COMPARATIVE STUDY OF URBAN AND RURAL OPERATION AND MAINTENANCE PRACTICES OF WATER DISTRIBUTION SYSTEMS AT KAI !GARIB MUNICIPALITY

by

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Abstract

The South African Government has invested heavily in the provision of water to its citizens. These efforts are however futile if appropriate operation and maintenance (O&M) plans are not put in place to ensure sustainability of the infrastructure. The operation and maintenance requirements of rural areas differ from those of urban areas due to differences in demand patterns, lengths of mains and consumer densities. This study investigated O&M practices in both rural and urban areas in the Kai !Garib local municipality. The study applied selected performance indicators from the International Water Association and the Regulatory Performance Measurement System (Department of Water Affairs) to evaluate and compare the performances of the selected rural and urban systems. The study also used questionnaires administered to the technical personnel in the municipality to attain more detailed information on the O&M practices. It was found that the urban areas had more varied O&M practices. The urban systems were also found to have more resources and personnel dedicated to O&M than the rural systems.

KEY WORDS: operation and maintenance, water distribution systems, rural and urban

Abbreviations

WDS	Water Distribution System
O&M	Operation and Maintenance
WSA	Water Service Authority
WSP	Water Service Provider
IWA	International Water Association
RPMS	Regulatory Performance Measurement System
PI	Performance Indicators
KPI	Key Performance Indicators
NWSRS	National Water Services Regulatory Strategy
MDG	Millennium Development Goal
CBO	Community Based Organizations
NGO	Non-Governmental Organizations
RA	Regulatory Actions
eWQMS	Municipal Water Management Tool
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
SCADA	Supervisory Control and Data Acquisition
Ofwat	Office of Water Services
OPA	Overall Performance Assessment
CCC	Customer Care Centre

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1. INTRODUCTION

South Africa has made substantial progress in the delivery of improved water supply to its population since 1994. In the first decade of the new democratic dispensation, the South African Government invested R11.3 billion in water supply and 13.4 million more people were provided with basic water supply (DWAF, 2005). By the end of 2013, an estimated 95.2% of South Africans had access to drinking water with microbial, chemical, and physical characteristics that meet the South African national standards; this is a vast improvement on the 59% in 1994 (DWA, 2014). Furthermore, South Africa has already met its Millennium Development Goal to 'halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation' in 2010 (UN, 2014).

Despite the good progress with water service provision, service backlogs cannot be eliminated solely by building new infrastructure (Roux, 2010). Sustainable service delivery requires properly operated and maintained infrastructure, and thus investment in operation and maintenance (O&M) is essential to ensure the sustainability of these services.

The understanding and undertaking of adequate O&M therefore forms the basis of efficient water service provision. South Africa is the 25th largest country in the world that stretches over rural and urban regions. The Department of Water and Sanitation has the superseding responsibility of water provision services undertaken by local government to over 51 million (StatsSA, 2011) people living in different geographical and economic regions.

The main differences between urban and rural water distribution systems (WDSs) are related to their settlement densities and economic bases. Urban systems serve higher numbers of consumers living in higher concentrations and are thus able to serve more people with the same infrastructure. Since maintenance requirements are often linked to the quantity of infrastructure rather than to the number of people served, the maintenance requirements per consumer will invariably be higher for rural systems. These differences are invariably reflected in the O&M needs and practices of the WDSs.

1.1 Background

A WDS uses hydraulic components such as pipes, valves and reservoirs to connect consumers to water sources (Alperovits & Shamir, 1977). The purpose of a water distribution network is to reliably supply consumers with the quantity of water required at adequate pressure under various loading conditions (Mays, 2006).

O&M of water services infrastructure may be described as the entirety of activities required to manage a water supply utility (World Bank, 2007). O&M is a continuous process involving various activities with the ultimate purpose of delivering good quality services to all customers at all times (Roodie, 2009).

In this study, a rural area is defined as a geographic area located away from cities and towns whose main economic activity is agriculture. Rural areas generally have lower population densities and exhibit dispersed settlement patterns, with most consumers practicing subsistence farming.

In this study, an urban area is described as a geographic area constituting a city or town characterized by high population density and is more industrialized in comparison to rural areas. The socio-economic zones found in an urban area include residential areas, commercial areas or the central business district, and industrial areas. It is the duty of a water utility to provide adequate quantities of water, at sufficient pressure and of good quality to enable the socio-economic zones to carry out their functions.

When funds are invested in new infrastructure, the relevant Water Service Authority (WSA) should necessarily allocate additional budget for the increased O&M requirements. However, factors such as shrinking of overall municipal budgets, increased electricity tariffs and increased wages based on agreements negotiated at national level deter the allocation of an adequate budget for the O&M of water infrastructure (Roux, 2010). In addition, local municipalities in South Africa struggle with the acquisition of technical capacity required to implement a sustainable operational and maintenance system for their infrastructure; research undertaken in 2006 revealed that an additional 1 100 municipal plumbers were needed countrywide in order to cope with O&M of water service infrastructure. Furthermore, local municipalities were found to be operating with an average of 2 civil engineering professionals per 100 000 population which is far below the prescribed 5 civil engineering professionals per 100 000 population (Lawless, 2008). Reduced spending on O&M may lead to a deteriorating infrastructure and service breakdowns. In the long term, capital investments are then required to rehabilitate and prematurely replace such infrastructure. Supposed savings by a WSA result in higher cost to national government before the end of water infrastructure design life (Roux, 2010).

The Department of Water Affairs (DWA) strongly emphasizes maintenance in its terms of reference for the National Water Services Infrastructure Asset Management Strategy:

> *Money 'saved' on maintenance of assets is never a saving. This is a short-term outlook, often said to be due to political short-term imperatives and lack of capacity and know-how within the municipality. It can become a vicious cycle once infrastructure is allowed to deteriorate. Expensive refurbishment becomes necessary and there is even less money for on-going maintenance. In addition, deteriorating infrastructure leads to poor service delivery and reduced payment by consumers, exacerbating lack of cost recovery. Government is facing a looming crisis unless something is done. (DWAF, 2005)*

Besides the financial implication, poorly operated and maintained WDSs also result in a lack of, or limited supply of clean water. This in turn affects both rural and urban communities in various ways.

According to Lewis (2010), the lack of adequate provision of water in a rural community may lead to outbreaks of water-borne diseases such as cholera that can be avoided by the provision of clean water in sufficient amounts. These water-borne diseases often cause the premature deaths of young children. Furthermore, women and young girls are often forced into the role of water providers. They prioritise their time in search of water sources and carrying the water back to their homes instead of concentrating on income generating activities and attending school.

On the other hand, in urban areas rapidly growing populations place a lot of pressure on the existing water distribution systems. This leads to an increased extraction of water from the existing water sources, hence decreasing the amount of available water, and in some cases leading to an irregular water supply. Another problem is the disposal of waste into the water sources due to outpaced waste water reticulation and treatment systems. This has led to increased pollution of the natural water bodies, unintentional use of waste water for irrigation and endangering of aquatic life.

Lewis (2010) found that the underprivileged population in an urban community pay more for water than the wealthier population who receive better water and sanitation services (Lewis, 2010). This is because the wealthier residential suburbs areas generally get direct access to clean water from the Water Service Provider (WSP) via house connections. The informal settlements are unplanned and will in most cases not have a proper WDS; they end up relying on water vendors such as water kiosks and water trucks to provide clean water at higher costs than they would have paid had they received the water directly from the WSP.

The lack of appropriate O&M will affect a community negatively even though the effects may vary between rural and urban areas.

This study seeks to understand the differences and similarities of O&M practices implemented in rural and urban WDSs and highlights the weaknesses and strengths of existing practices. The Kai !Garib local municipality was selected as the case study area as it provides water to both rural and urban areas within its jurisdiction. Another factor that contributed to the selection of the Kai !Garib local municipality was the researcher's familiarity with the region which made for easier data collection.

1.2 Goals and Objectives

The goal of this study is to compare O&M practices in the rural and urban areas of the Kai !Garib local municipality.

The objectives of this study are as follows:

1. To present an overview of O&M of WDSs and its components based on available literature.

2. To determine the level of O&M practices used in selected urban and rural WDSs in the Kai !Garib local municipality based on selected performance indicators through in the following ways:

3. To determine the level of expertise (skills, both technical and managerial) of staff responsible for O&M in the selected urban and rural areas.

4. To determine the resources and equipment dedicated to the O&M of the WDSs in the selected urban and rural areas.

5. To determine the level of service and efficiency provided by the O&M method used in the selected urban and rural areas.

1.3 Layout of this dissertation

The rest of the dissertation has been structured into four sections. The first is a detailed review of literature available on WDSs, the O&M of these systems, rural and urban WDSs and available performance measurement systems used to gauge WDSs performances. The literature review also discusses the South African legislation pertaining to water provision as well as the selected case study area.

The second section deals with the methodologies used to undertake this research, the third discusses the findings and analyses them while the fourth concludes the research and proposes recommended additional research on the subject matter.

2. LITERATURE REVIEW

2.1 Introduction

A typical water supply system consists of a source, treatment process, a pump station, and a distribution system (Hammer & Hammer, 2009). The distribution system may further be broken down into sections such as pumping stations, distribution storage, and distribution piping containing numerous connections that supply water directly to users (Trifunovic, 2006; Mays, 2006). Figure 2.1 shows this graphically.

While the piping systems play a major role in distribution of water, the WDS would not be complete without taking the other components such as pumps and storage systems into consideration. A WDS therefore consists of a large number of pipes and components connected in form of a network and functioning as a whole (Van Zyl, 2014).

