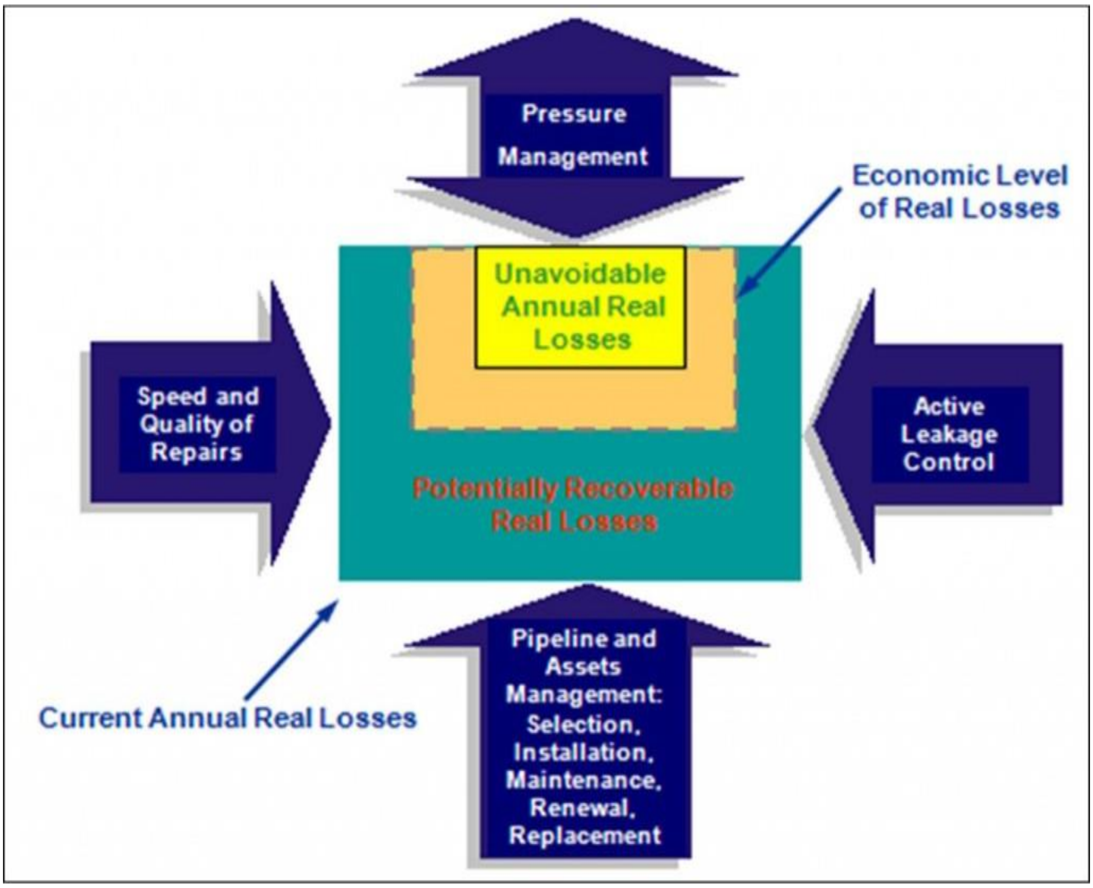


Figure 2.10: The four-basic method of managing water loss

The Figure 2.10 shows the relationship between Current Annual Real Losses (CARL), which is represented by the larger rectangle and UARL, represented by the smaller rectangle. Each of the four component methods of controlling real losses, according to Farley and Trow (2003: p 42), influences leakage in specific way or manner. Long term pipe line management influences the numbers of new leaks that develop each year while pressure management influences the frequency of new leaks and flow rates of bursts and leaks. In the same way, the average duration of leaks is influenced by the speed and quality of repairs and active leakage control determines how long unreported leaks can run before being detected (Farley and Trow 2003: p 42).

The standard form of the equation is as follows:

UARL = (18 Lm + 0.8 Nc + 25 Lp) P -------------------- Equation 2.2

Where : UARL = Unavoidable Annual real Losses (Litters/ Day)

Lm = Length of mains (Km)

Nc = Number of service connections

P = Average operating Pressure at average zone point(m)

Lp = Length of service pipe (underground) from street edge to customer meters(km)

The basic equation is based on an average length of pipe from the water main up to the customer meter of 10 m. The term (Lp) is therefore only used in cases where the customer meter is located in excess of 10 m from the water main (McKenzie et al., 2002).

In some countries where the customer meter is located at the street edge, the equation can therefore be simplified as follows:

UARL = (18 Lm + 0.8 Nc) P-------------------------------- equation 2.3

2.9.4 Infrastructure Leakage Index (ILI)

The difference between UARL and the CARL is the potentially recoverable real losses (Farley and Trow, 2003: p 43). The ratio of CARL to UARL is the infrastructure index (ILI). It is given by the formula:

ILI = CARL / UARL--------------------------------------- equation 2.4

ILI is a good indicator of how a distribution system is performing as opposed to current methods of expressing water loss in terms of percentage of system input as is done in many developed and developing countries. According to Liemberger and McKenzie (2000) it was found that this significantly underestimates the true extent of the leakage problem in developing countries and tends to penalize systems with lower consumption.

Liemberger (2000) suggested a simple look-up table based on the ILI to help address the issue. This allows a first simple assessment using liters per connection per day in combination with the approximate average pressure. This is presented in Table 2.3.

Table 2.3 : Relationship between leakages and Average System Pressure & ILI in developed and developing countries

Technical Performance Category		ILI	Liters/connection/day (when the system is pressurized) at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
Developed Country Situation	A	1 - 2		< 50	< 75	< 100	< 125
	B	2 - 4		50-100	75-150	100-200	125-250
	C	4 - 8		100-200	150-300	200-400	250-500
	D	> 8		> 200	> 300	> 400	> 500
Developing Country Situation	A	1 - 4	< 50	< 100	< 150	< 200	< 250
	B	4 - 8	50-100	100-200	150-300	200-400	250-500
	C	8 - 16	100-200	200-400	300-600	400-800	500-1000
	D	> 16	> 200	> 400	> 600	> 800	> 1000

From Table 2.3 different ILI ranges have been provided for developing and developed countries (Liemberger and McKenzie, 2000). The proposed table attempts to classify the leakage levels within the water utilities into four categories based on the ILI value as follows:

Category A: Good; further loss reduction may be uneconomical and careful analysis needed to identify cost- effective improvements.

Category B: Potential for marked improvements: consider pressure management, better active leakage control, and better maintenance.

Category C: Poor; tolerable only if water is plentiful and cheap, and even then, intensify NRW reduction efforts.

Category D: Bad; the utility is using resources inefficiently and NRW reduction programs and imperative.

Since most water utilities in the developing world will have ILI values exceeding the upper limit of 16, reducing real losses to below 16 will be the starting point. As soon as the utilities starts to introduce active leakage control, carry out flow and pressure measurements, and improve overall data quantity and the band width of the ILI will dramatically be reduced. Often leakage reduction will also lead to an improved supply situation and pressure increases that will make the calculation of the UARL formula more accurate (Limburger and McKenzie 2005).

2.10 Benefits of NRW reduction

According to the World Bank (2006), it is not realistic to expect water utilities to eliminate all commercial and physical losses. However, in developing countries, it is certainly not unrealistic to expect that the high levels of physical losses could be reduced by half. This would provide 8 billion cubic meters per year of already treated water—enough water to service an additional 90 million people who currently lack access to piped water and to save an estimated US$1.6 billion per year in production and pumping costs for public utilities.

Similarly, if commercial water losses in developing countries could be cut by 50 percent, then another US$ 1.3 billion in additional revenues could be generated each year (The World Bank, 2006).

According to the World Bank (2006), Benefits of NRW reduction include;

- Eight billion cubic meters of already treated water would be available to service customers.
- Fairness would be promoted among users by acting against illegal connections and those who engage in corrupt meter-reading practices.
- Consumers would have improved service delivered by more-efficient and more-sustainable utilities.
- Revenue can be increased without increasing tariff
- Risk of water quality issues would be reduced

2.11 Optimal level of NRW

There is some debate as to what an economically optimal level of leakage is (Pearson and Trow, 2005). From a financial point of view, there are fewer incentives to reduce NRW if water production is cheap, if there is no or little metering (and revenues thus are independent of actual consumption), or if volumetric tariffs are low in metered areas. From an economic point of view, NRW reduction usually makes more sense than from a financial point of view, because the economic benefit from water use normally exceeds the financial revenues to the utility, since households typically derive a higher benefit from water than what they pay for it. However, even from an economic point of view it is not appropriate to try to reduce NRW to the lowest possible level, because the marginal cost of reducing NRW increases once the cheaper options have been exploited. Once the marginal cost of reducing NRW exceeds the marginal benefits or water savings, an economic optimum has been achieved (Wyatt, 2010).

From a public health and drinking water quality point of view it is being argued that the level of real water losses should be as low as possible, independently of economic or financial considerations, in order to minimize the risk of drinking water contamination in the distribution network (Wyatt, 2010).

According to AWWA (2009), it is recommended that water utilities conduct annual water audits as a standard business practice. AWWA recommends that water utilities should track volumes of apparent and real losses and the annual cost impacts of these losses. Utilities should then seek to control excessive losses to levels that are economic for the water utility. In 1999 the California Urban Water Conservation Council identified a 10 percent benchmark for unaccounted-for water.

Chapter 3

3 METHODOLOGY

3.1 Introduction

This research work is carried out using two approaches;

i) Desk Study

ii) Field study

Each of these two approaches has its unique contribution to the success of research. The study methodology is summarized in Figure 3.1. Again, there are several methods and tools which can be used to carry out both the desk study and field work. Under desk study; Previous Studies, estimation of water loss, Calculation of Performance Indicators, review of existing network and current practices were done. Figure 3.2. shows field study which included house surveying programmes, field observations and field tests.

3.2 Development of Flow Chart of Research Methodology

The strategic approach was proposed after looking at what type of methodologies and techniques were applicable to the Panadura- Horana region and what were the constraints and limitations of applying these methodologies and techniques in field studies area. The study methodology is summarized in Figure 3.1.

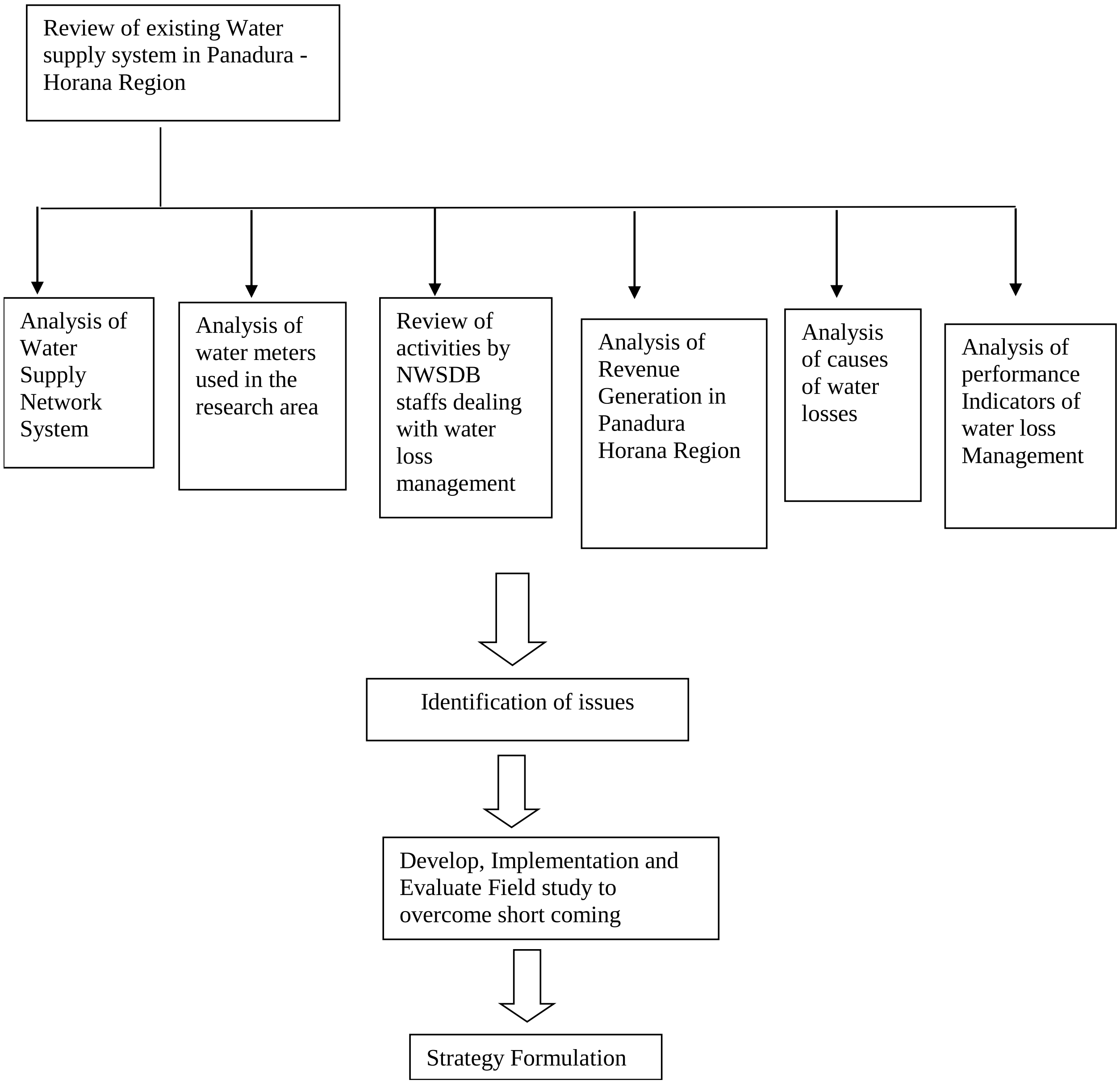


Figure 3.1 : Flow Chart of Research Methodology

3.3 Desk Study (Directly Involve)

The desk study involved reviews of previous studies, estimation of water losses and calculation of performance indicators. The 'best practices' carried out in these countries to manage water losses were used to formulate appropriate method to develop water loss management strategies for Panadura- Horana region.

3.3.1 Estimation of Water Loss (Directly Involve)

Water losses in the study area is analyzed with respect to monthly water production and consumption, by using IWA format which helps to understand and evaluate the water loss situation on water distribution network by component basis (billed, unbilled, metered, unmetered). This gave an indicator to the causes of water losses and enabled a categorization to be made of the factors having an impact on the water losses, leakages, bursts, water meters, ages of pipes and other local conditions.

NRW was calculated using the following equation:

Non-Revenue Water = System Input Volume – Revenue Water *…………equation 3.1*

Unbilled authorized consumption was calculated using the following assumptions;

Assumptions:

Usage from one stand post = 11 m^3/day

Usage from one bath tap = 28 m^3/day

(Source: Commercial Division)

Volume used for firefighting works not included since all the fire hydrants are inaccessible.

Only free water volume was calculated as follows:

Volume supplied by bowsers = V_B (taken from O&M division)

Hence consumption for 8 stands posts and zero common bath taps

= [(8x11) +(0x28)]x30 m^3/month

= 2,640 m^3/month

Total unbilled authorized volume = V_B + 2,640 m^3/month

………… equation 3.2

Then total authorized consumption could be calculated using the following equation:

Authorized Consumption = Billed Authorized Volume + Unbilled Authorized Volume

……………… equation 3.3

Finally, real losses were calculated using reported and repaired leaks.

$$Q = NQ_vT \qquad \text{…………......... equation 3.4}$$

Where; Q = Volume of the water lost

N = Number of reported bursts

Q_v = Average leak flow rate – taken as 60 m^3/h for main leaks and 30 m^3/h for minor leaks (according to the system Flow rate)

T = Time of water wasted

Using the above equation, Q was calculated for all the leakages

Then apparent losses could be calculated using the following equation:

Apparent Losses = NRW – (Unbilled Authorized Volume + Real Losses) …..equation 3.5

3.3.2 Calculation of Performance Indicators

Key performance indicators were calculated after assessment of water losses of the distribution system by the Unavoidable Annual Real Losses (UARL) and Infrastructure Leakage Index (ILI). This was done both at the Panadura- Horana region and pilot areas.

UARL was calculated using the following equation:

UARL = (18 Lm +0.8 Nc) x P ……………… *equation 3.6*

Where; UARL = Unavoidable Annual real Losses (Litters/ Day)

Lm = Length of mains (Km)

Nc = Number of service connections.

P = Average operating Pressure at average zone point(m)

ILI was calculated using the following equation:

ILI = CARL / UARL ………………*equation 3.7*

3.3.3 Review of Existing Net Work

Current network practices in selected area were reviewed to identify shortcomings to exist such a huge water loss of both the physical and operational characteristics. Then, sustainable management concept is developed to handle water losses.

3.4 Field Study

A field study was made to identify the methodology to reduce the NRW due to various factors. The field study was implemented in North Part of Panadura. The area map with natural boundaries is annexed as Annex I. The area was easily isolated with natural boundaries and flow meters were installed to measure inflow. This area is comprised of 6828 water connections and divided as six zones named as DMA1, DMA 2, DMA 3, DMA 4, DMA 5 and DMA6. The study was commenced with an assessment of initial NRW.

During the initial stage of this study, all the study teams were well educated about the survey. Further, the staff members in the area office including meter readers were also made aware of the survey, to avoid any unpleasant instances. Officers of these gangs always discussed problems with meter readers and their support was obtained resolving the problems especially in house closed situation.

Figure 3.2 is a flow chart showing the implementation plan in field study area.

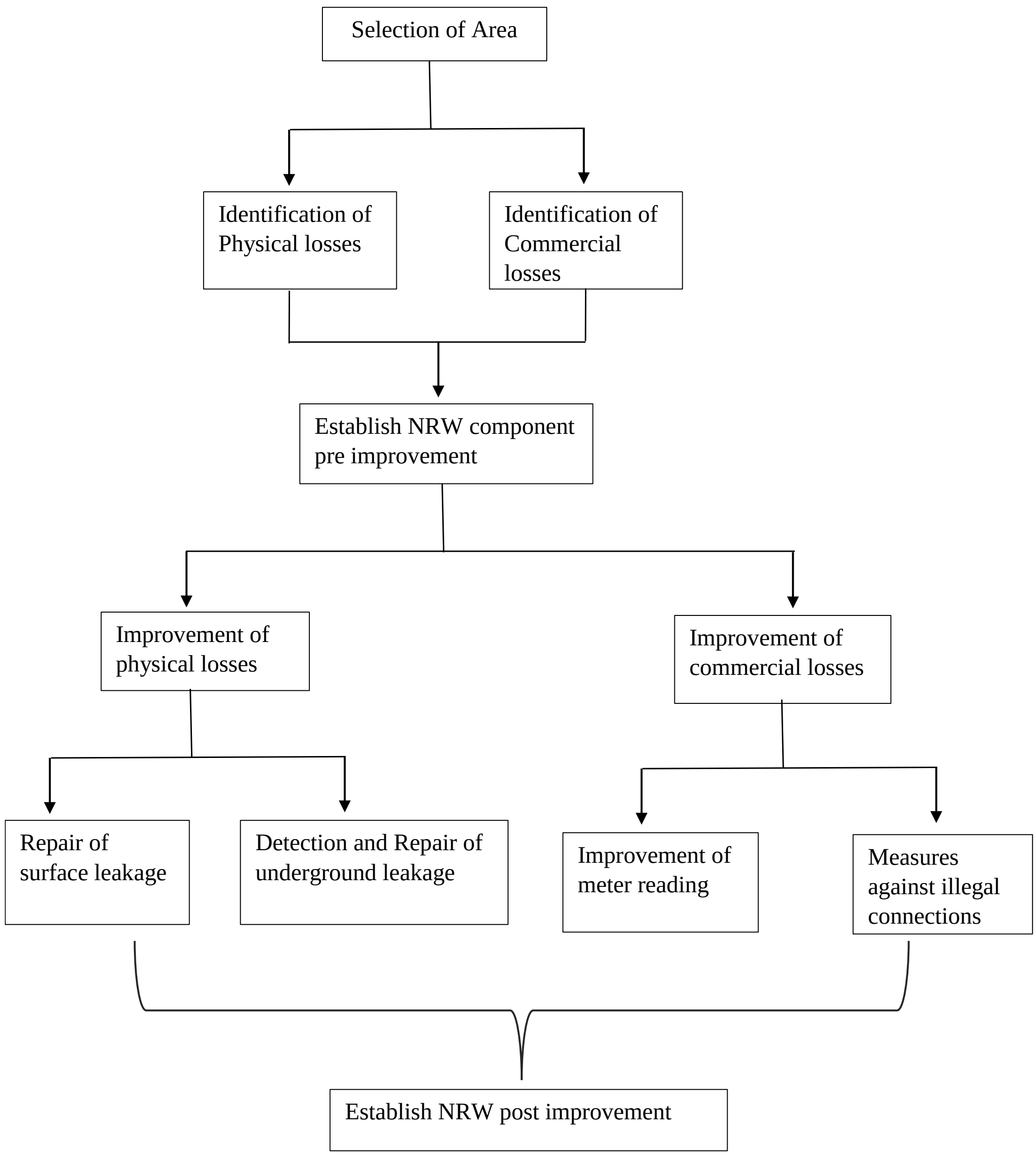


Figure 3.2 : Flow chart for Field study

Chapter 4

4 DATA COLLECTION

4.1 Introduction

This chapter deal with data collection. The raw data was analyzed to reflect the progress of field study and appropriately developed methodology was adopted to achieve the research objectives. The analysis was mostly of quantitative nature with the use of excel spread sheets to calculate performance indicators such as UARL and ILI.

4.2 Method of Data Collection

At present mainly the following three sections of the NWS&DB deal with water loss management of the study area to achieve different scopes in different scales. However, none of these sections have been successful in water loss management effectively or to achieve their targets. This is mainly due to lack of resources. They rather manage day to day activities for survival.

- Panadura – Horana operational and maintenance (O&M) section deals with the maintenance of distribution network and water balance
- Commercial section in Western -South office deals with all commercial and consumer related activities.
- NRW management division is responsible for prevention of illegal connections and free water supply.

Accordingly, data was collected as mentioned in the Table 4.1.

Table 4.1 : Type and Method of Data Collation

Information Required	Core source
Water Production Consumption Details	NRW Section of NWS&DB
Digital Drawings and Pipe Lengths	Mapping Division of NWS&DB
Consumption Data	Commercial Division of
Number off Service Connections, Customer Meter	O&M Section (P-H), NWSDB
Frequency of Bursts, Leakages and Repair Programme , Average Pressures	O&M Section (P-H), NWSDB
Current Practices (Staffing structure, Staff numbers and skills) equipment and techniques	Western -South Region of NWS&DB

Digital drawings and mapping lengths details were collected from Mapping division, NWS&DB. The detail of pipe network was compiled in ARC GIS as shown in Figure 4.1. After that ARC GIS details was converted to excel spread sheet which was used for the analysis.

Details of Consumption Data, Number of Service Connections, Frequency of Bursts and Leakages were compiled in Management Information System (MIS), NWS&DB as shown in the Figure 4.3. However, each detail is handled by different section as shown in Table 4.1. All details were converted to excel spread sheet which was used for the analysis.

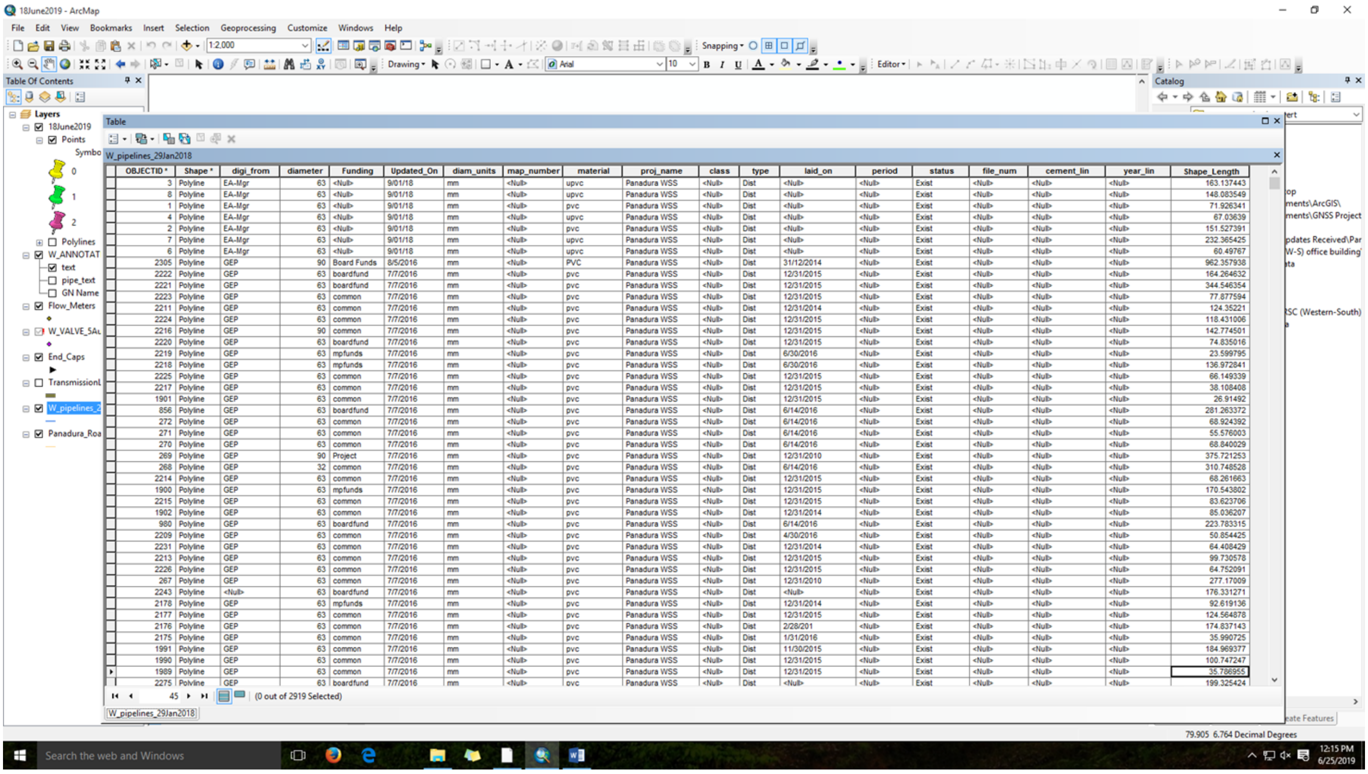
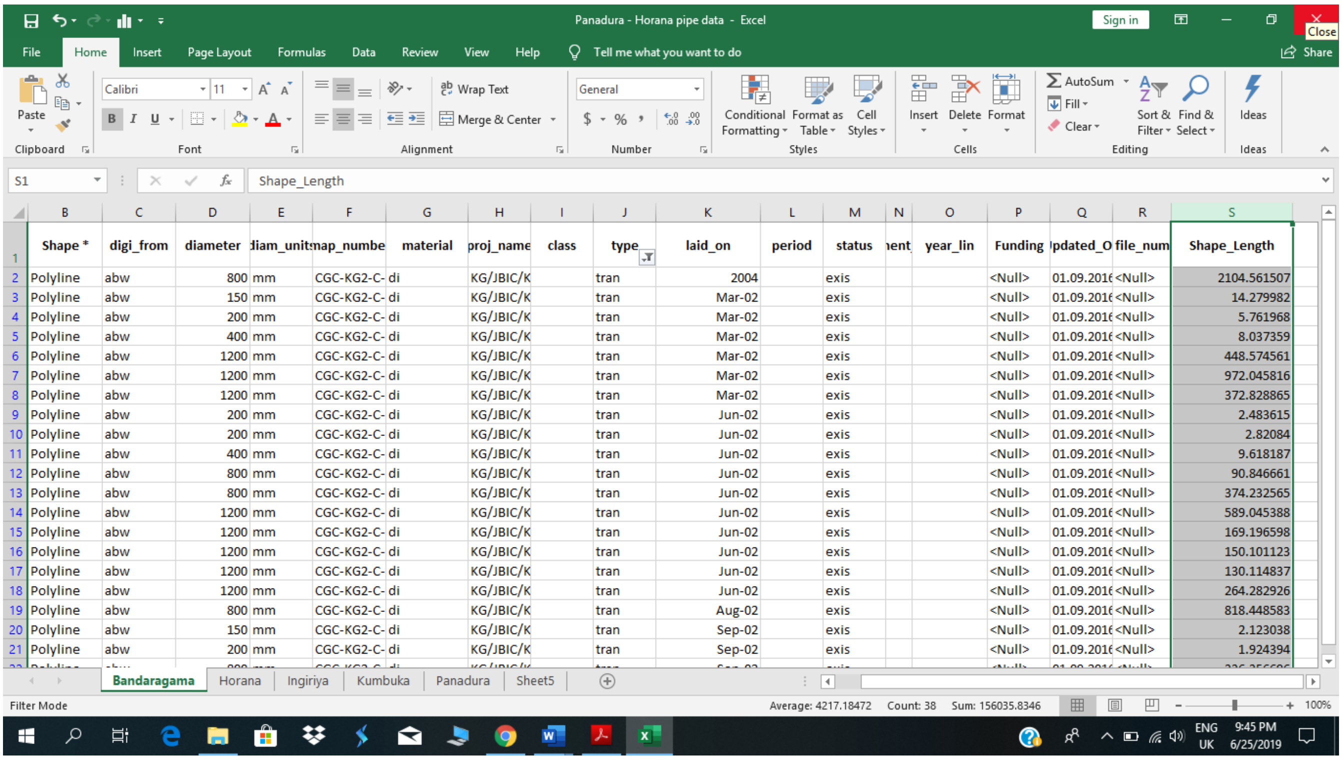


Figure 4.1 : Pipe Network details in Arc GIS



	Shape *	digi_from	diameter	diam_unit	map_numbe	material	proj_name	class	type	laid_on	period	status	ient	year_lin	Funding	pdated_O	file_num	Shape_Length
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3	Polyline	abw	150	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Mar-02		exis			<Null>	01.09.201(	<Null>	14.279982
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6	Polyline	abw	1200	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Mar-02		exis			<Null>	01.09.201(	<Null>	448.574561
7	Polyline	abw	1200	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Mar-02		exis			<Null>	01.09.201(	<Null>	972.045816
8	Polyline	abw	1200	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Mar-02		exis			<Null>	01.09.201(	<Null>	372.828865
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11	Polyline	abw	400	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Jun-02		exis			<Null>	01.09.201(	<Null>	9.618187
12	Polyline	abw	800	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Jun-02		exis			<Null>	01.09.201(	<Null>	90.846661
13	Polyline	abw	800	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Jun-02		exis			<Null>	01.09.201(	<Null>	374.232565
14	Polyline	abw	1200	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Jun-02		exis			<Null>	01.09.201(	<Null>	589.045388
15	Polyline	abw	1200	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Jun-02		exis			<Null>	01.09.201(	<Null>	169.196598
16	Polyline	abw	1200	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Jun-02		exis			<Null>	01.09.201(	<Null>	150.101123
17	Polyline	abw	1200	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Jun-02		exis			<Null>	01.09.201(	<Null>	130.114837
18	Polyline	abw	1200	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Jun-02		exis			<Null>	01.09.201(	<Null>	264.282926
19	Polyline	abw	800	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Aug-02		exis			<Null>	01.09.201(	<Null>	818.448583
20	Polyline	abw	150	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Sep-02		exis			<Null>	01.09.201(	<Null>	2.123038
21	Polyline	abw	200	mm	CGC-KG2-C-	di	KG/JBIC/K		tran	Sep-02		exis			<Null>	01.09.201(	<Null>	1.924394

Figure 4.2 : Pipe Network details in Excel sheet

Figure 4.3 : Details of MIS

Chapter 5

5 DATA ANALYSIS AND RESULTS

5.1 Introduction

This chapter deals with analyses of the data collected from Panadura – Horana water distribution system and field studies. The data collected from the distribution system include composition of pipe network, DMAs, status of pipes, distribution system pressure and quantification of water inflows, revenue generation analysis, consumer complaints analysis and impact of illegal consumption, and free water supply etc.