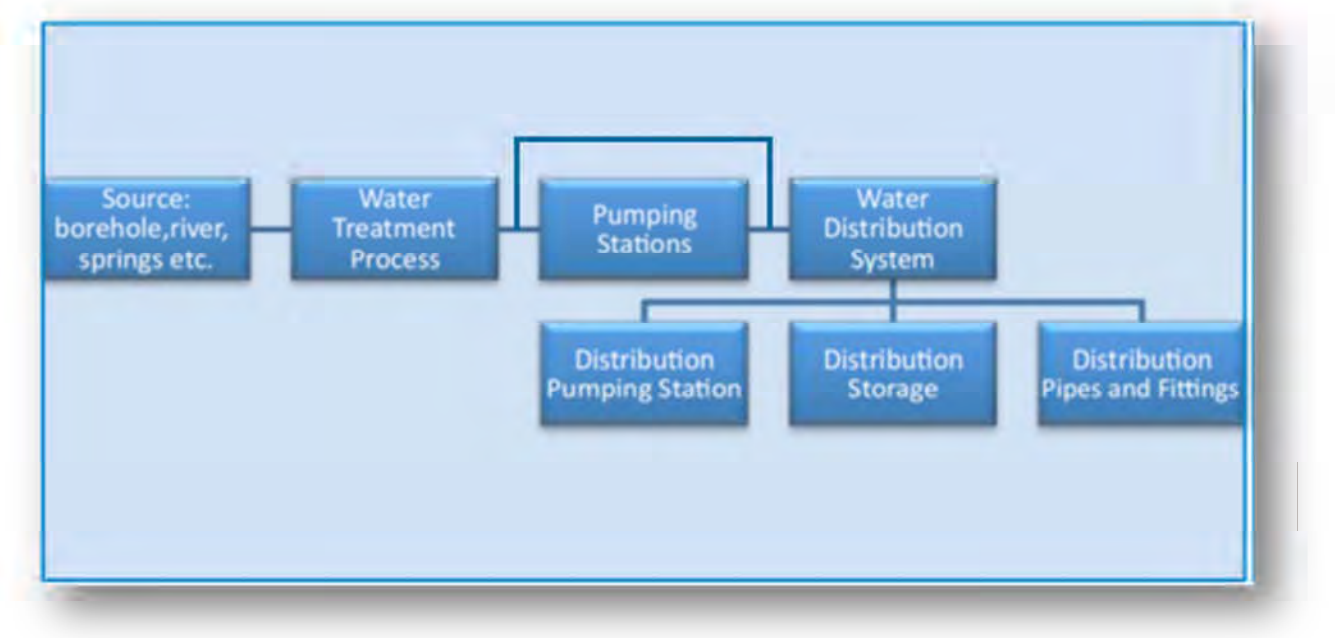

Figure 2.1: Stages of a Water Supply System

Differences exist between WDSs in rural and urban systems. These are often present in the design phase where the design criteria are often different; these include factors such as water demand estimation, peak factors, and components used. Urban water systems are generally larger serving a large centralized population while those in rural areas are smaller in size serving sparsely distributed populations.

According to Kjellén (2000) in her research on water distribution in Dar Es Salaam, Tanzania, the residents in informal settlements of urban areas do not receive water directly from the utility. Water is distributed to these areas via distributing vendors. The residents thereafter have to carry water from these vendors to their homes. Those with

sufficient income can pay to have their water transported via tankers and push carts (Kjellén, 2000). Water is also supplied through public stand-posts and yard taps as an intermediate step towards the ideal of direct house connections (Sundaravadivel & Vigneswaran, 2004).

The water distribution where water is transported from a connection to a consumer in urban informal settlements is rarely mentioned in conventional WDS definitions. Kjellén (2000) further suggests that secondary water distributors such as vendors and water trucks should be legally recognized as a mode of water distribution in Dar es Salaam, Tanzania. While this may not be ideal, ignoring them as part of the distribution system, especially in developing countries, means that they cannot be monitored. This may compromise water quality standards and increase the risk of cartels within the water distribution industry which may limit the amount and availability of water in that particular area, while increasing the cost of water.

The mode in which water is distributed and dispensed to a community is an important aspect of water supply; stand posts and yard connections can be used to distribute water in rural communities, as opposed to direct house connections like in urban areas (Sundaravadivel & Vigneswaran, 2004).

2.2 Components

In this section the basic components of WDSs are discussed. Understanding these components forms the foundation of the practices needed to operate and maintain the WDSs.

2.2.1 Pipes

Pipes can be classified as trunk mains, secondary mains, distribution mains, and service mains. Trunk mains transport water from the treatment plant to the distribution area, and secondary mains form the basic skeleton of distribution systems. Distribution mains transport water from secondary mains to various consumers, while service mains are pipes that lead from distribution mains directly to the consumer via a public or private connection (Trifunovic, 2006).

Pipes are found in different sizes and materials such as steel, cast iron, reinforced concrete, asbestos cement, polyvinyl chloride (PVC), polyethene and fibreglass (Mays, 2006).

Cast iron, steel and galvanized steel pipes are the stronger materials compared to concrete, asbestos cement, PVC, polyethene and fibreglass. In addition to the material strength, using galvanized steel pipes also result to low hydraulic frictional losses and are suitable for high operating pressures. However, the costs of these materials are relatively higher than the other pipe materials.

Asbestos cement pipes are relatively cheaper and hence were used instead of cast iron pipes; they are however not used or manufactured in South Africa anymore. Small polyethylene (PE) pipes are supplied in rolls; they are relatively flexible and easy to install. This means that the number of joints and bends are significantly reduced; they are also resistant to corrosion. Unplasticised polyvinyl chloride (uPVC) and modified polyvinyl chloride (mPVC) pipes provide good corrosion resistance, enhanced hydraulic performance, lower friction losses and are durable. PVC is however weakened by exposure to sunlight and should be stored in covered racks or inside a shed (Roodie, 2009).

The aspects to consider when conducting a pipe selection exercise include availability in the market, purchase price and cost of accessories and fittings, endurance against corrosion, mechanical damage and material ageing, storage costs, and the internal and external diameters of pipeline (CSIR, 2000).

2.2.2 Storage

Water storage is provided in the form of reservoirs or tanks. These are used in a WDS to meet variable supply to the network with constant water production, provide water during emergencies, and maintain stable pressures (Trifunovic, 2006). Supply during emergencies involves providing emergency storage (for instance when the reservoir supply pipe is shut down) and ensuring that water is available for firefighting (Van Zyl, 2014). CSIR (2000) further adds that water storage also allows for planned system shutdowns and provides for contact time for certain water treatment operations such as chlorination (CSIR, 2000).

Water storage reservoirs or tanks can be either positioned underground, at ground level, or elevated by means of a concrete or steel tower. Reservoirs are mostly constructed from reinforced concrete, although the smaller reservoirs are sometimes built out of bricks or steel panels, while water towers and elevated water storage containers are constructed out of reinforced concrete or steel panels (Van Zyl, 2014).

Reservoirs may also be constructed from ferro-cement, which consists of one part cement mixed with two parts sand. Water is added to form a paste-like consistency, and then the paste is forced onto layers over closely and evenly distributed wire mesh reinforcement by hand or by trowel (CSIR, 2000).

Other types of tanks include masonry, galvanised steel, asbestos cement, plastic, fibreglass, and polyethylene and rubber tanks. Ferro-cement and galvanized tanks are suitable for rural areas (CSIR, 2000).

Galvanized water storage tanks have a short erection period; however, they require specialized construction skills and equipment which are readily found in urban industrial centres. The distance between urban centres and rural settlements is often quite considerable which translates into high transportation costs; this coupled with lack of the

specialized skills and equipment makes the galvanized storage tanks quite expensive to install in rural areas and therefore may not be economically viable.

Galvanized tanks are considerably more costly than masonry and ferro-cement and so may not be suitable for rural areas. Masonry and ferro-cement tanks are suitable for water storage in rural areas as complex equipment and highly skilled manpower are not required for their construction.

Galvanized steel tanks and fibreglass tanks are more suitable for urban regions as specialized equipment is required to manufacture them which is most likely to be found in urban regions. Reinforced concrete reservoirs are, in most cases, not cost-effective unless they can store more than 200 m^3 (CSIR, 2000). They are therefore suitable for regions with a high population density (requiring large water volume storage) which is a common characteristic of urban regions.

2.2.3 Pumps

A pump is a machine or mechanical device that draws a fluid into itself through an inlet port and forces the fluid out through a discharge port by means of a roto-dynamic or reciprocating movement (Lottering & Maritz, 2009). Pumps are used to add energy to water in order to move it to a higher elevation, boost pressure, or increase its flow rate (Van Zyl, 2014).

Pumps may be classified into positive displacement and dynamic pumps. Positive displacement pumps move discrete ‘packets’ of water while dynamic pumps produce a continuous stream of water through a rotating mechanism (Van Zyl, 2014).

Dynamic pumps produce a continuous stream of water through a rotating mechanism pushing the water forward or spinning the water out using centrifugal forces as in the case of centrifugal pumps which are the most commonly used pumps in water distribution systems. Centrifugal pumps are further classified into single stage pumps and multi-stage pumps (Van Zyl, 2014; Lottering & Maritz, 2009).

The single stage pumps are usually used to pump larger volumes of water and are found in two types; the end suction and double entry pumps. The multi-stage pumps are used to lift water to considerably higher levels and occur in three types: the ring section, the barrel and submersible pumps (Lottering & Maritz, 2009).

The positive displacement pumps are found in two types based on their mechanism; these are the reciprocating and the rotor pumps. The reciprocating pumps are further found in two types, the plunger and diaphragm pumps, while the rotor pumps are found in single or multi-rotor pumps. The figure 2.2 depicts this breakdown of pump types as presented by Lottering & Maritz (2009).

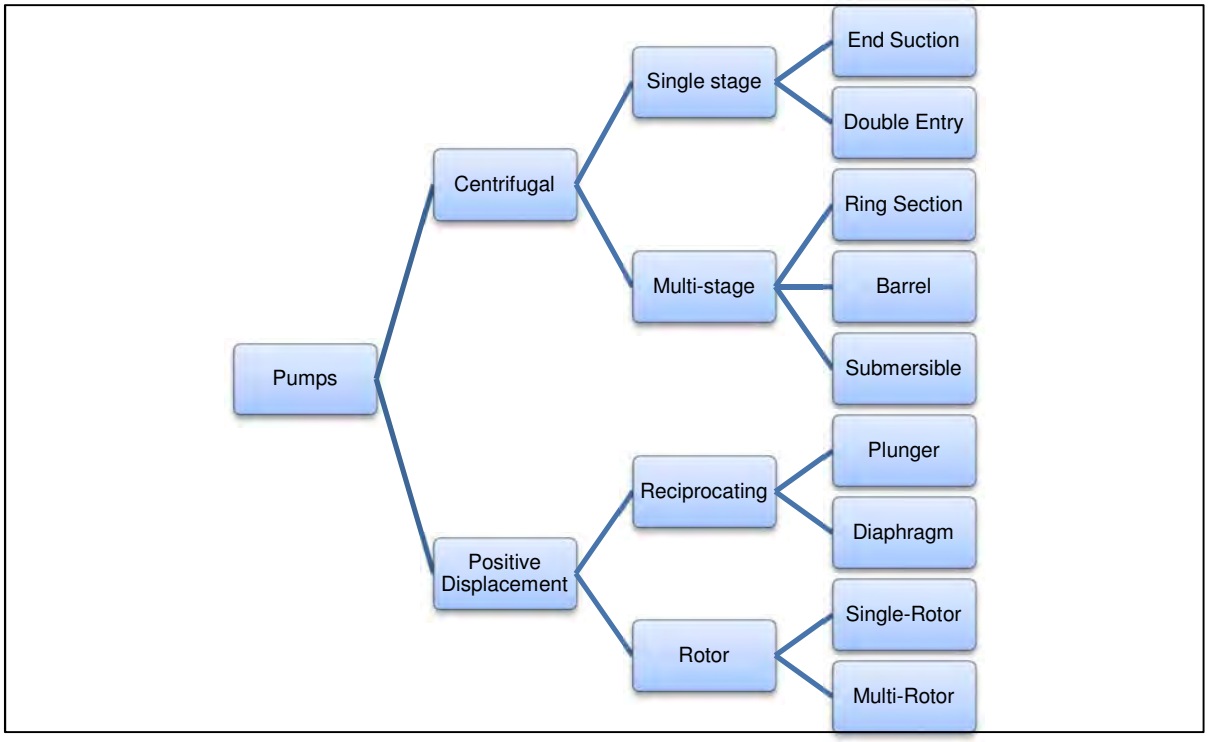

Figure 2.2: Types of water pumps (Lottering & Maritz, 2009)

Centrifugal pumps are most commonly used in water distribution applications because of their lower cost relative to positive displacement pumps, simplicity and reliability in the range of flows and head encountered (Mays, 2006).

Reciprocating pumps are frequently used in rural water supplies and can be divided into suction pumps, free delivery pumps, and single or double acting pumps (Huisman et al., 1983).

In recent times, there has been an introduction of pumps powered by solar energy; these can be used in rural areas that do not have access to the electricity grid. Solar powered pumps have become a feasible option, using photovoltaic solar panels to generate electricity that are connected to a battery. They are ideally suited for remote installations in provinces with an abundance of sunshine, like the Northern Cape in South Africa. The initial costs of solar pump installations are high, but overall pumping costs are economical in the long run (Lottering & Maritz, 2009).

Other sources of power used to operate pumps include animal power, wind power, electric motors, and diesel engines (Huisman et al., 1983).

2.2.4 Valves

Valves in a network are used to regulate the flow of water at any given point by controlling the magnitude and direction of water flow (Roodie, 2009; Hammer & Hammer, 2009). The main types of valves are isolation valves, air valves, scour valves, non-return or check valves, and control valves (Van Zyl, 2014).

Isolating valves isolate sections of a network for maintenance and other purposes, and air valves serve to prevent the accumulation of air at high points along the pipeline. Scour valves are used to drain a particular part of the system, while pressure reducing valves (PRVs) are used to reduce high inlet pressure to lower fixed outlet pressure. Non-return valves are normally used to regulate flow in a particular direction and block flow in the opposite direction (Roodie, 2009).

Valves are an important aspect of any WDS regardless of whether it is in an urban or rural region. They are available in various sizes and materials (brass, steel and plastic). Aspects to consider when selecting a valve include the function of the valve, the diameter of the pipeline it is to be fitted in, pressure and direction of flow, availability on the market, purchase price and the cost of associated fittings, its susceptibility to corrosion, and material ageing.

2.2.5 Fire hydrants

A fire hydrant constitutes of an isolation valve and a standard fitting for connecting a fire hose (Van Zyl, 2014). Hydrants provide access to water mains for the purpose of firefighting, flushing of pipes and washing of streets (Hammer & Hammer, 2009).

They also provide a means of releasing air and logging pressures. However, the primary purpose of a hydrant is to provide water for firefighting. The locations of the hydrants should be clearly marked so as to allow fire services find them with ease and they should be protected against obstruction (Van Zyl, 2014).

In both rural and urban water networks, fire hydrant provision has to be made and should be clearly marked out on water infrastructure map and physically on the ground. Other than having the hydrants in the network, constant training to responsible personnel on how to use the hydrants in case of emergencies has to be conducted on a regular basis.

2.2.6 Water meters

The two main reasons for metering in WDSs are; to provide information about the hydraulic behaviour of the distribution system which is useful for the operation, maintenance, and future network extensions. It is also used as a base for water billing. In both cases, accuracy of the information is vital (Trifunovic, 2006).

A water meter is a device that measures the volume of water that passes through it within a certain time interval. Water meters can be classified according to mechanism: mechanical, electromagnetic and ultrasonic (Van Zyl, 2011).

Venturi meters and orifice plates measure flow based on the pressure difference between two cross-sections and are used for flow measurement in trunk mains where accuracy is not of great concern. An electromagnetic flow meter measures velocity by emitting a direct current magnetic field that is proportional to the flow velocity. Electromagnetic meters are widely used for measuring bulk flows in pump stations and main trunks (Trifunovic, 2006).

Ultrasonic flow meters use ultrasonic waves to acquire the velocity profile within a pipe. Inferential meters are mechanical meters used in the measurement of flows in small and medium size distribution pipes, and are mainly used in individual domestic service connections. Volumetric or positive displacement meters are mechanical meters mainly used for billing purposes (Trifunovic, 2006).

Meters can also be classified according to application. There are consumer meters which are used to measure water delivered to different consumers, bulk transfer meters used to transfer water from bulk supplier to a municipality, and management meters used to measure distribution of water to different parts of the WDS (Van Zyl, 2011).

Meters play a pivotal role in billing of consumers for provision of water, and in this regard two main metering strategies are observed. One is the conventional metering strategy that installs water meters in all consumer connections and sends monthly water bills based on actual or projected consumption. The other is the prepaid metering strategy which involves the use of prepaid meters. These are water meters with built-in processing units and a mechanism that automatically shuts off consumer supply. The consumer purchases water credits which are transferred by means of token or electronic signal to the meter. Once the credit is used up, the meter automatically shuts off supply until such time that credit is purchased and transferred once again (Van Zyl, 2011).

There are several meters available on the market today and it is important to conduct meter selection in terms of application, availability, and mechanism. Accuracy is of utmost importance when using meters. Therefore the operation, reading of the meter, availability of spares and calibration of the meter has also to be taken into consideration when selecting meters for rural and urban use.

2.2.7 Markers

Employees working in a WDS must know where a pipe and other components are located before any excavations for road works, pipe works or leak repairs, can be conducted (Van Zyl, 2014). Pipe markers are placed along pipelines to enable locating of the pipe (Roodie, 2009.) Valve boxes and hydrants may also be used to indicate the position of a pipe. It is good practice to install components at fixed locations, such as opposite stand boundaries to make it easier to find them (Van Zyl, 2014). This is done through the use of permanent marker posts or by painted symbols on the road surface, kerb, telephone poles or other structures (Van Zyl, 2014).

2.2.8 Thrust blocks

Water in a distribution system exerts forces on pipes and fittings in the system through pressure changes in momentum and transient pressure waves (Van Zyl, 2014). The sudden stopping of the flow causes the water energy to exert pressure on the pipe walls and joints. The resulting forces cause movement in the joints and fittings in the pipeline which may lead to pipe bursts.

Thrust blocks prevent fittings from moving when pressure is applied to the pipeline by counteracting any resulting unbalanced loads (Roodie, 2009). They should be installed where there are changes in flow direction, such as bends and junctions, at dead ends, where there are changes in pipe diameter and at components that may be susceptible to internal forces, such as valves (Van Zyl, 2014).

2.2.9 Chambers

Chambers house various network fittings such as valves and meters, to enable easy access for repairs or replacement of these fittings (Roodie, 2009). They may be constructed from reinforced concrete, bricks, cast iron, or even plastics in the case of small chambers (Van Zyl, 2014).

Chambers should have sufficient working space and a roof slab that can be removed. Cover slabs should be above normal ground level and venting of air-valve chambers should allow for adequate air flow (Roodie, 2009). Furthermore, these chambers should also anchor pipes in the valve chamber walls, secure exposed parts of the network from accidental damage and vandalism, have an access opening with lockable covers, and steps should be taken to ensure that chamber covers are not covered by soil.

2.2.10 Service connections

These are points where consumers receive water from the network. The most common delivery points in a water network are standpipes at yard connections, house connections, and communal standpipes (Roodie, 2009).

A yard connection provides water with adequate pressure at a tap on the boundary of an erf, just inside the yard. There are no storage facilities provided on site and no direct supply to the house itself. There are two types of house connections: conventional house connections that are fitted with an ordinary domestic meter and pre-paid connections fitted with a domestic prepaid water meter. Communal standpipes are standpipes in open public spaces or road reserves. Householders bring their containers to the standpipe, fill them, and carry them home (Roodie, 2009).

Bulk filling points are service connections designed to dispense large volumes of water. A bowser, which is a water tank on wheels, may be used to deliver water; it has a small engine attached to pump the water in and out. A bowser enables a technical department to transport limited amounts of water at short notice in emergencies, or make regular deliveries to isolated communities and settlements. It can also be used to provide water for special social events (Roodie, 2009).