5.2 Analysis of Panadura -Horana Water Supply System

The source of Panadura – Horana water supply system is Kandana-Kalu Ganga Water Treatment Plant. First the water from the treatment plant is collected into the Horana high level reservoir. Part of this water is pumped to an elevated reservoirs from where it is distributed to the region while the other part is directly distributed in the region. This section presents the analyses carried out on collected data of water pipes and accessories, frequent bursts and leakages of pipes, system pressure, bulk and domestic water management, NRW and water balance.

5.2.1 Water pipes and Accessories

The analysis of data shown in Figure 5.1, The Panadura- Horana region pipe network consists of approximately 38 km of transmission mains and about 1191 km of distribution mains. Most of the pipes in the network comprise of DI Pipes and uPVC Pipes in transmission main and distribution main respectively.

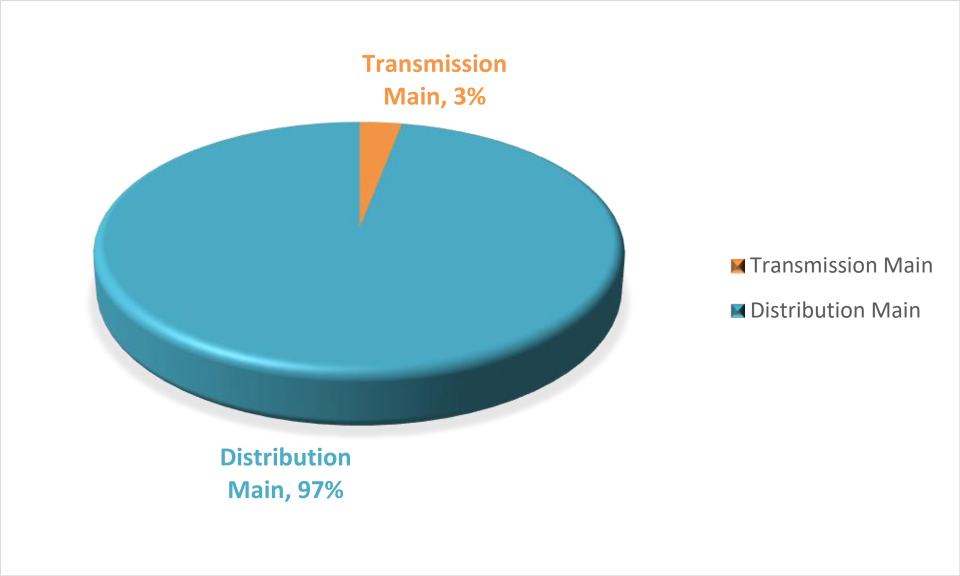

Figure 5.1 : Pipe Network by percentage

As per report published by Management Information System (MIS) of National Water Supply and Drainage Board of Sri Lanka for March 2019 Panadura –Horana region, there are 86,434 Service connections including bulk connections, stand post and Institutes etc. Length of service connections is estimate as approximately 250 km.

The network consists of different kinds and age group pipes as mixture of Cast Iron (CI), Ductile Iron (DI), Un-Plasticized Poly Vinyl Chloride (uPVC) and Asbestos Cement (AC), All new pipe extensions are mainly in uPVC and DI. Figure 5.2 shows the different proportions of each pipe material makes up in the Panadura- Horana water supply system.

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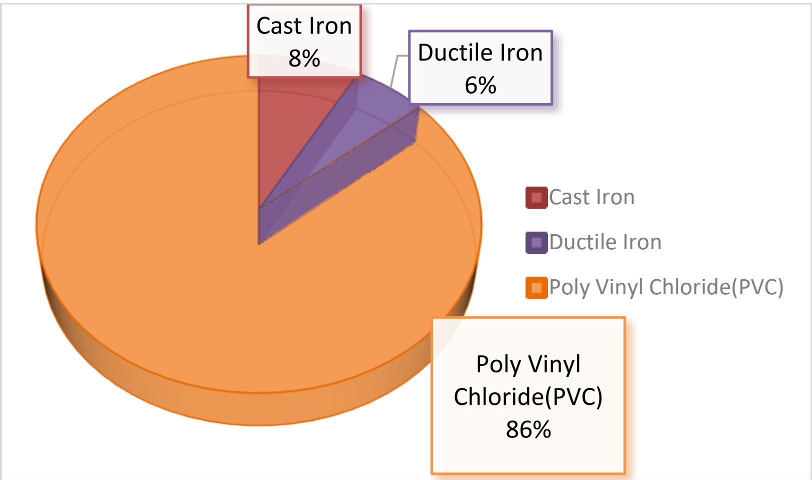

Figure 5.2: Pipe Material Composition by Percentage

Accordingly, most of the pipelines in Panadura- Horana water supply system are the uPVC i.e. 86%.

Percentages of the different pipes types (CI, PVC and DI) categorized on diameter is shown in Figures 5.3, 5.4 and 5.5.

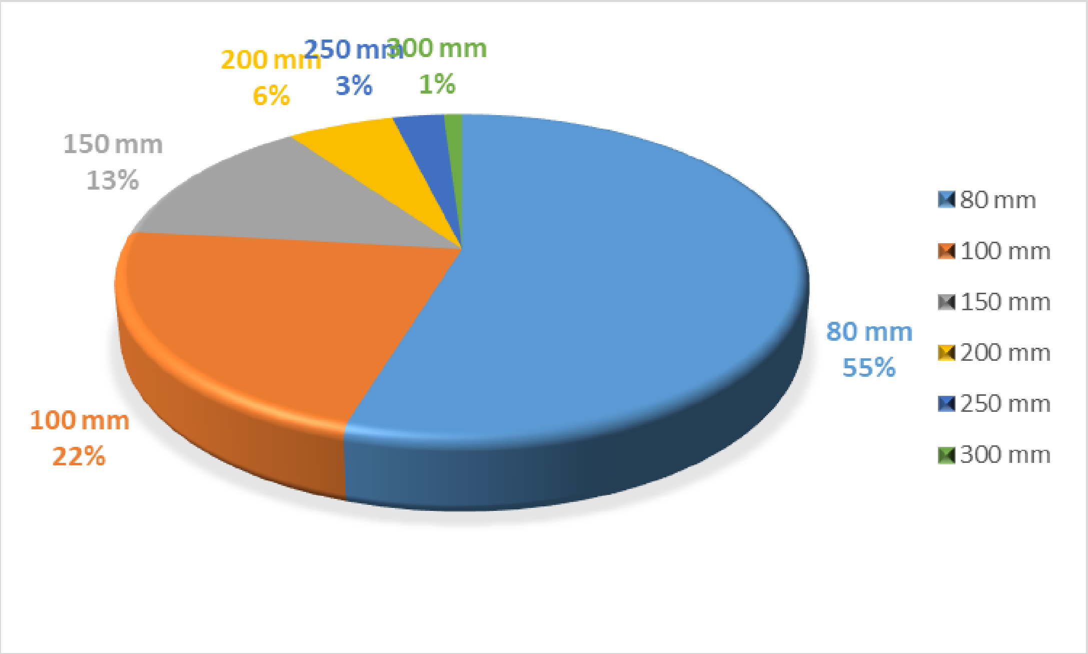

Figure 5.3 : Percentage of diameters of CI pipes

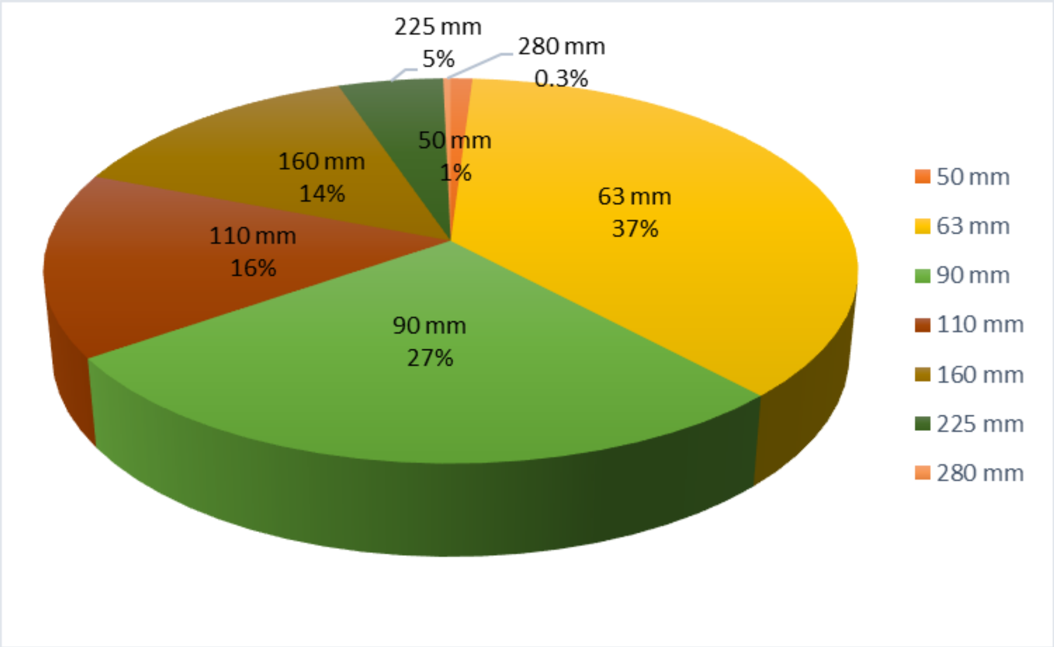

Figure 5.4 : Percentage of diameters of PVC pipes

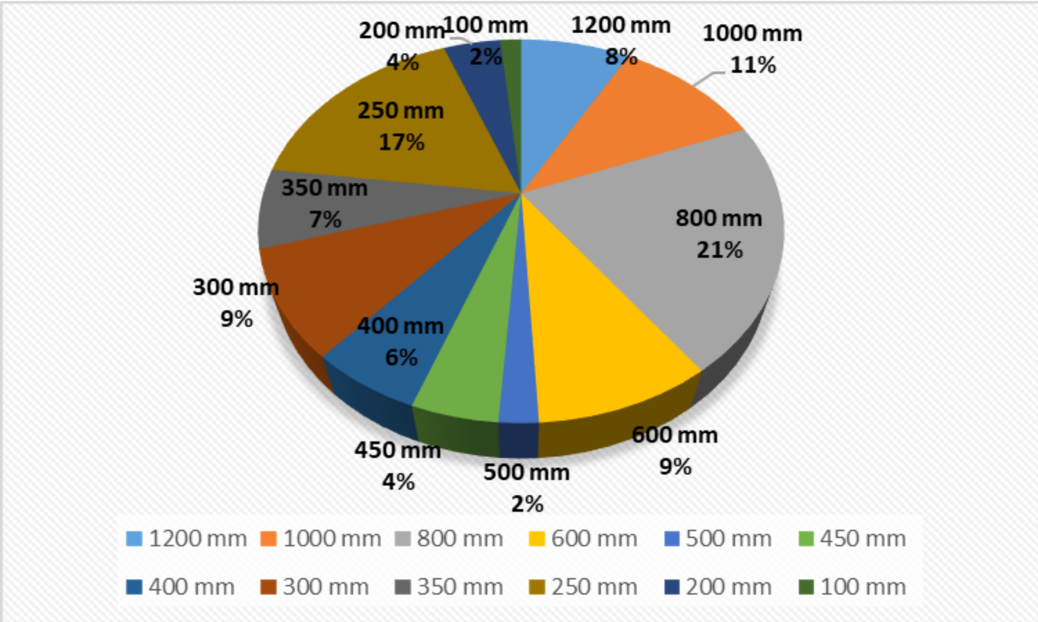

Figure 5.5 : Percentage of diameters of DI pipes

In the Panadura-Horana region, water supply system consists of 1760 sluice valves but most of the valves are buried and are not in operational status. There are also 101 fire hydrants spread in the distribution system. Fire hydrants act as air releasing points in the distribution system in addition to catering for the fire demand. However, these need periodical operations and maintenance to meet system requirements. Due to lack of resources, most of the valves are not functioning properly.

5.2.2 Frequent Bursts and Leakages in Pipes

An attempt was made to estimate frequent bursts and leakages in pipes. From the data available at MIS from Oct-2018 to Mar-2019, the pipe bursts and leakages were estimated. Table 5.1 shows the estimated pipe bursts and leakages per km according to the material composition.

Table 5.1 : Number of Pipe leaks per km in Panadura – Horana area - material wise

Type	Month											
	Oct-18		Nov-18		Dec-18		Jan-19		Feb-19		Mar-19	
	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km
PVC	248	0.22	233	0.21	238	0.21	200	0.18	197	0.18	164	0.15
CI	65	1.45	65	1.45	63	1.41	49	1.10	50	1.12	50	1.12
DI	10	0.14	8	0.11	13	0.18	14	0.20	12	0.17	12	0.17

The magnitude of leakages diameter wise and classified as major and minor are illustrated in Figure 5.6. Major leaks are leakages appeared in pipes of diameter larger than 90 mm and minor leaks are leakages appeared in pipes of diameter equal or less than 90 mm.