In urban areas of developing countries, the urban informal settlements are generally provided with water through communal standpipes, and in rural areas this is also the main means of service connection for the majority of the population (Sundaravadivel & Vigneswaran, 2004). Truck delivery of water is not usually a preferred mode of water distribution due to the high costs associated with operating and maintaining the trucks for the delivery of relatively small amounts of water when compared to conventional communal standpipes, yard connections, and house connections. It is however still employed for delivery of water to remote rural areas and in informal urban settlements that are not directly connected to the water networks (Roodie, 2009).

The components discussed above depend on each other and affect one another's performance. Quantity and quality requirements of a system can be met by making proper choices in component selection and their materials. The components should be manufactured from durable material resistant to chemical and mechanical degradation whilst not harmful to human health (Trifunovic, 2006). Availability of these components and their spare parts should also be considered because of future repairs and replacements.

2.3 Design and O&M of Water Distribution Systems

When designing a WDS, the engineer has to consider the way in which the operational components, pumps and valves, will be used to supply the required demands with adequate pressure. The distribution system has to perform satisfactorily under varying demand loads. In the design process one considers several significant loads; these are maximum hourly, average daily and low-demand periods during which reservoirs are to be filled (Alperovits & Shamir, 1977).

Operational decisions for these loads are essentially part of the design process, since one cannot separate design decisions such as the sizing of components from the operational decisions (Alperovits & Shamir, 1977).

A major factor that contributes to water system failures is poor planning and design of water distribution systems (Wagner & Lanoix, 1959). Water distribution and storage are the most costly aspect of a water supply system. A good design will result in significant saving in project costs as well as costs associated with operating and maintain the water system (Roodie, 2009).

A well designed network should be fed from more than one direction. If one section gets damaged, fails, or needs to be shut down, the remainder of the system will still deliver water. A network should also be cost-effective in terms of minimum pipe sizing for current demand, but take into account population growth and possible extensions (Roodie, 2009).

There should be effective valve-placing to stop water flow in blocks for maintenance purposes. There should also be effective hydrant placing to service demarcated areas, and the designed network should adhere to the minimum pressure and flow for hydrant operation and firefighting. A good design also provides good quality service connections that can withstand tough operational conditions. Poor design may lead to O&M difficulties, costly replacements, or even total system failures (Roodie, 2009).

2.4 Characteristics and benefits of an adequate Water Distribution System

According to the Wagner & Lanoix (1959), the objectives of a water supply system include the supply of safe water to consumers in adequate quantities and to make water readily available to these consumers so as to encourage personal and household hygiene. A water supply system should further provide water in adequate quantity and pressure for fire protection and for industries (Momba et al., 2006).

While providing water in adequate quality and quantity are set out as primary objectives of a water supply system, an adequate system should also provide support to the economic and social needs of a community. Economic activities and social needs of

rural and urban regions differ, and the water supply systems should support these differing needs, i.e. provide water for agricultural activities in rural areas and industrial activities in urban areas.

The primary characteristics and benefits of a WDS are evaluated below in terms of quantity and quality of water parameters.

2.4.1 Quantity

An adequate WDS should consistently deliver water of acceptable quantities at a suitable pressure with minimum interruptions and outages, inoperable valves and hydrants, and main breaks (Deb et al., 2000). It should provide the flows and pressures required for an acceptable level of service (Van Zyl, 2014). In South Africa, the design guidelines stipulate that the maximum head during reticulation under static conditions should not exceed 90 m and the minimum head during the design peak flow should be 10 m for yard connections and 24 m for house connections. The typical domestic demands for developing areas are 25 l/c.d (litres per capita per day) at communal standpipes, 55 l/c.d at yard connections and 80 – 405 l l/c.d at house connections; for developed areas these demands range between 600 – 1,200 l/c.d (Roodie, 2009).

Furthermore, an adequate WDS should have the ability to handle internal and external stresses in such a way that its components do not fail. Internal stresses result from operating pressure variations, water hammer and internal corrosion, while external stresses result from soil stresses, external loadings and external corrosion (Van Zyl, 2014). This will depend on the proper selection of system components during the design phase. It involves not only taking consideration of the internal hydraulic conditions but also the external environment such as soil conditions and electric currents that may be in the soils or around the environment that the WDS will be exposed to (Roodie, 2009). These considerations should be used in selection of the components that will be used to construct the system in terms of functionality, durability, and maintenance while at the same time being cost effective.

The tendency to use water in abundant quantities may arise when water is readily available and conveniently accessed by people, in turn personal cleanliness is promoted and maintained (Wagner & Lanoix, 1959). If the community uses the water in quantities more than it was designed for, it will put the WDS under pressure and will not provide enough water to meet the unrealistic needs of one such community. Whilst improvement of personal hygiene levels is a desired benefit of a WDS, it must not lead to wasteful practices of the water resource, the consumers must be sensitised to being mindful on how to sensibly use the water resource.

An adequate WDS will reduce the time required to collect and transport water, and more time can be spent of economic activities such as farming, herding etc. There will be improved opportunities for keeping livestock and undertaking subsistence farming, for attracting small businesses and thus may reduce emigration (Okun et al., 1987). In rural areas, women and children often are given the role of water provider. The provision of

water to their communities would mean that they do not have to spend time in search of water and can engage in income generating activities and attend school (Lewis, 2010).

An adequate WDS will therefore free women from the task of looking for, collecting and transporting water and will provide more time for income-generating work, the children, the household, as well as for educational programs and training. Children who were previously obliged to carry water will spend more time in school and on their studies (Okun et al., 1987).

2.4.2 Quality

A WDS should also deliver water that is of good quality and meets all drinking water standards and is aesthetically pleasing to the customer; water should be chemically, microbiologically and aesthetically sound (Deb et al., 2000).

The WDS should not adversely affect the quality of the water it transports; this is on the assumption that it receives water of acceptable quality from its source, whether from a borehole, water treatment plant, reservoir or a pipeline (Van Zyl, 2014). Deterioration of water quality during transportation may be caused by external contamination, for example through leaking pipes and fittings along the transmission lines that have very low water pressure or through storage tanks that are not properly covered and are susceptible to contamination from bird droppings or dust that may be blown into them. Contamination may also be brought about from internal sources such as deteriorating pipes that may cause discoloration and foul taste in the water. Internal contamination may occur as a result of long water retention times within the network such as at dead ends or in large storage tanks with long retention times. This may cause the residual disinfectant to degrade, leaving the water susceptible to microbiological contamination.

High-quality drinking water will provide an increased incentive for business and industry that would be reluctant to re-locate operations, or site new facilities, in an area with marginal to poor drinking water (Wagner & Lanoix, 1959).

An adequate WDS will lead to the reduction and eradication of water-borne diseases (Wagner & Lanoix, 1959). It contributes to the reduction of mortality rates in children and an increase in life expectancy. An adequate WDS further reduces the effects of water-related diseases and significantly benefits individuals; it promotes saving in acquisition of medical treatments, travel costs to medical centres, and time taken off productive work to attend to the sick by relatives responsible for their care. An adequate WDS encourages increased productivity and extended lifespan (Okun et al., 1987). This in turn will contribute to the increase in economic welfare of a community.

Apart from the primary characteristics described above, there are secondary characteristics that a WDS should have for it to function adequately and meet its objectives.

A well-trained, motivated operating team is one such characteristic. This team will ensure that the system is operating within its stipulated hydraulic parameters and that the system components are all in good working order. The team also ensures the water quality received by the consumers is not compromised. The WDS should have a well-trained and motivated maintenance team that undertakes routine maintenance of the system components as well as reactive and emergency maintenance. An adequate WDS should also have an O&M manual, a good maintenance schedule and an adequate reporting and recording system that is used by the O&M personnel to execute their duties. A WDS that is physically adequate but does not display these secondary characteristics will struggle to meet its objectives and in time will also lose its primary characteristics.

2.5 Life cycle of a Water Distribution System

A WDS, like any other asset, is expected to have a life cycle from inception through to decommissioning or replacement. There are different approaches to describing the life cycle of a WDS as outlined below.

2.5.1 The life cycle according to the Red Book (CSIR, 2000)

Five stages presented by CSIR (2000) are: these are identification and preparation stage; report approval and design stage; implementation stage; operation stage; and evaluation stage.

At the identification stage, the need for water access or improved water services is identified; a report including a tentative planning program is drafted. In the preparation stage, feasibility reports and preliminary designs are drawn up and submitted to the relevant authorities for approval. Appraisals of the feasibility reports and financial decisions are undertaken at the approval stage. Thereafter, a detailed design of the proposed water system is undertaken in preparation for the implementation stage. At the implementation stage, a suitable contractor is appointed and the construction commences with close supervision from the designers. Once complete, the water system is commissioned and handed over to the stakeholders, complete with as-built drawings of the system. After the commissioning, the water system then carries out its function at the operation stage.

The system is operated and maintained appropriately so that it may continuously meet its objectives. The evaluation stage runs concurrently with the operation stage; in this stage the project outcomes are compared to their initial objectives and any lessons learnt from this project are documented for future similar projects. Evaluation should continuously be undertaken to ensure that the water system satisfactorily meets its objectives. Once the system struggles to do so due to either an increase in the community population or deterioration of the components, the need for improved services is considered and the water system cycle begins again.

Design periods for the integral components should not exceed 10 years; beyond the 10 years, the system should undergo extensive rehabilitation or replacing.

The following figure 2.3 depicts the breakdown of the WDS life cycle as depicted by CSIR (2000).

<table>
<tr><th colspan="2">STAGES</th><th>ACTIVITIES</th></tr>
<tr><td rowspan="4">Pre-investment planning</td><td rowspan="2">Identification</td><td>• Awareness of need for improved services
• Assignment of planning responsibilities</td></tr>
<tr><td>Identification report</td></tr>
<tr><td rowspan="2">Preparation</td><td>Pre-feasibility report</td></tr>
<tr><td>Feasibility report
Preliminary design</td></tr>
<tr><td colspan="2">Approval</td><td>• Appraisal
• Investment decision
• Detailed design</td></tr>
<tr><td colspan="2">Implementation</td><td>• Construction of facilities
• Supporting activities
• Commissioning
• Completion drawings</td></tr>
<tr><td colspan="2">Operation</td><td>• Operation and maintenance of facilities
• Continuous provision of services</td></tr>
<tr><td colspan="2">Evaluation</td><td>• Monitoring of project results
• Feedback for future projects</td></tr>
</table>

*Figure 2.3: Development stages for water supply and sanitation projects (*CSIR*, 2000)*

2.5.2 The life cycle according to the O&M of the Water Services Handbook, Northern Cape (Carlsson et al., 2010)

Carlsson et al. (2010) uses the asset management cycle to depict the stages of a WDS. A new project begins with the needs assessment stage, followed by the planning and funding stage, the construction and commissioning stage, and then the O&M stage that runs concurrently with the continuous evaluation and needs assessment stage which leads to a new project. The figure 2.4 shows these stages:

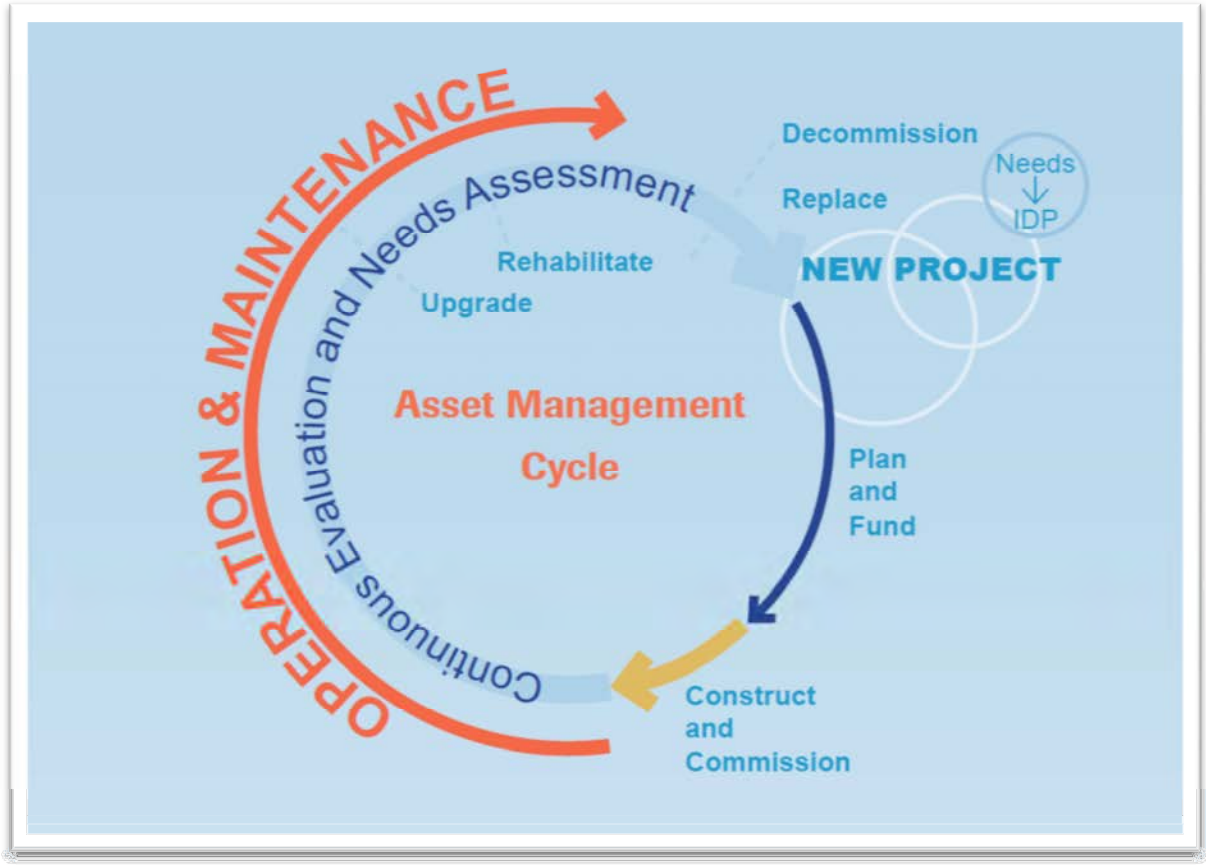

Figure 2.4: Asset Management Cycle (Carlsson et al., 2010)

The process described by the O&M Handbook is similar to the one provided by CSIR (2000). A description of the stages is given below.

The creation of a WDS can be broken down into seven stages that flow into each other; the last stage leads to the first stage thus forming a cycle of events that constitutes a life cycle.

Concept Phase: This phase involves the awareness of the need to provide a WDS or the need for improved services and the assignment of planning responsibilities.

Planning Phase: In this phase, several reports pertaining to the project are compiled, these include: identification report, feasibility report, preliminary designs, application for funding (if necessary).

Approval and Design: The documentation of the planning phase is reviewed by the relevant authorities and approved once it meets the criteria. After approval, the project is designed in detail, taking into account sizing of each system component so that it meets the identified needs. In this phase, the operation and maintenance of the system is taken into account; this means considering the best technology for the system so that appropriate O&M will be undertaken, using the available resources.

Implementation: In this phase, the WDS is physically constructed according to the detailed designs. It is important that proper construction procedures are adhered to. A water utility should have a set of written and filed construction standards; during implementation experienced personnel constantly need to inspect the construction works to ensure that the construction standards are met (Deb et al., 2000). Testing of the completed WDS is done in this phase before the project is handed over.

Handover and Monitoring: After the constructed system has been tested and satisfactorily meets all requirements, it is handed over to the authorities that will be responsible for the O&M of the system. This also includes the thorough training of personnel that will be operating the system. It involves a monitoring period during which those responsible for implementation will be constantly involved in the operation of the system as an active process of knowledge transfer to the appointed operator(s). It also involves the monitoring and documenting of the project outputs and results that will be used as feedback for future projects.

Operation and Maintenance: This phase accounts for the lengthiest part of the WDSs life span. The WDS is operated with the aid of an appropriate set of O&M instructions found in an O&M manual. The O&M manual typically includes the overview of the water system, drawings, standard operating procedures, log sheets, maintenance schedules, emergency response plans etc. (Ministry of Health, 2010). Appropriate O&M practices ensure that the water system lives out its design life and does not require earlier replacing.

Replacing: This is the phase in which the system has reached the end of its design life, usually with an increase in the cost of O&M. It is marked by frequent breakdown of the water system components caused by aging. At this point, consideration should be given of extensive rehabilitation of the system or even total replacement because it no longer meets the needs of the users and it is time to plan for a new system.

2.6 Water Distribution Systems in rural and urban areas

Water distribution systems in rural and urban areas are essentially similar. The differences between distribution systems in rural and urban areas are found in the engineering design standards and assumptions used (Wagner & Lanoix, 1959). These standards and assumptions stem from of the differences in water use and settlement patterns found in rural and urban areas. Such differences include the amounts of water for domestic consumption, the standards of protection against fire, and the degree of water treatment (Wagner & Lanoix, 1959).

Below are descriptions of the water use, settlement patterns, and water access found in rural and urban areas respectively. Their respective challenges are also discussed.

2.6.1 Rural Water Distribution Systems

Many deep rural areas are characterized by scattered households located predominantly on hillsides above flood plains. In South Africa, up to 2,7 million people (approximately 6% of the national population) live in such scattered patterns. They are clustered into over 15 000 groupings of settlements. The remaining rural settlements are classified into over 7 500 small villages for those that have less than 5 000 people and over 500 larger rural villages for those with more than 5 000 people (DWAF, 2008). This settlement pattern is a challenge in providing WDSs in rural communities.

2.6.1.1 Water uses in rural areas

Typical uses of water in rural areas vary from domestic uses (drinking, washing, cleaning and preparing food) to agricultural uses such as watering vegetable gardens and feeding livestock, and for small commercial businesses that prepare food for sale. Water provision services in the rural areas have to be planned and designed with these additional needs in mind, with the aim of maximising benefits for rural populations from water provision (Moriarty et al., 2012).

In the Dominican Republic, the government constructed rural water schemes with limited focus on the social and organizational development of the communities; as a result the communities were unable to manage, operate, and maintain these systems efficiently. The water schemes therefore fell into disrepair or were not working to full capacity (Lockwood, 2002).

Rural water users obtain water from both formal and informal sources to meet their water needs. There is therefore a need to raise awareness of the health risks of using water from informal sources and adopt a more integrated approach to providing rural water services that takes into consideration the full range of water use in people's livelihoods. It is also important to provide more opportunities for rural communities to express their demand for water services tailored to their needs (Moriarty et al., 2012).

2.6.1.2 Water access in rural areas

Reasonable access is described as the availability of at least 20 l/c.d from a source within one kilometre of the household. Government policy on water provision in South Africa defines basic water supply as 25 litres per person per day, within 200 metres of the home, and of acceptable quality (World Bank, 2002).

The proportion of people without access to safe drinking water is significantly higher in rural areas than in urban areas. The Millennium Development Goal (MDG) target pertaining to water is to 'halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation'. In South Africa, this target was achieved in 2010; however, globally 748 million people still relied on unsafe drinking water sources in 2012 (UN, 2014).

When a water supply system is provided by a water utility, organization or governmental department, communal standpipes may be used as a means of water access in rural communities. These standpipes should be located within the population clusters found in rural areas and should meet the basic water supply criterion in South Africa, i.e. at a distance of not more than 200 m from any household (World Bank, 2002).

In rural areas, especially in developing countries, wells equipped with hand pumps are also used a means of accessing domestic water supply for households and villages. In such a setup, distribution is mainly by carrying water in cans or buckets from the wells to the houses. The amount of water carried in cans or buckets is far too small for the effective promotion of health and personal hygiene (Wagner & Lanoix, 1959). Wells should therefore be installed in close proximity to the rural population clusters so as to minimize the distances from the households.

Wells may be used when the ground water table is high enough for extraction and the water is of acceptable quality. If not, other means of water supply and access should be explored. The O&M of the wells should also be taken into consideration when designing and installing them. The community should have the competency to operate the wells and have access to spare parts and the expertise to maintain the wells.