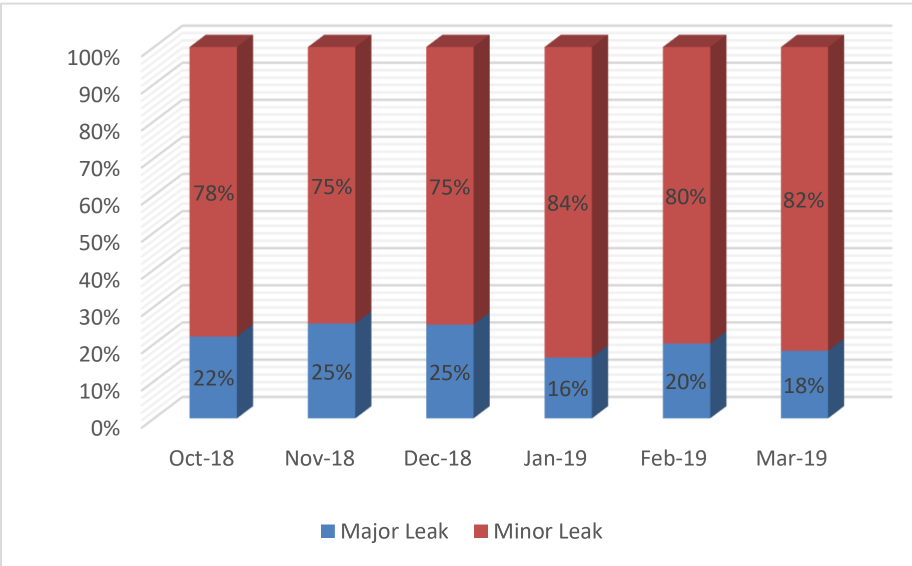

Figure 5.6 : Major and minor pipe leaks

Analysis of the above major and minor leaks according to the pipe material composition is illustrated in Table 5.2 and 5.3.

Table 5.2 : Major Leaks per km on material composition

Type	Month											
	Oct-18		Nov-18		Dec-18		Jan-19		Feb-19		Mar-19	
	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km
PVC	21	0.02	27	0.02	28	0.03	13	0.01	17	0.02	11	0.01
CI	46	1.03	48	1.07	43	0.96	26	0.58	32	0.72	29	0.65
DI	4	0.06	3	0.04	8	0.11	4	0.06	3	0.04	1	0.01

Table 5.3 : Minor Leaks per km on material composition

Type	Month											
	Oct-18		Nov-18		Dec-18		Jan-19		Feb-19		Mar-19	
	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km	Nr	No of leaks / km
PVC	227	0.20	201	0.18	228	0.20	183	0.16	174	0.16	170	0.15
CI	25	0.56	27	0.60	7	0.16	37	0.83	33	0.74	15	0.34

According to the analysis mentioned in table 5.2 &3, majority of major and minor leakages appear in CI pipe. Therefore, CI pipes are more hazardous. As per the table 5.1, leakages on CI pipe in total distribution system was appeared with the monthly average of 1.275 leaks/km.

5.2.3 System Pressure

The water pressure depends on the level of reservoir location. Reservoir that feed Panadura - Horana water supply system is situated around 60 – 65 meters above Mean Sea Level. Average level of the Panadura- Horana area is 10 m. However, during the daytime, significant pressure fluctuation exists in the distribution system. Yet, no pressure management system is functioning in the Panadura - Horana water supply system at present other than the periodical valve operations to feed low pressure areas. Panadura – Horana region was divided into five section for checking the pressure as shown in Table 5.4. In the Panadura field study area some time pressure went to 0 m in daytime.

Table 5.4 : System Pressures in the Five Areas

Area	Horana	Ingiriya	Bandaragama	Panadura	Kumbuka
Pressure range	5m – 32m	5m -20m	10m- 35m	0m -23m	10m -30m

5.2.4 Bulk and Domestic Water Management

Accuracy of entire operation specially the water loss management mainly depends on readings of bulk and domestic meters. As a policy most of the water authorities have installed high accuracy meters for the bulk readings and less accurate meters for domestic meters because of the meter cost. In Panadura- Horana region Ultrasonic meters which can produce high accurate reading are installed to measure inflows of reservoir from treatment plant. But Turbine type meters, which provides readings with less accuracy, are still being used for measuring bulk consumptions.

Most of the income is generated from domestic consumptions. It is clearly shown in Table 5.5 that 93% of income generated by the less than 75% of domestic connections. Presently cost of producing one unit (one m^3) of treated water to NWS&DB is Rs.75.00, while tariff for domestic consumers progressively vary from Rs. 5.00 to 140.00 per m^3 depending on consumption. Tariff for commercial institutions, Government institution and industries export processing zone of the Board of Investment are Rs. 75.00, Rs.58.00 and Rs. 61.00 per m^3 respectively. High income is generated from domestic and commercial connection. Hence close monitoring should be carried out on the high consume commercial and domestic consumers by fixing high accuracy meters. Current tariff structure of NWS&DB is given in Annex II.

Table 5.5 : Impact of Average Monthly Consumption with Income Generation in Different categories of Consumers in Panadura – Horana region in month of 2019 March

Customer Category	No of Connections	Consumption(m^3)	Revenue SLRs.	Consumption per connection	% of Income	% of Connections
Domestic	80,605	1,244,599	44,418,789.24	15.44	73.00	93.31
Schools	119	21,446	426,690.17	180.22	0.70	0.14
Govt Institution	296	32,514	2,094,664.20	109.84	3.45	0.34
Commercial Institutes	4,902	124,348	11,433,869.41	25.37	18.81	5.68
Indust/Construt	29	29,766	1,889,217.67	1,026.41	3.10	0.03
Religious	289	16,302	361,308.10	56.41	0.60	0.33
Bulk (C.B.O.)	31	10,634	154,925.50	343.03	0.25	0.04

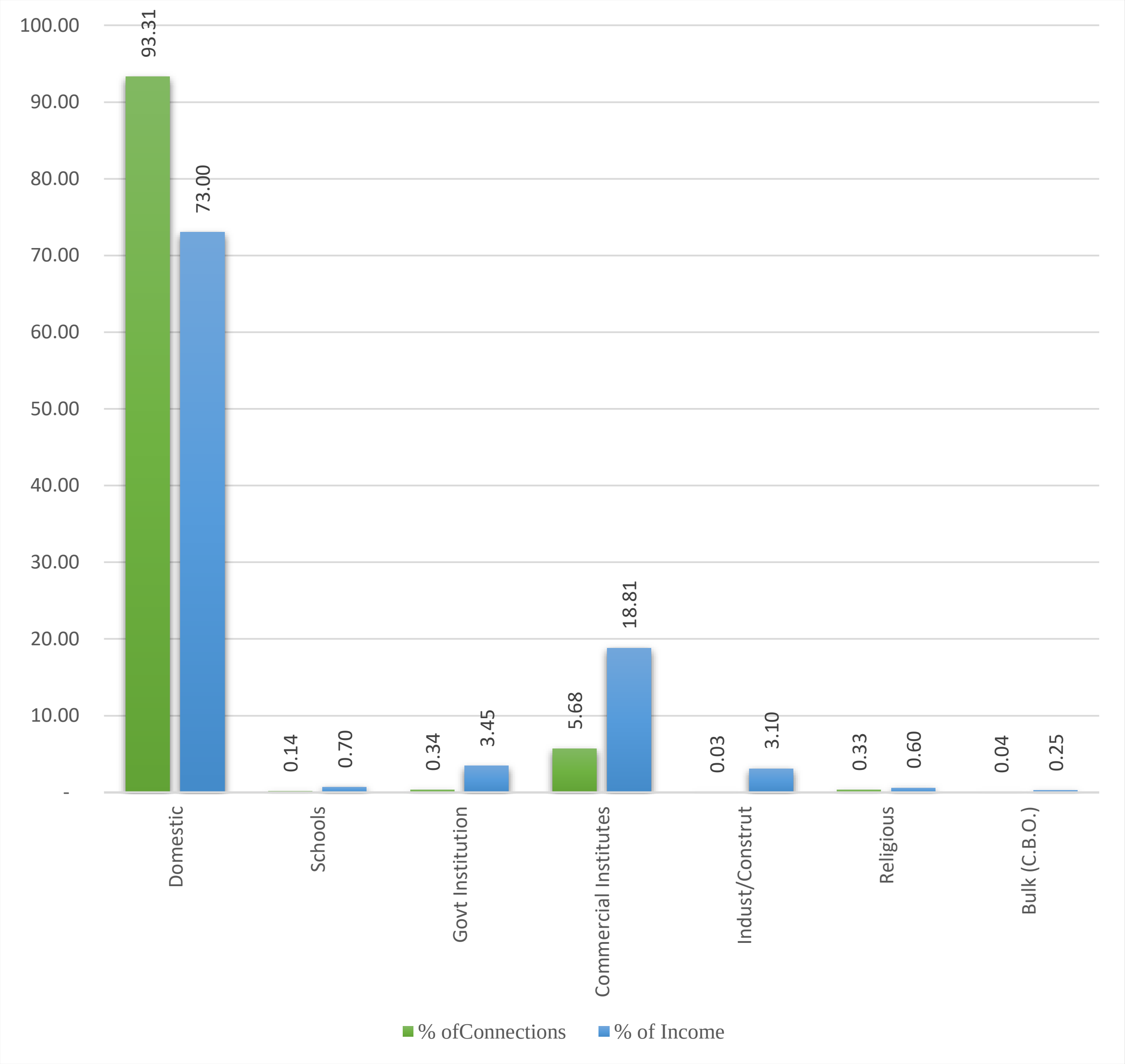

Figure 5.7: % of Connections Vs % of Income in Each category in Panadura – Horana region in month of 2019 March

Figure 5.7 shows on one hand, that the percentage of income generated from the domestic category is less than the percentage of connections. On the other hand percentage of income generated from commercial category is more than the percentage of commercial connections. Therefore, more attention should be paid to the commercial category with good monitoring as the stability of the income depends on them.

5.2.5 Statistics and status of Domestic Meters

In 1982 turbine type water meters had been introduced to measures domestic consumption. Nowadays they are replaced with volumetric type meters due to their better accuracy. In March

2019 Panadura- Horana region distribution system, which consisted of 86,434 individual connections and those were metered connection. In some special situations such as the presence of air, silt and sand, debris etc., these meters are not suited. As a result, in the year 2018, more than 0.2% of meters have become defective and considerable amount of fund was needed to replace the same. Yearly progress of estimated bills and defective meters are tabulated in Table 5.6 and Figure 5.8

Table 5.6: Percentage of Estimated Bills and Defective Meters in Panadura- Horana region

Category	Year			
	2015	2016	2017	2018
Estimated Bill %	0.16	0.2	0.51	0.2
Defective Meter %	0.11	0.28	0.21	0.20

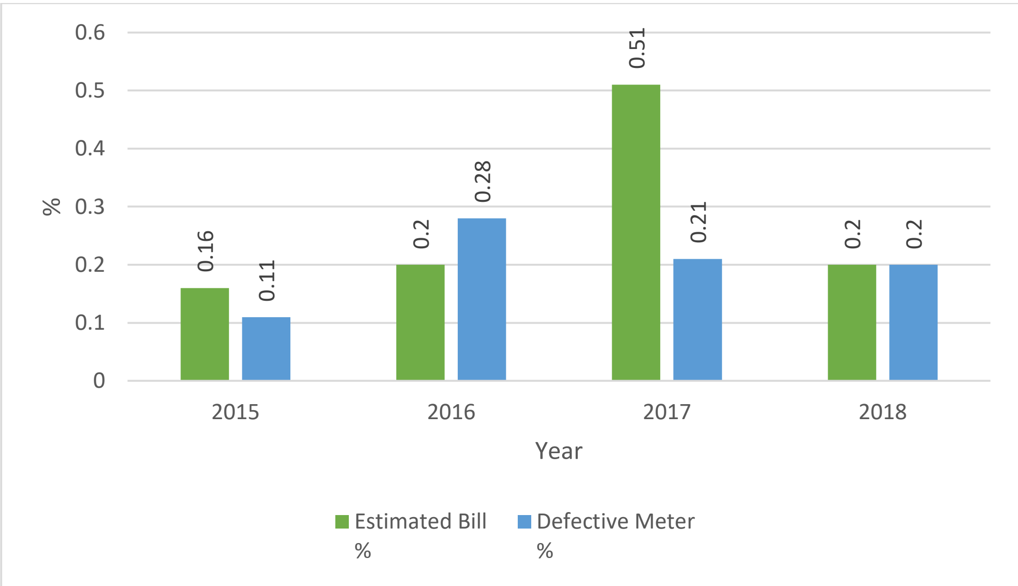

Figure 5.8 : Estimated bill and Defective Meter Percentages in Panadura -Horana region.

According to the Table 5.6, percentage of estimated bill was increased from 2015 to 2017 , then it was reduced in 2018. Percentage of defective meter was decreased from 2016 to 2018.
The main problems identified in domestic Metering in Panadura- Horana region as per the records in O&M section.

- Frequent Meter defects
- Absence of a meter replacement Policy

- Meters used are not suitable to the system requirements in special events such as air, debris and sand etc. in water.

Normally defective meters contribute to a considerable amount of NRW as once consumers get aware about their defective meters, they use water freely and result in high wastage while paying a low monthly bill. However, it is difficult to measure the quantity of consumption because once a defective meter is replaced, consumer usage becomes normal.

Meter replacement is carried out only when a meter is damaged, stolen, defective or faulty. At present there is no proper meter replacement policy in the NWS&DB.

5.3 NRW in Panadura – Horana region and Water Balance

NRW in Panadura- Horana region from 2014 to 2018 is mentioned in Table 5.7.

Table 5.7 : Non-Revenue Water in Panadura Horana region from 2014 to 2018

Year	2014	2015	2016	2017	2018
NRW%	27.21	23.27	21.36	31.86	31.00

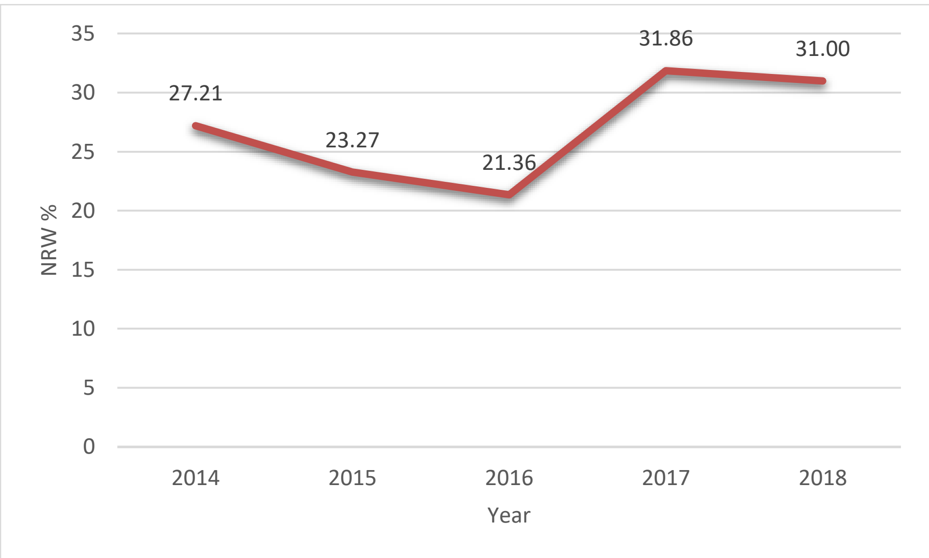

Figure 5.9 : Non-revenue Water in Panadura Horana region from 2014 to 2018

By reviewing NRW in Panadura -Horana region, it was observed that percentage of NRW decrease from 27% to 21% for the period from 2014 to 2016. Then it was increased by 10% in 2017 and 2018 as shown Table 5.7. The difference in the percentage of NRW between 2016 and 2017 is unpredictable.

The above NRW figure are based on the system input volume and the billed authorized consumption over the period of 2014 to 2018 and expressed as a percentage. Accordingly, it was noted that NRW percentage has increased 21.0 to 31.0 during the period October 2018 to March 2019. The major contributory factors for the high amount of NRW might be system leakages, illegal connections, administrative losses and flow meter error.

Due to high NRW in 2017 and 2018, research was initiated to find out the reason for this deviation. For that, out flow meter of Ellakanda reservoir was checked with Ultrasonic Flow meter. This detail is illustrated in the Figure 5.10.

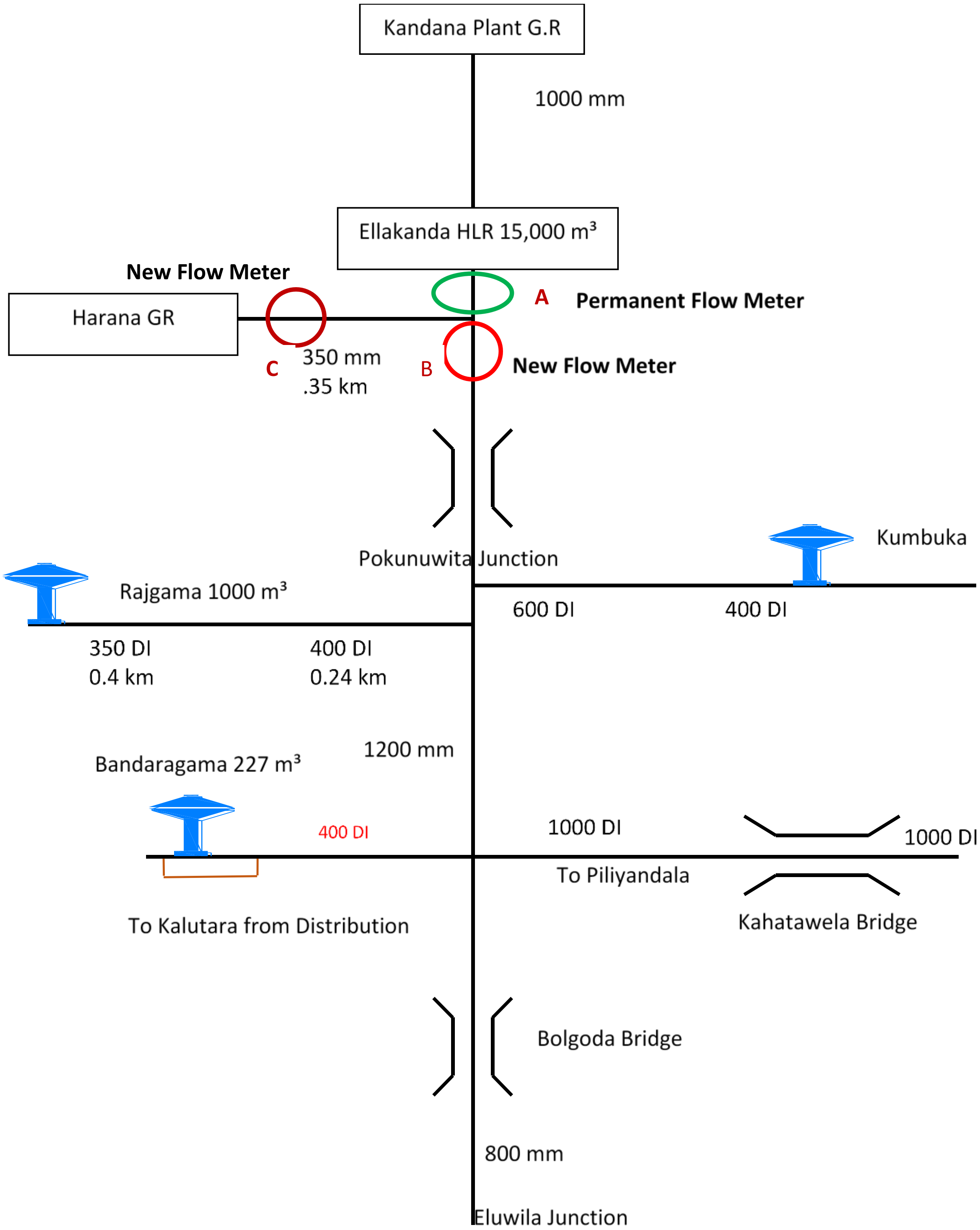

Figure 5.10 : Network diagram for Panadura- Horana water supply system

In the above network diagram, "A" is existing flow meter and "B" and "C" are newly installed Ultrasonic Flow meter. Readings of "A", "B" & "C" flow meters were recorded in two times. Table 5.8 shows the variation of existing flow meter.

Table 5.8 : Comparison of existing and new flow meter at Ellakanda Reservoir

No	Location of Flow meter	1st time		2nd Time	
		Flow Rate		Flow Rate	
		m^3/day	m^3/hr	m^3/day	m^3/hr
1	**Ellakanda Reservoir Out Flow-Permanent meter (A)**	137,396.6	5,724.9	137,356.8	5,723.2
2	Ellakanda HLR outflow NRW (Portable)meter (After Horana Ground sump supply) (B)	117,229.4	4,884.6	117,621.6	4,900.9
3	Horana Ground Sump inflow (C)	9,257.2	385.7	9,360.0	390.0
4	**Total HLR Out flows (2+3)**	126,582.6	5,274.3	126,981.6	5,290.9
5	Difference (1-4)	10,813.9	450.6	10,375.2	432.3
6	**% Variation with permanent meter**	7.9%		7.6 %	
7	**% of Average Variation**	7.8 %			

According to Table 5.8, variation of flow between the portable meter and the existing permanent meter is 7.8%. It reveals that there was an error in existing flow meter “A”. Thereafter, Flow meters “B” and “C” are considering for NRW calculation.

Then, NRW percentage in Panadura – Horana area is gradually reduced as shown in Table 5.9. In the Table 5.9, monthly consumption data was obtained from computerized billing system and flow measurement was calculated from Ellakanda reservoir out flow meter. But this study was not considering the any losses between Kandana Treatment Plant to Ellakanda reservoir. During this research period, NRW was reduced by 7 %.

Table 5.9 : Non-Revenue Water for month of February 2019

Supply Quantity (m^3)	2,060,724
Billed Authorized Consumption (m^3)	1,570,724
NRW volume (m^3)	490,000
NRW (%)	23.8%

5.3.1 Water Balance

Practicing of the IWA format for water balance analysis is the first step in getting started with a water loss reduction programme. Knowing the various components of consumption and losses will give an idea of where the losses are occurring and at what magnitude. This will help to identify key resulted areas with priority order to give more weightage to reduce water losses. Reduction of real losses is very important. Because real losses leads weightage to wastage of water as well as money.

5.3.1.1 Calculation of Real losses

Calculation of distribution losses due to reported leaks

Total Volume of Leakage from mains = Number of reported bursts x Average leak flow rate x Average Duration

Number of reported main bursts in month of February = 52

Average leak flow rate for main burst = 60 m^3/h

Average leak Duration for main burst = 48 hr

Number of reported minor bursts in month of February = 207

Average leak flow rate for minor bursts = 30 m^3/h

Average leak Duration for minor bursts = 24 hr

Total volume of leakage from mains =(52 x60 x48) +(207x 30x 24)

= 298,800 m^3

Real losses % due to reported leaks in distribution = 298,800 / 2,060,724

=14.5 %

Calculation of Background Losses

Length of mains = 1229 km

Average operating pressure = 10 meters

No of service connection = 86434

Total length of service connection = 250 km

Table 5.10 : Background losses for month of February 2019

Infrastructure component	Background Leakage	Unit	Total Background losses m^3/Month
Mains	9.6	Liters per km of mains per day per meter of pressure	3,539.52
Service connection - Main to property	0.6	Liters per service connection per day per meter of pressure	15,558.12
Service Connection - property boundary to customer meter	16	Liters per km of service connection per day per meter of pressure	1,200
Total Background leakage (m^3 per month)			20,297.64
NRW % due to Background losses			0.98%

Calculation of Transmission losses

Table 5.11 : Transmission losses for month of February 2019

Row No	**Location of Flow meter**	**Flow rate (m3/h)**
Outflows		
1	Total Outflow = Ellakanda HLR outflow	4884.6
Inflows		
2	Kumbuka Tower	220
3	Raigama Tower	94
4	Bandaragama Tower	354
5	Kesbewa Supply	2064
6	Panadura Supply through Bolgoda Bridge	2102.7
7	Total Inflows = Row (2+3+4+5+6)	4834.7
8	Difference between outflow and inflow = Row (1-7)	49.9
9	Transmission losses (NRW %)	1.02%

Total Real losses = Transmission loss + Background Loss + losses from leaks

= 1.02 + 0.98 +14.5

= 16.5 %

The components of the water balance for Panadura – Horana region water supply system in 2019 February (Water volume in m^3 / month) are illustrated in Table 5.12.

Table 5.12 : Water Balance Panadura – Horana region for the month February 2019

<table>
<tr><td rowspan="4">System Input Volume
2,060,724 m^3
100 %</td><td rowspan="2">Authorized consumption
1,581,080 m^3
76.72 %</td><td>Billed authorized Consumption
1,570,724m^3
76.22 %</td><td>Revenue Water
1,570,724, m^3
76.22 %</td></tr>
<tr><td>Unbilled Authorized Consumption
10,356m^3
0.5 %</td><td rowspan="3">Non - Revenue Water (NRW)
490,000 m^3
23.8 %</td></tr>
<tr><td rowspan="2">Water Losses
479,644 m^3
23.3%</td><td>Apparent Losses
139,624.54m^3
6.8 %</td></tr>
<tr><td>Real losses
340,019.46m^3
16.5%</td></tr>
</table>

Non-revenue water in Panadura – Horana area water supply systems makes up 23.8% of system input volume and stands for 490,000 m^3/month

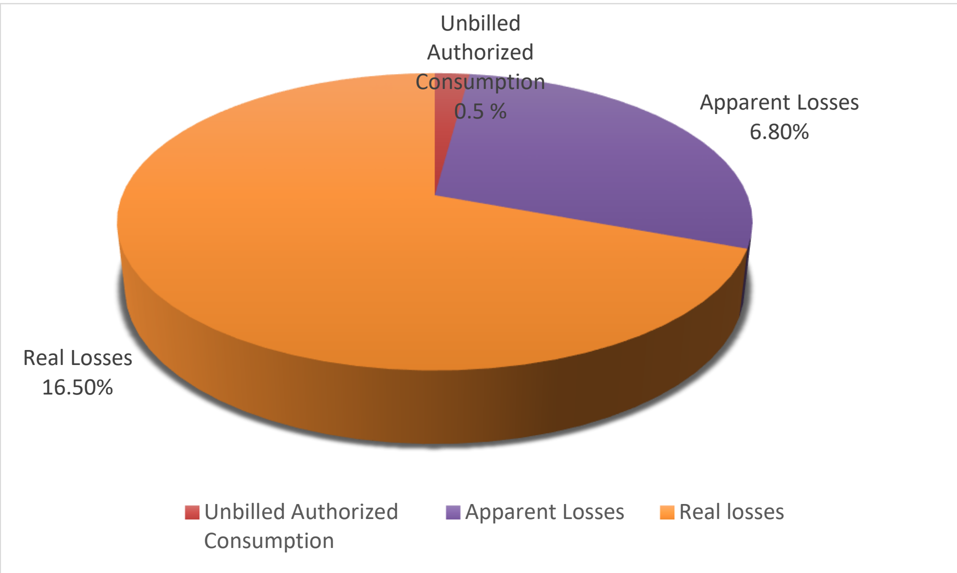

Figure 5.11 : Composition of Non- Revenue water in Panadura – Horana region

5.4 Unavoidable Real Losses and Infrastructure Leakage Index

The Unavoidable Real Losses (UARL)and Infrastructure Leakage Index(ILI) for the Panadura- Horana water supply system are calculated in order to assess the operational performance of the distribution system and to gauge how well the water loss reduction programmes put in place and working. It also enables making comparisons with other international utilities. The calculations are based on the theory outlined in section 3.3.3.

In Panadura Horana region length of most the connection are less than 10m. Hence equation 3.6 can be used to calculate UARL

UARL = (18 Lm +0.8 Nc) x P ……………. from equation No 3.6

The Parameters are:

UARL (liter / day)

Lm = Length of mains (km) = 1229

P = Average operating pressure when system is pressurized = 10 meters

Nc = No of house connections = 86,434

UARL = (18 x 1229 + 0.8 x 86,434) 10

= 912, 692 liter /day

= 912, 692 x 30

= 27,380,760 liter / month = 27,380.76 m^3/ month

System data is summarized and presents in Table 5.13 with the UARL, CARL and ILI in Panadura – Horana region.

Table 5.13 : Present summarizes of system data and presents the UARL, CARL and ILI in Panadura – Horana region

Input Description	**Unit**	**Actual Data**
Length of mains (Transmission + Distribution) (Lm)	km	1229
Length of Mains (Service) Lp	km	250
Number of Service Connections (per km of mains)	Numbers	86,434
Density of service connections (per km of mains) (Nc/Lm)	per km	70.33
Average operating pressure when system pressurized (P)	meters	10
Current Annual Real Loss (CARL)	m^3/ month	340,019.46
UARL	m^3/ month	27,380.76
ILI		12.4

From table 5.12, the CARL is approximately 340,019.46 m^3 / month. This is approximately 16.5% of the system input. This is significantly high compared to corresponding CARL in cities of developed countries (refer chapter II). With the system input of 2,060,724 m^3/ month and NRW of approximately 490,000 m^3 in month of February 2019, the UARL is approximately 27,380.76 m^3/ month.

It was noted that the average system pressures vary from 0 to 35 m in the Panadura – Horana region. This ILI index only indicates the average picture of the entire distribution system. In order to assess the branches and to get the correct picture, ILI was calculated according to the system pressure as shown in Figure 5.12.

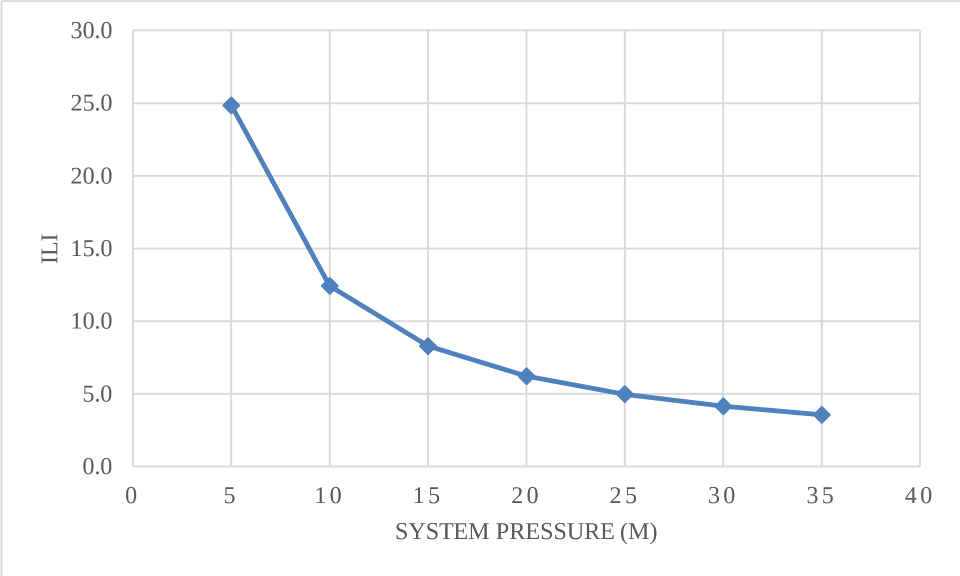

Figure 5.12 : Relationship between ILI Vs Distribution pressures in Panadura – Horana region

The ILI was calculated from equation 3.7 in section 3.3.3. Panadura -Horan region ILI was estimated to be 12.4 at the average pressure of 10 m. This is very high compared to the developed countries. According to IWA, the ILI is an indicator for the status of the distribution system and how well the utility is managing its real losses; it is quite evident that Panadura Horana water supply system is performing poorly in this aspect.