Rural areas can have water supply systems operated by community groups as opposed to having an external body such as an NGO or government operating it. In Kenya, 30 percent of the rural dwellers with improved access to water supply via piped or point source systems are served by community managed water supply schemes (Rukunga et al., 2006).

Due to the scattered cluster settlement patterns that are predominant in rural areas, an O&M model that may be adopted is have a community based group in each rural cluster operate and maintain the water systems with the support of an external body such a government department or an NGO. This will increase access to water in rural areas. Obstacles that deter rural communities from running community based water supply

systems are the lack of start-up and running capital, access to spare parts and lack of technical personnel to operate the water supply systems.

Before 1994, there was no central government department dedicated to the supply and management of water resources in South Africa. The homeland governments operated the water service infrastructures, and in poor rural areas these were inefficiently operated by uncoordinated government structures (Nnadozie, 2011). These rural communities had limited access to clean drinking water and in some cases the communities had to build their own water supply schemes. After 1994, these schemes were taken over by the government under the Department of Water Affairs and Forestry (DWAF, 2005_a) that inherited 600 rural water supply schemes (Matji, 2003). Access to clean water in South Africa has improved from 63% to 88% between 1990 and 2012 (WHO &UNICEF, 2012).

2.6.2 Urban Water Distribution Systems

Urban areas are shaped by leading corporate organizations, institutions and by the planners who aim to implement their visions (Landman, 2010). Urban areas are structured along socio-economic activities such as industrial areas, city and town centres, residential areas; upper, middle and lower income, and entertainment centres (DWAF, 2008).

Water supply systems are part of this urban planning process. WDSs in urban areas are therefore expected to be well organized and structured to meet the needs of all socio-economic groupings. Many urban areas, however, experience rapid rates of rural-urban migration accompanied by development of informal settlements on the urban periphery. This is often combined with an influx of low income households into areas of the city centres that were formally inhabited by affluent businesses and middle-income households (DWAF, 2008).

As a result, the water supply challenges experienced in urban areas include; access to water services in informal urban settlements, over-exploitation of water resources, pollution of surface and ground water resources, inadequate sanitation facilities, contaminated drinking water supplies, and water loss through leakage in WDSs (Carden & Amitage, 2012).

In South Africa, despite accelerated basic service delivery, many local authorities are battling to keep pace with urbanisation, and a critical lack of capacity and technical skills has also seriously impacted on the ability of national and local authorities to control and manage the water sector (Carden & Amitage, 2012).

2.6.2.1 Urban water use

Increased urbanisation, population growth, and rising living standards have been major drivers in the increase of urban water use in the past century. As a result, there is a growing concern about the depletion of water resources (Lallana & Thyssen, 2003).

A water use research undertaken in urban areas of Europe revealed that during the period 1993-1999, the urban use per capita had slowed down from an average of 104 to 99 m^3/inhabitant/year. Changes that could have influenced water use over this period include; change of population habits, use of more efficient technologies and water saving devices, use of alternative sources of water (desalination, wastewater re-use), increased metering, use of economic instruments (water charges and tariffs), increase of tariffs, and restructuring of institutional framework (privatization of water supply services). This has resulted in a decrease of water usage by 40% in urban areas of these developed countries (Lallana & Thyssen, 2003).

In developing countries, the scenario is somewhat different. An increase in rural-urban migration patterns means that the population in urban areas is on the rise, hence an increase in water demand. Although offering more opportunities and amenities, cities in developing countries often experience problems due to overcrowding and poor infrastructure especially in the low-income areas (Kibue & Craven, 2000)

Urban areas in developing countries also experience accelerated urbanization. This means an increase in industries and commercial activities which in turn increases the amount of water usage in these regions. WDSs are therefore expected to be upgraded to meet this unprecedented increase of water use. Failure to do this may lead to illegal connections to the areas not served by the WDSs, cross contamination, lower water pressure available to consumers and loss of revenue due to illegal connections.

2.6.2.2 Water access in urban areas

Residents in urban areas receive water from private connections, water trucks, yard and communal standpipe connections, water kiosks, water vendors and piped private connections to households.

Ethiopia is a developing country with a fast growing population within its capital city, Addis Ababa. A water supply research was conducted in Addis Ababa and it was found that residents in the poor urban areas were getting low levels of water supply services and low quality water while paying relatively high price for water. Average water consumption was less than 20 l/c/d, meaning that these residents were considered to having no basic access to water supply by World Bank standards (Sharma & Bereket, 2008).

If the local authority allowed them to pay the installation cost in instalments, most of the residents would prefer to have private taps and have their connections metered (Sharma & Bereket, 2008).

Similar results were found in water supply researches conducted in urban poor residences of Dar es Salaam, Tanzania (Kjellén, 2000) and in India (McKenzie & Ray, 2009). It is likely to be replicated in other poor urban areas of developing countries.

McKenzie & Ray (2009) recommends that the initial installation cost of metered water be broken down and paid in instalments as opposed to a lump sum; this would make metered water more affordable to the urban poor residents (McKenzie & Ray, 2009). Kjellén (2000) further recommends that for a short term solution to the water supply crisis, water vendors, water kiosks, and water trucks should be recognized as formal means of water distribution by the local authority and the water and sanitation authority. This means availing water to these vendors at subsidised rates and regulating the price of water sold to the end user.

As a long term solution, the full privatization of the water supply system was the way to go (Kjellén, 2000). Privatization of the operation and maintenance of a water supply system may present as a viable idea, however, caution must be taken by both the governmental body and private firm when getting into such a contract to avoid disappointments as in the case of Government of Tanzania and City Water (an international professional firm). The lease contract for the operation and maintenance of the Dar es Salaam Water Utility was prematurely terminated amid allegations of breach of contract from both parties (Kjellén, 2000).

While urbanization and population increase do affect the performance of a WDS, other factors that may also affect the WDS include; the level of expertise of the O&M teams running the system, the equipment, and resources available for O&M, management and support system (customer care) of the WDS and even the O&M practices used in operating the WDS. This research seeks to investigate these other factors that affect the performance of a WDS in both urban and rural setting.

2.7 Operation and Maintenance

Operation and Maintenance (O&M) may be described as all activities needed for a water supply and sanitation entity to function (World Bank, 2007). It is a continuous process involving various activities with the ultimate purpose of delivering good quality services to all customers at all times (Roodie, 2009). O&M of a water supply, water treatment and WDS is an important part of any effort to ensure on going production and delivery of high quality drinking water (Royal Haskoning DHV, 2013).

Operation involves activities necessary to deliver an adequate and reliable supply of safe water to its users; it includes operating and monitoring the system as well as enforcing policies and procedures. Maintenance on the other hand involves activities that keep the system in good operation condition. These activities involve servicing, repair and replacement of system components and also condition assessment of the components (Van Zyl, 2014).

Below are detailed discussions of the activities that constitute O&M of a WDS.

2.7.1 Operation of a Water Distribution System

A WDS must be properly operated for it to perform at acceptable levels of service. Human operators may be used to monitor performance and operate a water distribution system; when certain characteristics change, the operator takes remedial action to counter these changes so that the system operates within reasonable bounds (Chase, 2000).

Poorly operated WDSs could lead to low operating pressures causing inadequate supply, high operating pressures causing leakages in the system, and low velocities causing retention of water in pipes and reservoirs. Long water retention periods could subsequently lead to settling of suspended particles. High water velocities on the other hand could lead to frequent changes of flow direction causing water turbidity. These problems will not only affect water supply and cause damage to the system elements but can also have serious impact on public health. Dealing with them also influences maintenance requirements and the overall exploitation costs (Trifunovic, 2006).

There are certain parameters that can be measured to provide an indication on whether the WDS is being operated appropriately. If a selected parameter is outside the recommended limits, remedial actions can be carried out to bring it back to acceptable limits. The typical parameters that are monitored in a WDS are described below.

2.7.1.1 Pressure

It is common in developing countries for water distribution networks to suffer from excessive pressure, large daily pressure variations, and high water consumption per capita (Babic et al., 2014). Pressure in most cases should be kept above 21 meters and below 70 meters during normal operations. In emergency conditions, such as a fire, pressures should be maintained above 14 meters throughout the entire system (Gagnon & Bowen, 1996).

South African guidelines provided in the Red Book indicate that maximum head during reticulation under static conditions should not exceed 90 m while minimum head during peak flow should not be less than 24 m for house connections and 10 m for yard standpipes. Pressure much greater than 90 m tend to waste water through leaks and could damage residential and commercial plumbing systems or even cause main breaks (CSIR, 2000).

WDS leakages are often quite sensitive to pressure changes in the system. Pressure management is a technique formulated to reduce leakage rates in the system (Van Zyl, 2014). Pressure management was first practiced thirty years ago in Japan and the United Kingdom after the reduction of excess pressure was identified to significantly

reduce flow rates of existing leaks and bursts. The practice has since been promoted and is now widely known and practiced by many water utilities worldwide.

Utilities that have implemented pressure management have realized benefits other than leakage control. These include deferred pipe renewals, increased life of water infrastructure, reduced costs of active leakage control and improved service to customers through fewer interruptions (Lambert & Fantozzi, 2010). Reliable concepts of pressure management and practical methods are needed to make sound financial decisions for such investment, and for prioritising individual pressure management schemes (Lambert & Fantozzi, 2010).

Pressure management is a process that requires specialized personnel, equipment and a sound management base that will use the resulting information to make appropriate decisions in WDS operations and maintenance. Pressure management practices may not be prioritized in a water utility that is operating on a limited budget and limited technical personnel.

2.7.1.2 Flow

Flow and pressure are directly related to one another. When the flow in a pipeline increases, the pressure at the end of the line will decrease. When the pressure in part of the system falls below acceptable limits, it does so because the usage in that part of the system is most likely to be high (Gagnon & Bowen, 1996).

Pressure management may be used to control flow in a system and keep it within acceptable limits to prevent system pressure from being too high or too low. Water meters record the quantities of water that enter the system, how it is transported to different parts of the network, and how much is delivered to consumers (Van Zyl, 2014).

The efficiency of a WDS is measured by the difference between WDS input volume and water delivered to customers and billed. Non-revenue water (NRW) constitutes water losses (real and apparent) and authorized unbilled consumption such as water used for pipe flushing and firefighting. Real losses include leakages in the WDS and tank overflows, while apparent losses include the unauthorised consumption and metering inaccuracies (Babic et al., 2014).

Water and revenue losses are a major problem for water utilities worldwide (Babic et al., 2014). The pressure management technique uses meters and pressure reducing valves to control the flow of water in the system and consequently controlling the amount of water lost through leakages.

2.7.1.3 Velocity

CSIR (2000) indicates that the water velocity in a distribution system should be approximately 0.6 m/s and not exceed 1.2 m/s. Water velocities below this can lead to stagnation conditions within the pipes. This in turn can lead to settling of suspended particles as well as contamination of the water caused by long retention times which degrades the amount of residual chlorine in the water (CSIR, 2000). High velocities on the other hand cause turbulence within the system that may lead to high turbidity levels in the water.

2.7.1.4 Tank levels

A water storage tank is designed so that the water level fluctuates with the change of hydraulic conditions over the course of the day; stagnation depletes the water of disinfectant residual and water quality problems may develop (Deb et al., 2000).

Gagnon and Bowen (1996) advise that operators must ensure that sufficient volumes of water are stored in tanks at all times in the event of an emergency such as a fire, power failure or source outage. Reservoirs located on higher ground above the system or water towers provide the WDS with the required pressure (Van Zyl, 2014). Reservoirs and water towers should be designed in such a manner that the daily peak demand is met, that there is ample system pressure, that water stagnation is avoided, while at the same time retaining enough water in case of emergencies. Water tank levels should constantly be observed to ensure that there is a healthy fluctuation level to avoid stagnation while at the same time ensuring that the daily peak demands are met.

Monitoring of the operation parameters of a WDS may be conducted manually by an operator who physically checks the parameters using instrumentation such as flow meters, pressure gauges, tank level indicators etc. In such cases, should any parameter be outside the stipulated range, the operator is expected to take action that will bring it back to range. This could be by opening or closing a valve, or switching a pump on or off. These parameters can also be monitored and controlled with the assistance of an automated system such as the Supervisory Control and Data Acquisition (SCADA) system.

2.7.1.5 Supervisory Control and Data Acquisition (SCADA) system

A SCADA system is a collection of field instrumentation, communication systems, and hardware and software systems that permit a system's behaviour to be monitored and controlled, typically from a remote site (ASCE, 1991). The purpose of the field instrumentation is to collect information on the state of the hydraulic system. Such instrumentation may include programmable logic controllers (PLCs), remote terminal units (RTUs), liquid-level switches, or other instruments (AWWA, 1983). These devices are used for measuring, recording, and controlling the operating parameters, such as pressure, flow, or tank water levels. The SCADA systems are helpful in controlling and monitoring large complex WDSs such as those found in urban areas.

2.7.2 Maintenance of a Water Distribution System

The O&M Manual used by the Kai !Garib local municipality in the Northern Cape in South Africa defines maintenance as the activities required to sustain the water treatment and supply system in a proper working condition. It divides maintenance into preventative, corrective and crisis maintenance. Preventative maintenance is the regular inspection and servicing of system components with the aim of preserving assets and minimize breakdowns. Corrective maintenance on the other hand involves minor repair and replacement of broken and worn out parts to sustain reliable facilities. Crisis maintenance is the unplanned responses to emergency breakdowns and user complaints to restore failed supply (Royal Haskoning DHV, 2013).

The World Bank on the other hand breaks down maintenance into preventive and reactive maintenance. Preventive maintenance is the continuous practice of the systematic routine actions required to keep the water utility plant and equipment in good condition. It also includes minor repairs and replacement when faults are detected during the routine examination. Reactive maintenance occurs as a result of a sudden emergency situation such as pipe breaks and the malfunctioning of equipment (World Bank, 2007).

Preventative maintenance involves the drawing up of a pre-established schedule that outlines a list of maintenance activities to be carried out on a regular basis. This schedule should be adhered to closely by the maintenance team. Once a routine inspection has been conducted, it should be signed, checked and signed off by the team manager and filed for record keeping.

The list of activities should include but not limited to: cleaning, equipment lubrication, leak detection, valve inspection, pump inspection, pipe inspection, and inspection and repair of meters.

It is important to have a workshop to conduct repairs on equipment (World Bank, 2007). A maintenance schedule should be accompanied by relevant training of the maintenance team to ensure a better understanding of the WDS components and the reasons for the maintenance procedure. This will increase commitment to undertaking the maintenance tasks and the ability to detect system issues before an emergency situation is reached.

2.7.2.1 Scheduling of Operation and Maintenance

Planned or proactive O&M should be scheduled and systematic. All activities need to be recorded and reported. Record keeping forms the basis of planning and budgeting of O&M (Carlsson et al., 2010). Once maintenance is performed, it must be properly recorded in good time; preventive maintenance tasks are not complete until their accompanying paperwork is done (Brandt et al., 2000).

To prepare an adequate schedule, an updated WDS map with contours indicating location of valves, flow meters, pipes etc. is required. Based on this map, the water utility responsible for O&M should set up routine procedures for updating the map and the inventory of the distribution system components (WHO, 2005).

Routine operations should be specified activities for adjusting valve and pump operations to match prevailing conditions, i.e. flow, pressure, and reservoir levels. This schedule should contain the procedures of obtaining, processing, analysing the parameters and the consequences of manipulating control devices so that the hydraulic status matches water demand. Apart from routine maintenance, activities that need to be carried out during breakdowns and emergencies also have to be specified. Procedures of an emergency response plan should be outlined in case the hydraulic conditions of the distribution system are outside of a stipulated scope (WHO, 2005).

For an improved level of maintenance of a WDS through co-ordinated and planned administrative and field work, a maintenance schedule is required. This schedule should be flexible so as to achieve optimum team work with available resources. Preventative maintenance schedules may include tasks, set priorities, issue of work orders, list of task schedules not completed, records of tasks that are completed as well as a records of tools, materials, labour and costs incurred for each complete task (WHO, 2005).

Preventative maintenance and record keeping systems are typically card systems. Single card systems use one card for each piece of equipment or WDS component. The card indicates the equipment details, maintenance requirements and is used to record the details of the maintenance performed. Many utilities are however moving from the card system to one of the many available software programs developed specifically for scheduling and tracking of preventative maintenance (Brandt et al., 2000).

2.7.3 Operation and Maintenance activities

The bulk of O&M activities are and should be preventative in nature, that is, checking the entire network and fittings to ensure that they are in good operational condition (Carlsson et al., 2010). These activities are discussed below.

2.7.3.1 Pipeline maintenance

Pipelines should be checked for leakage on a regular basis and inspected one section at a time. Inspection should be guided by the water balance of the section and discrepancies between produced and consumed volumes should be investigated (Carlsson et al., 2010).

Pressure management techniques may also be used to detect and control leakages in a WDS. Pressure in the different pipeline sections should be measured and pressure losses should be investigated as they could be caused by pipe leaks. Old pipes and pipes susceptible to leakage should be inspected more regularly. Sufficient stock of

pipes, couplings and other maintenance materials should be checked and regularly replenished (Carlsson et al., 2010).

Apart from leakage detection and control, maintenance of distribution pipes should also consists of checking for corrosion and accumulation of scale. Each time a pipeline is opened, the interior of the piping should be observed. The life of a distribution system can be greatly extended by workmen who report pipe damage when installing or replacing house connections (WHO, 2005).

Regular system flushing improves water quality and reduces the system's need for reactive maintenance. Flushing assists in the removal of bacteriological growth, sediments, corrosion products and encrustation. A flushing program should be devised such that it is workable within the water system constraints. If a system is too large to have it flushed annually, a program should be developed that will ensure the entire system is flushed within the course of several years. It is important to incorporate flushing of dead ends and problem areas in the program. The best time to conduct a flushing program is during low water demand seasons (Deb et al., 2000).

Proper treatment operations and cleaning of system reservoirs should also be planned along with the flushing programmes. Prior planning and good publicity will allow the flushing program to proceed efficiently and quickly. If flushing does not improve water quality mechanical cleaning devices such as swabs and scrapers can be used to clean the pipelines (WHO, 2005).

If there is evidence of tuberculation or corrosion, water main swabbing using a soft foam swab should be conducted. Water mains should be flushed periodically, in response to customer complaints or to none-compliant sampling. Unidirectional flushing is recommended which starts at the source and progresses from the largest pipes to the smallest (Genivar, 2007). It requires a considerable amount of planning and crew coordination. It also tends to be manpower intensive but is considered to be the most effective flushing method (Deb et al., 2000).

Flushing checklists should include carefully selected flush out locations, notify the consumers in advance of possible impact and duration, and ensure reservoirs are full to ensure that there will be enough water to conduct the flushing program (Genivar, 2007).

The minimum flushing velocity is 0.75 m/sec while the preferred flushing velocity is 1.5 m/sec. This will ensure that biofilm and sediments in the network are flushed out. Flush out points, which are typically hydrants, should be open for a period of 5-10 minutes to stir up sediments, and flushing should continue till the water is clear. System pressure in other parts of the distribution network should not drop below 14 m. Two water samples should be tested for chlorine residual. The first sample should be tested after 2-3 minutes of flushing and the second sample just before completion of the process. The results should then be documented and records updated accordingly (Genivar, 2007).

Once the flushing program is completed, data from the exercise should be input into the key databases. If the flushing was as a result of customer complaint, completion of the program should be noted in the customer complaint database. Water quality sampling should be obtained, recorded, and used to evaluate the effectiveness of the flushing (Deb et al., 2000).

2.7.3.2 Valve maintenance

WDSs are designed with a sufficient number of valves to isolate system breaks. If they are found to be broken, stuck, buried or not locatable, the amount of time required to isolate and repair a break will increase; this may also lead to an increase in the cost of repairs (Deb et al., 2000). If valves do not work when needed, the entire system may be required to be shut down. It is therefore important to exercise the valves in the system at least once a year (Genivar, 2007).