5.5 Field test and Surveys

To identify the appropriate methodology, field studies were carried out by adopting different appropriate strategies on trial and error basis. Field tests and Surveys carried out aimed at identification and finding remedial measures with assessment of impact to NRW due to illegal connections, defective meters, unmetered connections, house closed, meter reading audit, service leaks, road leaks, night visible leaks etc.

Pressure control an internationally accepted method was technically feasible to reduce water loss due to prevailing low-pressure situation. Hence studies were commenced by adopting part to whole method of water loss management. Along with the field study of the distribution system of study area, a list of consumers was obtained with available details. It included batch vise data road by road. Initially road vise house to house survey was carried out to the identification of all possible means for NRW and provided remedial actions accordingly and simultaneously. Format was developed to carryout survey is in Annex III.

5.5.1 Analysis of Distribution System in field study area

The pipe network consists of approximately 6.0 km of transmission mains and 57.2 km of distribution mains. This network in this area consists of 5.0 km of DI and 58.2 km of uPVC pipes.

There are 6828 service connections. Length of service connections is estimate as approximately 20 km. The pipe composition is tabulated in Table 5.14.

Table 5.14: Length and percentage of pipe composition in field study area

Type of Pipes	Length(km)	Percentage
PVC	58.2	92%
DI	5	8%

5.5.2 Step Testing

Once the DMA has been created then it is prudent to carry out the zero-pressure test (PZT) first. The procedure of this zero pressure test method is obviously performed by isolating the incoming flow into given area with all identified boundary valves in the closed position whilst monitoring the Reduction in pressure falls to zero. If this pressure falls to zero then it indicates and is evident that no other inflow occur into the DMA area. If the system is not reaching zero pressure then the procedure described in the IWA guideline for DMAs shall be followed to investigate inflow points to the DMA.

Therefore, in DMA 4, zero pressure test was carried out to confirm the DMA4 was entirely isolated

Step testing was carried out section by section and road by road to find out invisible leaks and minimize night flow due to leakage. In this study, it was planned to carried out step testing for six zones. However, the study was limited to DMA 4 (Kaduruduwa area) due to the condition of existing valves, difficulties in obtaining road cutting permission and limited resources. DMA 4 map is depicted in figure 5.13. DMA 4 consists 328 water connections and pipe network consists of 4.6 km.

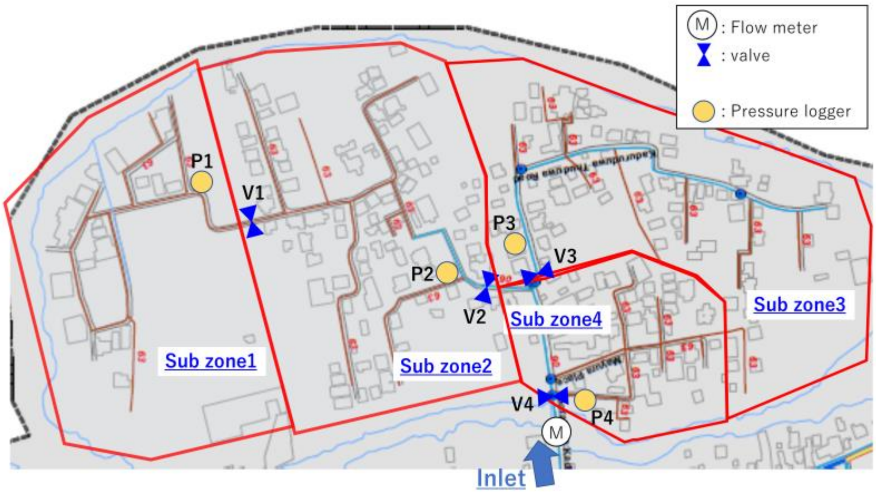

Figure 5.13 : Field studies area in Kaduruduwa area (DMA 4)

After reviewing pipeline and utilities in the road, DMA 4 was divided as a four subzone as shown in the Figure 5.13. Every subzone boundary valve was installed before starting the step test. These valves are numbered, VI to V4 as step valves as shown in the Figure 5.13.

Test was carried out during midnight by recording the Minimum Night Flow (MNF) because of minimum consumption. Before commencement of the test, bulk meter reading (M) were recorded in 10 minutes intervals in the following steps. After obtaining initial bulk meter reading, V1 valve was closed for 10 minutes. Closing valve in 10 minutes intervals up to V4 valve was followed. Results of the subsequence closing valve are in Table 5.15

Table 5.15: Sequence of valve closed in step testing in Kaduruduwa

	V1	V2	V3	V4	Flow Rate l/min	Difference l/min
Valve Position	Open	Open	Open	Open	66.58	
	Closed	Open	Open	Open	59.36	7.22
	Closed	Closed	Open	Open	44.01	15.35
	Closed	Closed	Closed	Open	33.90	10.11
	Closed	Closed	Closed	Closed	4.48	29.42

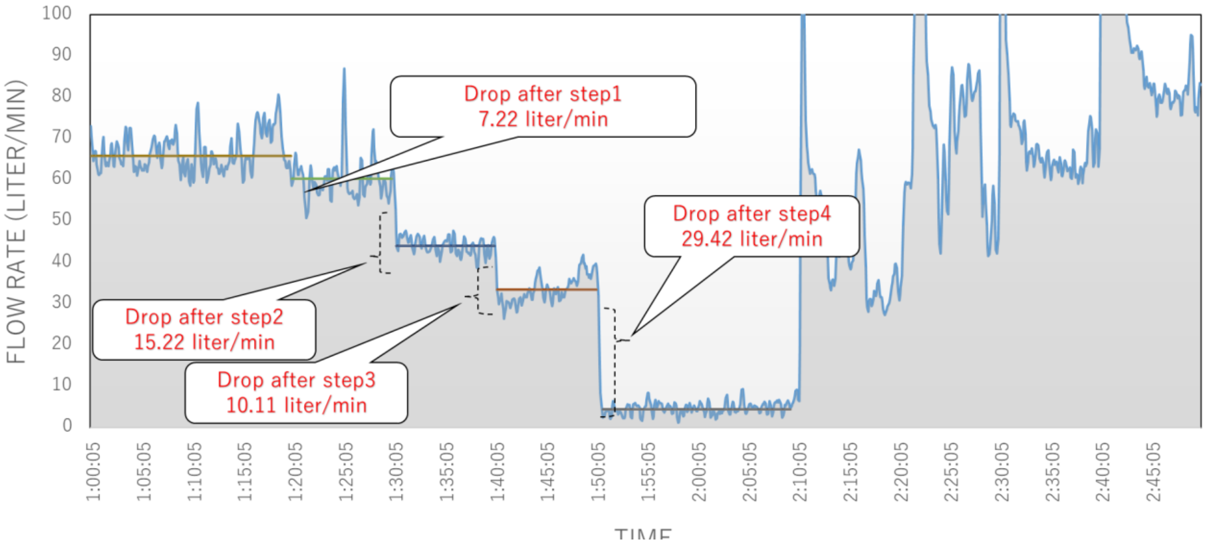

Figure 5.15 : Input Flow Rate of Step Test in Kaduruduwa

Result of the test is like a step. It is called step test. However, during the test, it was observed that order of main leak from high to low as subzone 4, subzone 3, and subzone 2 and subzone 1 respectively.

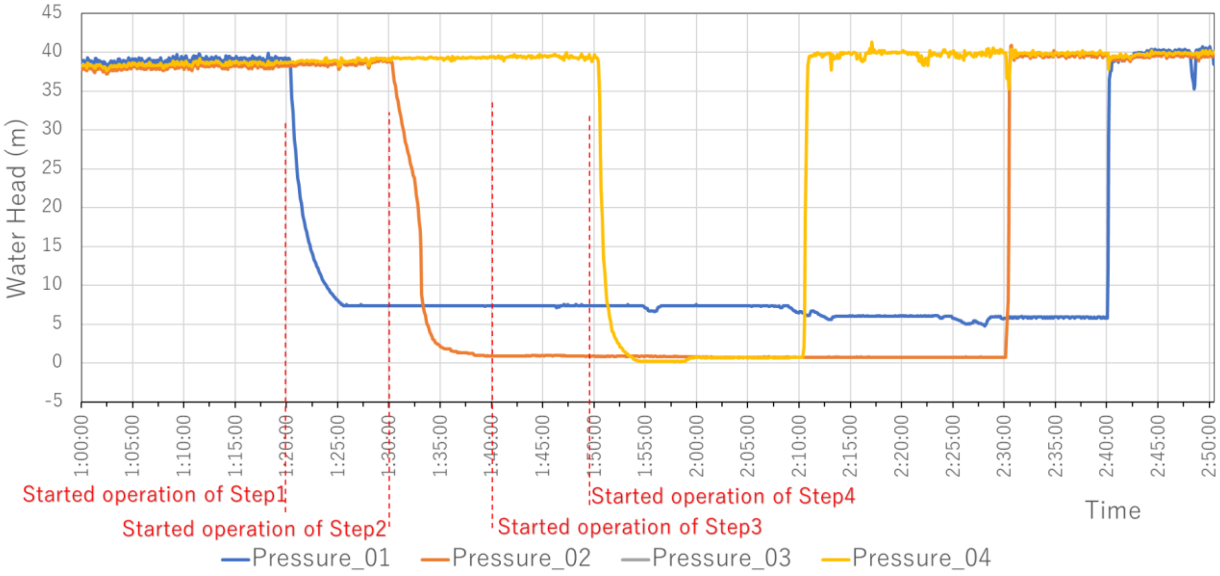

Figure 5.16 : Pressure Record of Step Test in Kaduruduwa

During the step test four houses were selected and pressure loggers (P) were installed according to the Figure 5.16 and numbered as P1, P2, P3 and P4. In Figure 5.15, shown that fluctuating pressure for the four location during the step testing. P3 pressure logger was not worked and P1 pressure logger also remaining the pressure around 5m when closed the valve V3. This may happen P1 logger not working properly or be reverse flow from consumer's water tank.

5.5.3 Detection of Underground leakage

As per the result of step test, Road to Road survey and House to House survey was carried out by using leak detection equipment such a listening Stick or Acoustic bar for DMA 4 excluding sub zone 1. As identified leaks in sub zone 1 is very low compare with other zone. Summary of the underground detected leaks were listed in Table 5.16 and Table 5.17.

Table 5.16 : House to House Survey in Field study area.

Date	Status	Sub Zone 1	Sub zone 2	Sub zone 3	Sub zone 4	Total
14/03/2019	Surveyed (Nos)	0	0	12	73	85
	Leak identified location (Nos)	0	0	2	5	7
15/03/2019	Surveyed (Nos)	0	0	70	12	82
	Leak identified location (Nos)	0	0	1	0	1
26/03/2019	Surveyed (Nos)	0	42	7	0	49
	Leak identified location (Nos)	0	2	0	0	2
28/03/2019	Surveyed (Nos)	0	65	0	0	65
	Leak identified location (Nos)	0	3	0	0	3
Total	Surveyed (Nos)	0	107	89	85	281
	Leak identified location (Nos)	0	5	3	5	13

In DMA4, house to house survey was carried out in 281 households and 13 numbers underground leaks were detected (Table 5.16). High number of leaks were identified in subzones 2 and 4. Road to Road survey (Table 5.17) was carried out for 3290 m road length and 4 numbers underground leaks were detected. High number of leaks was identified in subzone 2. The detected leak was marked as illustrated in Figure 5.17 during the night leak surveying.

Table 5.17 : Road to Road Survey in Field study area

Date	Status	Sub Zone 1	Sub zone 2	Sub zone 3	Sub zone 4	Total
1/4/2019	Surveyed (m)	0	0	410	650	1060
	Leak identified location (Nos)	0	0	0	1	1
4/4/2019	Surveyed(m)	0	677	796	161	1634
	Leak identified location (Nos)	0	1	1	0	2
5/4/2019	Surveyed (m)	0	596	0	0	596
	Leak identified location (Nos)	0	1	0	0	1
Total	Surveyed(m)	0	1273	1206	811	3290
	Leak identified location (Nos)	0	2	1	1	4

Figure 5.17 : Detection of Underground leak

Figure 5.18 : Marked detected leak point

5.5.4 Repair of underground leakage

After the detection of underground leaks, leaks were repaired as shown in Figure 5.18.

Figure 5.19 : Repair of leakage

5.5.5 Record of leak location

Leak locations were marked in GIS Cloud which is one of mobile application. In this application leak location was updated in the site. It included GPS location, Time of repairing, Reference number of leaks, Road name, Road type, Diameter of pipe, Material of pipe, depth of pipe, Type of failure, Type of repair and Site photos as shown in Figure 5.19.

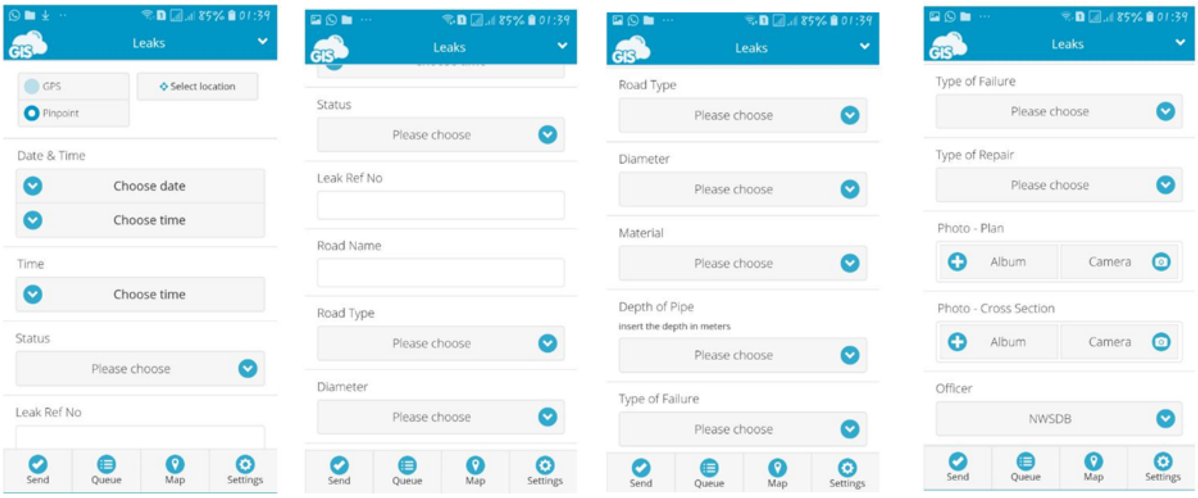

Figure 5.20 : Process of updating the leak details

Leaks Map Data Share Report To CSV Log Out Help

ID	Date & Time	Time	Status	Leak Ref No	Road Name	Road Type	Diameter	Material	Depth of Pipe	Type of Failure	Type of Repair	Photo - Plan	Photo - Cros
25	04/10/2019 1...	11:10:00 AM	Leak	M1	Kaduruduwa	Concrete	90mm	PVC	1m - 2m	Leaking Joint	Repair Socket		
26	04/24/2019 1...	13:06:00 PM	Leak	M2	Kaduruduwa r...	Concrete	90mm	PVC	1m - 2m	Crack	Repair Socket...		
27	04/24/2019 1...	11:34:00 AM	Leak	M3	Kaduruduwa	Concrete	90mm	PVC	1m - 2m	Breakage/ Bu...	Replace Fitting		
28	06/27/2019 1...	14:50:00 PM	Leak	M4	Kaduruduwa	Concrete	90mm	PVC	1m - 2m	Breakage/ Bu...	Replace Pipe ...		
29	04/22/2019 1...	11:51:00 AM	Leak	M5	Kaduruduwa	Concrete	90mm	PVC	1m - 2m	Breakage/ Bu...	Replace Pipe ...		
30	06/22/2019 1...	11:54:00 AM	Leak	M6	Kaduruduwa	Concrete	90mm	PVC	1m - 2m	Breakage/ Bu...	Replace Pipe ...		
31	04/29/2019 1...	10:59:00 AM	Leak	M7	Gamunu maw...	Concrete	90mm	PVC	1m - 2m	Breakage/ Bu...	Replace Pipe ...		
32	04/23/2019 0...	10:50:00 AM	Leak	M8	Kaduruduwa	Concrete	90mm	PVC	1m - 2m	Crack	Replace Fitting		
33	04/25/2019 1...	11:55:00 AM	Leak	M9	Maura palace	Concrete	90mm	PVC	1m - 2m	Leaking Joint	Replace Fitting		

Figure 5.21 : Leak Data in GIS Cloud

Through GIS Cloud mapping as shown in Figure 5.19 and 5.20, it can be found clear picture about the leak location and details.

5.5.6 Administration Losses

While implementing the house to house survey, all possible administrative losses were addressed. The recorded meter reading in the water bills were compared with actual. The estimated bills of houses closed was addressed by the water meter being shifted to readable location or providing option to forward meter reading to the relevant office.

In the DMA 4, meter accuracy for 16 houses was checked with Electronic test meter. Table 5.18 shows the summarized details of house meter reading.

Figure 5.22 : Meter Accuracy test

Table 5.18 : Meter accuracy check

Date	DMA	Sub zone	Account Number.	House No.	Customer meter			Test meter			Error ratio %
					Initial	Last	Flow amount	Initial	Last	Flow amount	
18/03/2019	4	4		6/23	0,688,511.9	0,688,613.9	102.0	0.00	101.20	101.2	0.79
18/03/2019	4	4	259/13	8/44	2,241,375.7	2,241,476.0	100.3	0.00	101.08	101.1	-0.77
18/03/2019	4	4	303/13	8/14 A	0,989,634.2	0,989,736.2	102.0	0.00	100.80	100.8	1.19
18/03/2019	4	4	333/13	8/43/1	0,357,423.1	0,357,525.6	102.5	0.00	100.95	101.0	1.54
18/03/2019	4	3	160/11 2	30/5	4,357,020.7	4,357,119.8	99.1	0.00	100.30	100.3	-1.20
18/03/2019	4	3	164/17 2	30/6	1,784,718.7	1,784,817.9	99.2	0.00	100.39	100.4	-1.19
18/03/2019	4	3	183/14	30/12 B	4,174,959.8	4,175,058.2	98.4	0.00	100.33	100.3	-1.92
18/03/2019	4	3	190/15	30/19	5,786,842.5	5,786,937.7	95.2	0.00	100.42	100.42	-5.20
19/03/2019	4	2	015/8	15 A Thilaka Rd.	0,621,929.0	0,622,033.7	104.7	0.00	101.20	101.20	3.46
19/03/2019	4	2	37/2	27/4 Thilaka Rd.	0,442,162.3	0,442,265.4	103.1	0.00	101.23	101.23	1.85
19/03/2019	4	2	115/17	16/44 Thilaka Rd.	1,711,424.9	1,711,527.6	102.7	0.00	101.36	101.36	1.32
19/03/2019	4	2	48/19	29 A Thilaka Rd.	1,233,416.1	1,233,518.6	102.5	0.00	102.14	102.14	0.35
19/03/2019	4	1	79/11	34 B Thilaka Rd.	1,238,782.4	1,238,885.7	103.3	0.00	101.36	101.36	1.91
19/03/2019	4	1	83/15	38/13 Thilaka Rd.	1,100,593.1	1,100,692.0	98.9	0.00	101.14	101.14	-2.21
19/03/2019	4	1	87/11	40/5 Thilaka Rd.	0,048,859.8	0,048,961.4	101.6	0.00	100.92	100.92	0.67
19/03/2019	4	1	315/15	40/27 Thilaka Rd.	0,941,237.2	0,941,339.1	101.9	0.00	101.20	101.20	0.69
Average Error Ratio											0.08

Average error ratio 0.08% in the DMA 4.

5.5.7 NRW in Field area and Water Balance

Table 5.19 : NRW variation in Field study area from February 2019 to April 2019

Month	Feb	Mar	April
Supply Quantity (m^3)	8110	7979.4	7865
Consumption (m^3)	6056	6116	6120
NRW volume (m^3)	2054	1863.4	1745
NRW (%)	25.3%	23.4%	22.2%

NRW percentage in field study area is gradually reduce with the progress of studies as shown in Table 5.19 and Figure 5.22. To tabulate this table, monthly NRW percentage reducing from February 2019 to May 2019 due to close monitoring in the study area.

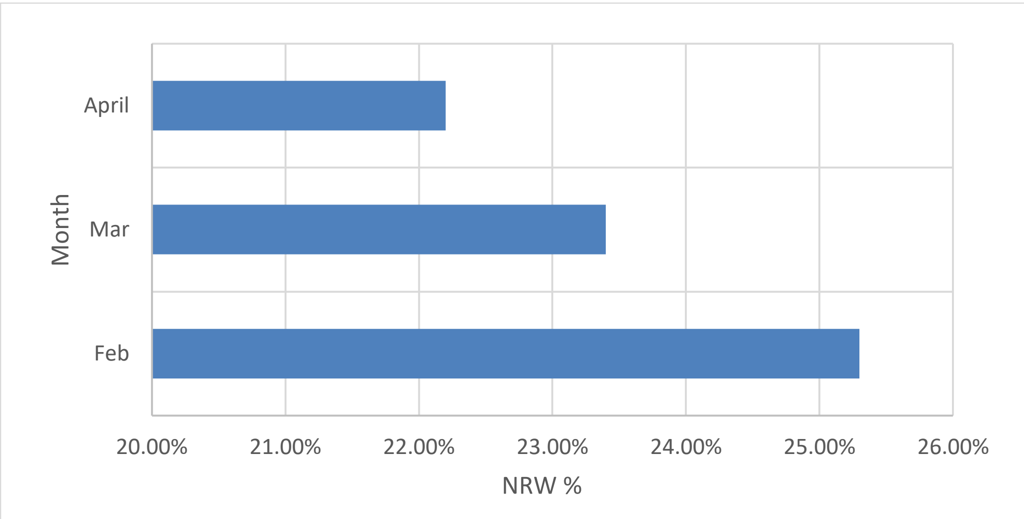

Figure 5.23 : NRW percentage in Field study area from February 2019 to April 2019

5.5.7.1 Water Balance in Field area

Assume the following design parameters (NWS&DB D2 manual)

1. The number of Person is 4.8 per connection

2. "LNU", Legitimate Night Use is 0.6 liter per person per hour

Table 5.20 : Real Losses in Field study area in month of March

Sub Zone	**Average Drop (liter/min)**	**Average Drop (liter/h)**	**Conn.**	**Person**	**Length (km)**	**LNU (liter/h)**	**Real Losses (liter/h)**	**Real Losses (liter/h/Conn.)**	**Real Losses (liter/h/km)**
1	7.22	433.2	47	225.6	1.4	135.36	297.84	6.3	212.7
2	15.35	921	107	513.6	1.3	308.16	612.84	5.7	471.4
3	10.11	606.6	89	427.2	1.1	256.32	350.28	3.9	318.4
4	29.42	1,765.20	85	408	0.8	244.8	1520.4	17.9	1900.5
Total	62.1	3,726.00	328	1574.4	4.6	944.64	2,781.36	33.9	2903.1

As per the Table 5-20 Real losses = 2,781.36 Liter/ h

= 2002.58 m^3/day

Real loss % $= \frac{2002.58}{7979.4}$

= 25.1%

Table 5.21 : Water Balance Field area in 2019 March

<table>
<tr><td rowspan="4">System Input Volume
7979.4 m^3
100 %</td><td rowspan="2">Authorized consumption
6116 m^3
76.65 %</td><td>Billed authorized Consumption
6116 m^3
76.65 %</td><td>Revenue Water
1,570,724, m3
76.22 %</td></tr>
<tr><td>Unbilled Authorized Consumption
0 m3
0 %</td><td rowspan="3">Non - Revenue Water (NRW)
1863.4 m3
23.4 %</td></tr>
<tr><td rowspan="2">Water Losses
1863.4 m^3
23.4%</td><td>Apparent Losses
(-139.18 m3)
(-1.7) %</td></tr>
<tr><td>Real losses
2002.58 m^3
25.1%</td></tr>
</table>

5.5.7.2 Impact of Field study

It was noted that after implementation of field studies the consumers' complaints in Panadura region (Field study area) was reduced. Summary of NWS&DB consumer complaint register with respect to water leaks, low pressure, No water are presented in Table 5.22 to Table 5.24 and Graphical from in figure 5.23 to 5.25Data of Panadura area plotted in "Italic letters" for easy identification.

Table 5.22 : Number of Reported Low pressures in Panadura- Horana region

Region	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
Panadura	***6***	***5***	***6***	***5***	***4***	***3***
Bandaragama	6	2	1	1	2	3
Horana	2	3	0	0	1	0
Ingiriya	0	0	0	0	0	0
Kumbuka	0	0	1	0	0	0

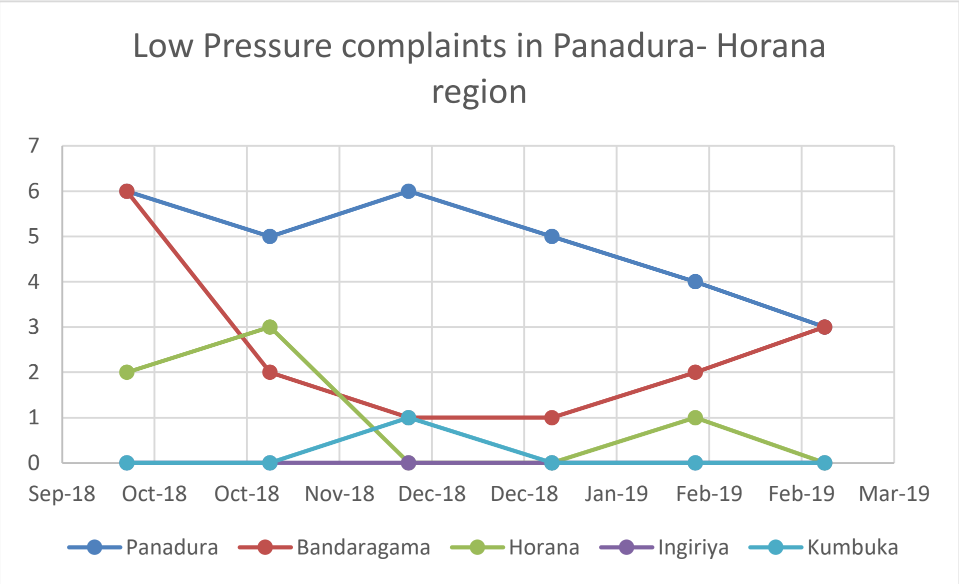

Figure 5.24 : Analysis of Reported Low Pressure in Panadura- Horana

Table 5.23 : Number of Reported Water Complaints in Panadura- Horana region

Region	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
Panadura	***107***	***51***	***45***	***35***	***36***	***35***
Bandaragama	26	29	17	16	25	16
Horana	17	16	12	31	25	17
Ingiriya	3	9	4	0	3	1
Kumbuka	16	14	14	7	17	7

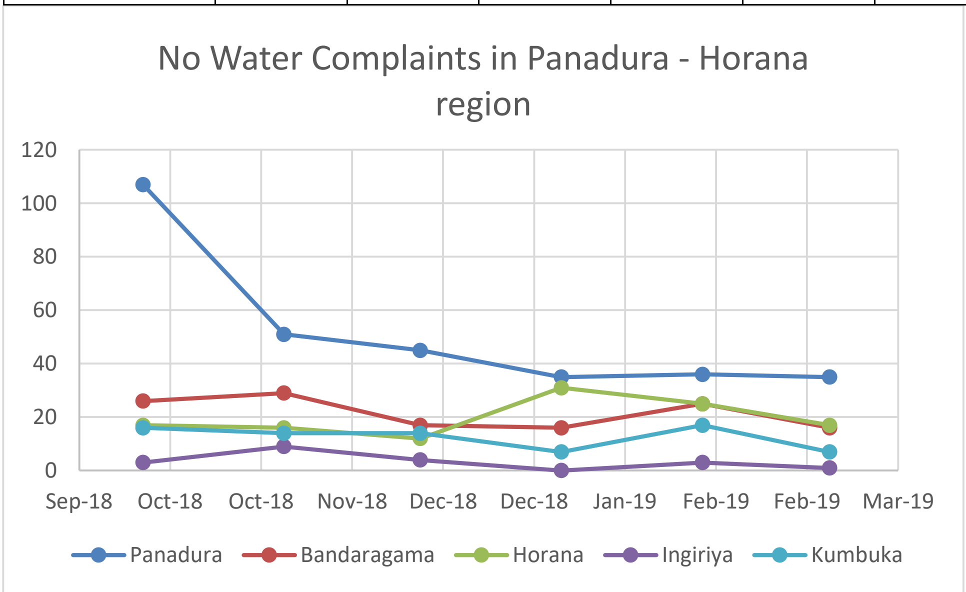

Figure 5.25 : Reported No Water Complaints in Panadura- Horana region

Table 5.24 : Water Leaks Complaints in Panadura- Horana region

Region	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
Panadura	***8***	***9***	***10***	***9***	***8***	***6***
Bandaragama	11	5	5	8	11	4
Horana	8	12	8	8	10	9
Ingiriya	5	3	2	7	9	2
Kumbuka	5	6	2	17	14	1

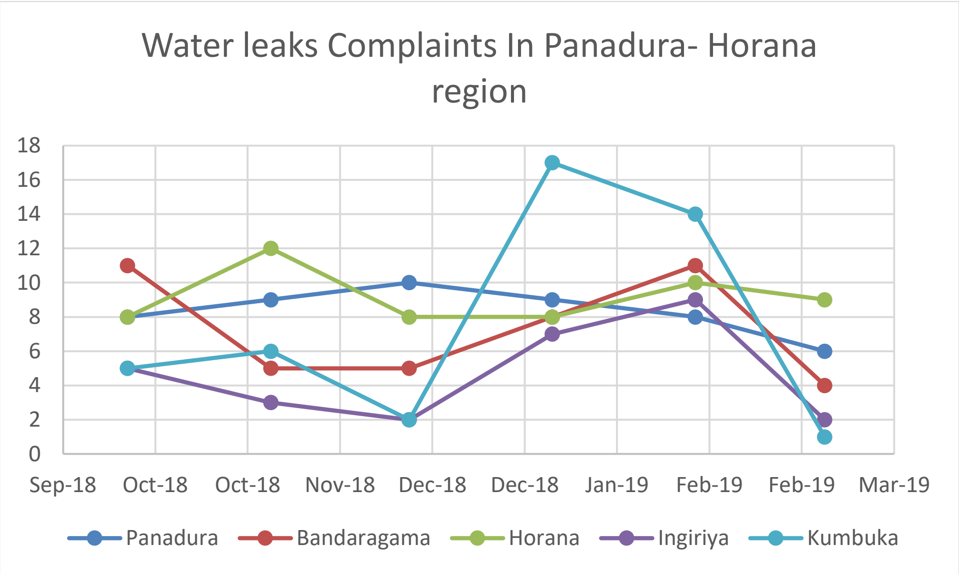

Figure 5.26 : Water leaks complaints in Panadura- Horana region

Chapter **6**

6 DISCUSSION AND STRATEGY FORMULATION

6.1 Introduction

The objective of this research work was to propose strategies that would help to minimize the NRW quantities and improve pipe borne water supply in Panadura - Horana region. The research work conducted in the non-revenue water levels, came out with some findings and this discussion seeks to draw attention to the key findings.

6.2 Discussion

In Manager (Panadura-Horana) region, there is no proper way to update the network map and hence it was very difficult to get a clear idea of the network pipes and accessories. It was difficult to provide 100% accurate breakdown for NRW for the selected zone since the area cannot be isolated because of the unsystematically laid pipe network.

Panadura-Horana region has never carried out a full-scale water audit before this study. But the officers have some understanding about the factors responsible for the water loss. However, water audit will help the staff for better understanding of water loss and the performance of the distribution network. For this purpose, free NRW software by World Bank Institute and American Water Works Association could be used.

Based on the methodology and equations adopted in this research, non-revenue water makes up 23.8% of system input volume of which 16.5% is real losses while 6.8% is apparent losses and 0.5% is unbilled authorized consumption.

Real losses show the dominant component of NRW in the panadura area and stands for 69% of NRW volume. Conversely, apparent losses and unbilled authorized consumption make up 29% and 2% of NRW volume respectively.
Evaluating the distribution network of the Panadura Horana region, it was revealed that 8% of the network is consists of old CI pipes and all the CI pipes are larger than 80 mm-300mm diameters. Based on the analysis of water supply system in Panadura- Horana, it was realized

that large amount of water leaks, frequent burst, high NRW and low pressure in most part of the Panadura. According to the results Major leaks have appeared on the CI pipes with a monthly average of 1.275 leaks/km. Since major leaks are from larger diameter pipes and take more time to repair; water loss quantity is much higher than the minor leaks and it affects to increase the NRW figure directly. Hence it is required a replacement of CI pipes with PVC/PE pipes for better service and improvement of system pressure.

Replacement of CI pipes up to 150 mm diameter would help to reduce most of the physical losses as well as apparent losses. With the replacement of pipes, all the house connections should be reconnected to the newly laid pipes, hence all legalized connections can be easily traced and all illegal connections to be legalized according to the procedures. Apart from that, most of the hidden leakages and wet patches will be eliminated with the pipe replacement. Hence frequent repairs cause inconvenience to customers and let mud particles to enter to the system, even though it is costly, it is more economical to replace pipe lines with valves and meters in order to improve the supply and cater for future demand.

There is no periodical maintenance system or preventive maintenance system for the valves and fire hydrants. This happens because of the lack of resources and the unbearable workload on zone officers. Because of this, more time is taken when there is a need to close a valve in a situation of a pipe burst etc. Introducing a periodical maintenance system is identified as a most important part of reducing NRW in the area.

Main reason of establishing DMAs is to facilitate controlling water loss in a small confined area in an effective manner. DMAs help mainly to control leakage in distribution system by monitoring night flows. In our research even though we carried out only one test of night flow monitoring, we were able to find out a significant pipe leakage. It also helps to identify deteriorated pipes need to be replaced.

6.3 Strategy Formulation for Water Loss Management

Operation & maintenance division paly active role in maintain water losses at the same level in the Panadura – Horana water supply system. It is necessary to implement a well-planned programme with sufficient resources and knowledge to reduce NRW to an acceptable level. Based on the field study and data analysis, it could identify key resulted areas with priority order of activities, strategies shall be formulated. Further network management and leakage control should be integrated to reduce the water losses and improve the provision of water service. Strategies have been formulated to address the water loss for Panadura- Horana region. Further a strategic framework has been developed to manage water loss with the support from operational staff.

The utility will have to implement the following programme to achieve significant gains in water loss reduction.

Table 6.1 : Current and Alternative Strategies

Alternative Strategy	Current Strategy
Water Audit and Creation of DMAs or water supply districts.	Improve leak repair techniques, materials and workmanship
Meter Reader rotation programme	Set target levels for water losses on a year by year basis
Meter replacement programme with a metering policy	Re-train staff in improved and latest methods of water loss management
Continuous monitoring in Zones; Intensified bulk and domestic metering	Continue and intensify house to house survey and leak detection programme
	Minimize illegal connections

6.3.1 Water Audit

A full-scale water audit has never carried out for Panadura -Horana region, therefore this is the first time to formulate a strategy to water loss management. In addition to water balance, the audit essentially includes an appraisal of the system. Even though they have some understanding about the factors responsible for the water loss. However, water audit will help the staff to understand water loss in detail and performance of distribution system.

The water balance will follow and will involve measurement of distribution input and water consumed. All component of the water balance should be qualified over the same designated period. When the components of the water balance are established, the leakage level should be estimated and the ILI determined more accuracy.

6.3.2 Improve repair techniques, materials and workmanships

In Panadura -Horana region, most of the water leakages occurred due to high pressure, settlements, heavy moving loads, illegal connections, poor workmanships etc. Currently, high night flow and high supply rate per connection show that there is a need for distribution system rehabilitation in dealing with leakage management. The following should be carried out to reduce the water loss;

- The right type of repair material should be specified.
- Leakage prone material should be replaced with appropriate pipe material
- Propaganda to encourage to report leaks.
- Time taken to attend to a leak repair should be shortened
- Leak repair time should be shortened by providing proper equipment
- Leak locations should be marked

Workmen should be improved

6.3.3 Meter Reader Rotation

Under this zonal arrangement meter readers will be assigned to zone officers, and limited 1800 connections to each reader, with rotational system. This connection area will be called a District Metering area or waste district system, which three-meter reading cycles and readers being rotated every 4 months' time as shown in Figure 6.1.

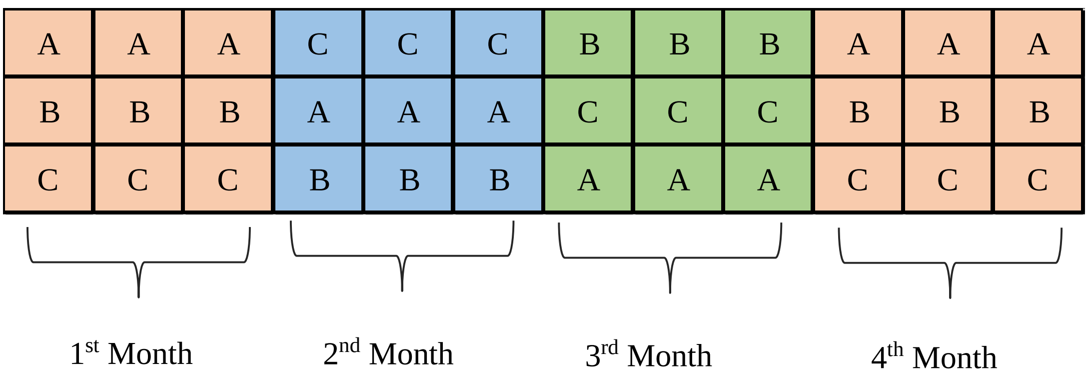

Figure 6.1 : Propose Meter Reader Rotation in Panadura -Horana region

Water loss management, especially the leakage management is a much-specialized area, hence it is important that all staff involved in water loss management should be re-trained in leakage technology and latest equipment and equipment usage. The training programme among others should include:

- Practical demonstrations and experiences in the use of a wide variety of equipment the utility possesses such as sounding probes and flow meters.
- Setup of DMAs
- Analysis of data using distribution system by distribution design software

6.3.4 Continue and Intensity House to House Survey and Leak detection programme

Panadura- Horana region was divided into 16 zones with resources to carry out the maintenance works. But concentration for long term consumer works is not feasible with day to day maintenance work activities. Therefore, NRW section will have to intensify house to house survey By introducing zonal management system to reduce NRW, and leak detection in the zone and with the leak repairs, the distribution plans should be updated and mapping of losses should be introduced by the zone officers.

New methods will have to be tried to improve leak detection performance with field study experience. Step testing should be carried out during the night and with the minimum night flow for small isolated areas or possible distribution branches.

The steps are as follows:

- Rearrange zone to have one or minimum feeding and fix bulk meters
- The test area is isolated by closing the boundary valves in the zone or district of interest
- Carry out valve proving test
- Identify night consume premises that obtained night consumption or stop taps on consumers service connections are closed.
- Recorded night flow is responsible for the water leakage, hence closing valve in sequences responsible branch or part can be identified
- Leak detection equipment is used to locate the leak points.

6.3.5 Assess and Mange Apparent Losses

Most of the water loss management practices are paid more attention to reduce physical losses, rather than reduce apparent losses due to small contribution to NRW. But sometimes most of the revenue losses will occur due to the apparent losses. With the progressive tariff adjustment of one unit, it will bring to the lower slab in tariff structure and change the bill by decreased high amount. Therefore, cross checking with close monitoring or by using improved apparatus are essential to have a good income to the utility.

House to house survey should be carriedout to wipe out all possible means of apparent losses with the following measures;

- Disconnected premises should be investigated to ensure that there is no further water use. If these places still use water, action is to be taken as illegal water usage.
- To identify registered & unregistered consumers if unregistered or unmetered connection is found, action to be taken according to the procedure.
- Identification and replacement of all defective meters.
- Identified reason for estimate and implement meter rectification programme.
- To reduce meter error, use one-liter bottle to be identified and replaced faulty meter at least for nominal flow.
- Identification of house closed estimated bill premises and implement method to be adopted obtain meter readings by shifting meter to readable location or mutual understanding with consumer to display or inform meter reading at schedule data.

The strategies were ranked according to the outcome of the research. The priority orders for the recommendation was provided reduction of real losses, reduction of apparent losses and reduction of unbilled authorized consumption accordingly.

Table 6.2 : strategy formulation for water loss management

Strategy	Current/ Alternative	Recommendation Rank	Justification
Water Audit and Creation of DMAs or water supply districts	A	2	Water audit to be carried to identified the losses.
Improve leak repair techniques, materials and workmanship	C	3	As per the research result, NRW mostly appeared in leakage in pipe line.
Meter Reader rotation programme	A	7	To minimize the human error.
Set target levels for water losses on a year by year basis	C	1	Initially target to be identified.
Re-train staff in improved and latest methods of water loss management	C	6	Training to be provided as per the new technology.
Continue and intensify house to house survey and leak detection programme	C	4	To identify the invisible leaks.
Meter replacement programme with a metering policy	A	8	To reduce the meter error.
Minimize illegal connections	C	9	As per the research result, illegal connections not identified.
Continuous monitoring in Zones; Intensified bulk and domestic metering	A	5	Most of income received from domestic meter. Therefore, continuous monitoring is essential.

Chapter 7

7 CONCLUSIONS AND RECOMMENDATION

7.1 Introduction

The comprehensive study carried out about water loss management with literature review, field study and data analysis which helped to gain a sound knowledge about the subject and the Panadura – Horana water supply system , the following conclusions could be drawn and recommendations made to improve the service level in Panadura – Horana region water facilities to provide consumer satisfaction, cope with future development.

7.2 Conclusions

Non-revenue water in the Panadura- Horana water supply system make up 23.8% of system input volume of which 16.5%is real losses, 6.8%is apparent losses and 0.5% is unbilled authorized consumption. In whole NRW volume, Real losses, apparent losses and unbilled authorized consumption make up 69%, 29% and 2% respectively.

It was difficult to provide a complete breakdown of NRW for Panadura – Horana region because it is not possible to breakdown the area manageable sections (Zones) that can be isolated using valves (DMA's) for flow monitoring. However, it could be seen that that the main cause of NRW in Panadura – Horana region is water leaks, under- recording customer meters, defective meters and inaccuracy in meter reading.

The UARL for Panadura- Horana region is 27,380.76 m^3/ month and the ILI for the Panadura- Horana water supply system is estimated to be 12.4. High ILI means, the infrastructure is not being managed well. One major factor for this situation is that infrastructure is aged with deteriorated pipes. This suggested that there is considerable scope for improvement in Panadura- Horana region through system rehabilitation for the CI pipes with a proper action plan.

The Field study established that an isolated manageable area with limited number of connections or one feeding point with isolated area (manageable connections with DMA) is one of the best practices of water loss management suitable to any city in the world. This helps close monitoring parameters such as minimum night flows, ILI and NRW are effective when considered within the entire isolated area and precautions can be taken accordingly.

Field study area further established that in case of effective water loss management, awareness and commitment of all the staff members, from top to bottom are very important. All the staff members have collective responsibility and commitment to reduce water losses. Further awareness of consumers too is essential to get information about illegal consumption, defective meters and water leakage etc.

7.3 Recommendation

Based on the study, following recommendations are introduced to reduce NRW, both for immediately and for future work.

- The Standard water balance audit to be introduced and implemented.
- The speed and quality of leakage repairs to be improved. This could be done by improving the resources provided to the zone officer such as manpower, equipment, allowances etc. Also outsourcing the leak rectification work would be more efficient and effective.
- Outdated CI pipes of diameter up to 150 mm, to be replaced with PVC or PE pipes in order to minimize the frequent pipe bursts
- Zonal isolation system to be implemented.
- Establishment of DMAA in proper manner and monitoring of night flows to be done Special attention to be paid for disconnecting all the unauthorized users or/and metering these premises.
- Active leakage control through metering and monitoring the flow to be practiced in case of unreported / invisible leaks
- Introduce proposed meter reader rotation system within the zone.
- Meter replacing policy to be introduced by considering the lifetime of the water meters

- Identify high income connections and installed high accuracy water meters with remote metering system(AMR system)
- Special attention to be paid to update the network map and enough training to be given to the staff.
- Periodical maintenance system for valves/fire hydrants etc. to be implemented.
- Regular awareness campaigns should be planned to identify illegal users.
- IT enabled system in the NWS&DB should be developed to accommodate IWA water balancing mechanism and derive and present performance indicators such as UARL, ILI to evaluate the condition of distribution system.

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