Carlsson (2010), however, advised that depending on the age and condition of the valves, inspection frequency may vary and once a month is recommended, but should not be less than twice a year. The WHO (2005) also recommends that valves and hydrants should be inspected every two months. This should be the field operators' primary duty and should be carried out on a regular inspection schedule. A simple check list could be used during such inspections to ensure that no valve is missed. Small WDSs that do not have too many valves may adopt a frequency of once or twice a month. This frequency may not be possible for large or understaffed systems. In such a case, priority is given to valves that are located in critical locations. These critical valves are those that control the mains and isolate pressure zones. These valves should be exercised and maintained once a year and the other valves can be exercised in a multi-year cycle (Deb et al., 2000).

Gate valves should be checked for leaks around the flange gaskets and valve stem. Bolts on flange mounted valves should be checked and tightened. The valve body should be cleaned and internal coating inspected; corrosion protection may be applied. The valve stem and nut should be lubricated, and every five years the stem seal and gaskets should be replaced. Air valves should also be checked and those that are not functional repaired or replaced. The valve boxes should be checked and cleaned. Damaged locks and covers should be repaired or replaced (Carlsson et al., 2010).

All valves should be clearly and correctly marked on as-built drawings of the entire system. The valves should also be clearly marked on the ground so that they are easy to locate by the O&M staff. The distribution system map must also be updated and should locate and identify all the valves in the system. Documentation for each valve (type, date of last exercise, number of turns to close, and record of maintenance work) should be available. The records should indicate the direction of opening or closing of the valve and whether the valve is normally open or closed (Genivar, 2007). Caution should be taken in opening and closing of valves; this should be done slowly to avoid water hammer (Carlsson et al., 2010).

Steps taken during a routine valve inspection must involve the accurate identification of the valve box location, removal of the valve box cover and the inspection of the stem and nut for damage. Any recommended maintenance should be recorded as well. Missing valve box covers should be replaced and the valve should be placed in its operating position, i.e. either closed or open (Genivar, 2007).

Valve chambers should be checked for damage or filling of earth material. A broken chamber cover may lead to damage of the valves or/and lead to the accidental fall of a person into the chamber. Road improvement procedures require constant attention since valves near the road outline that are not located and can be damaged in the process. The servicing procedure should contain the manufacturer's details and technical information of the equipment provided. Test certificates of inspection reports and warranty certificates should be included in the O&M manual (WHO, 2005).

The efforts spent on valve maintenance will repay many times during cases of emergency and fire when valves must be quickly located and operated. Packing and leakage can also be checked at inspection time (WHO, 2005).

2.7.3.3 Hydrant maintenance

Regular maintenance of hydrants provides assurance that they will be fully functional when needed (Genivar, 2007). According to Deb (2000), hydrants should be inspected a minimum of once a year, and dry-barrel hydrants in freezing climates should be tested twice a year (Deb et al., 2000).

In contrast, Carlsson (2010) suggests that hydrants in high fire risk areas should be checked monthly and others annually. This is to ensure that the hydrants perform properly during emergencies. While the regular inspection of hydrants is a recommended exercise, a frequency of once a month may be difficult in the case of large WDSs with limited resources. In such a case, a maintenance frequency of once every six months for major hydrants may be adopted, with minor hydrants to be inspected once a year (Carlsson et al., 2010).

Hydrants should be clearly marked on the ground and should be easy to spot and access. Sand and other debris that block the valve spindle should be removed. The valve should be easy to open and close. The stems and nozzles should be checked for leaks and flange bolts and nuts tightened (Carlsson et al., 2010).

A hydrant maintenance program should include the following; an updated system map indicating the location and number of hydrants, a schedule for flow testing and documentation of each hydrant (hydrant type, installation date, maintenance records etc.). The suggested general inspection and maintenance procedure involves checking for leakages, removal of nozzle caps, thread inspection, replacement of missing or damaged nuts, checking the barrel for cracks, checking for ease of closing and opening of the hydrant and checking for exterior obstacles that would interfere with hydrant operations. If a hydrant is found to be inoperable, it should be clearly tagged and the

condition immediately reported to the fire department. The record of inspection and maintenance and any repair work should be prepared and filed (Genivar, 2007).

Hydrant testing and maintenance should be done in coordination with fire flow testing as well as flushing (Deb et al., 2000).

2.7.3.4 Storage tank maintenance

It is good practice to have elevated storage tanks and ground level reservoirs cleaned and disinfected and placed back into service following major inspection and maintenance. Cleaning involves emptying the reservoir, removing accumulated sediments, washing down and rinsing the walls and floor, and inspecting the internal surfaces and joints to ensure they are in good condition (Van Zyl, 2014).

After cleaning, the tank should be disinfected before filling it with water for distribution. The water quality should be tested before distribution commences. Tank maintenance should be done once a year and should also include inspecting all openings to ensure that they are properly screened and ensuring vents and screens are free from blockage. The tank walls and foundations should also be checked for deterioration. Any material or reagents used to recoat and repair the interior of a tank should be certified by the national standards authorities. Minor inspections can be undertaken daily and involve checking and recording of water levels as well as checking of overflow and leaks (Genivar, 2007).

Deb et al. (2000) also adds that periodic overflowing of the tank is recommended to skim the surface. Detailed inspection and maintenance can be conducted between 3-5 years which will involve emptying the tank and putting it out of service (Deb et al., 2000). Other than the physical maintenance of the storage tank, it is also important to carry out the maintenance of the pipework, fittings, and the property around the tank area. This may include a weekly inspection and maintenance of the security fence, gate, locks, lighting, and water level indicators. Inspection for leakage and operation of water meters, pumps, valves and pipework should also be undertaken (Van Zyl, 2014).

Concrete tanks generally require little attention, steel tanks however must be painted often to prevent corrosion damage. Manufacturer's instructions regarding type of paints and methods for painting must be strictly adhered to (WHO, 2005). If adequate storage tank maintenance is not undertaken, this may not only lead to deterioration of the tank structure but also will compromise the quality of water leaving the storage tank for distribution.

2.7.3.5 Meter maintenance

Meter maintenance involves the cleaning and testing of meters as well as the replacement of worn-out parts. A small repair workshop is required to carry out these tasks. It can be a room about 4 m x 5 m, equipped with benches, small tools, water connections, gauges etc. It need not be complex and may be run by one of the trained maintenance personnel (WHO, 2005).

Bulk meters should be read, cleaned and checked for leakages on a monthly basis while calibration should be undertaking on an annual basis. Replacement of the registering unit should be undertaken when damaged or on a needs basis. Customer meters on the other hand should be read, checked for tampering and leakage, and the chamber cleaned on a monthly basis. Meter replacement and accuracy checks of customer meters should be done on a needs basis such as when the customers complain or when damage is detected during the routine inspection (Carlsson et al., 2010).

Most meters come with operation manuals that detail recommended maintenance and testing. Malfunctioning bulk meters could lead to much bigger losses for a water utility than malfunctioning domestic meters. For this reason it is good practice to concentrate on the bulk meters when it comes to maintenance. These should be maintained at least once a year while the smaller domestic meters require less attention. Maintenance programs should include the cleaning of strainers, cleaning and repair of meter boxes and replacing registers. In some cases, off site maintenance may be required where a meter is removed, serviced in the maintenance repair workshop, and placed back (Van Zyl, 2011).

2.7.3.6 Leakage control

The volume of water lost through leakages should be kept to a minimum by taking whatever action is technically and economically feasible to ensure that leaks are detected and repaired as quickly as possible. A water utility should prescribe the procedure of identifying, reporting, repairing and accounting of all leaks. This should include the conscious and active participation of consumers as well as the staff (WHO, 2005).

Sonic equipment can be used for leak detection, particularly of invisible leaks. This equipment allows an operator to 'listen' to the water flow in pipes and identify the source and magnitude of a leak. This procedure can easily be conducted in small water systems but may be difficult and often impractical in large complex systems. In such a case, it is beneficial to use metering data by analysing consumption patterns and night flows to give an indication of volume of water lost through leaks. By dividing the large system into isolated sections, metering supplied water and billed water can assist in identifying the areas that have high water loss. Areas identified to have high water loss are then further investigated for leaks. This also helps to uncover unauthorised water connections (Deb et al., 2000).

Leakage through house connections can be minimised by adopting correct plumbing methods and improving the methods used for tapping the main water supply. An analysis of leaks in house connections and an investigation of reasons for the leaks should be conducted. There should be an established procedure whereby the consumers can notify the utility of visible leaks, and in turn the utility should embark on

prompt and efficient repair of leaks; documented and adequate disinfection after repairs then be undertaken (WHO 2005; Genivar, 2007).

2.7.3.7 Cross connection control

A clean water system can get contaminated when non-portable water, such as treated effluent, is supplied in an area through a parallel distribution system and there is an unintentional connection between the two systems. The cross connection of the two systems can cause non-portable water to penetrate the clean WDS when pressures in the clean WDS are lower than in the non-portable system (Van Zyl, 2014).

Intermittent water supplies can aggravate cross connection contamination because during non-supply hours, polluted water may reach mains through leaking joints and pipes. Instances of extremely high water demands (such as when consumers use pumps with direct suction from mains) causes pressure in supply mains to drop, hence becoming susceptible to cross connection contamination (WHO, 2005).

Failed bacteriological tests along water distribution lines could be an indication of cross connection problems and should be cause for further investigation (Genivar, 2007). Minimum chlorine residual of 0.2 mg/l should be maintained in the network to ensure that small contamination is destroyed. Absence of residual chlorine could be an indication of heavy contamination and should prompt staff to undertake immediate investigation (WHO, 2005).

A cross connection control program should include training, inspection, testing of backflow prevention devices, review of plans for new connections and maintenance of adequate pressure in the distribution system (Deb et al., 2000).

Once a cross connection has been identified, remedial measures have to be taken such as providing a sleeve along pipes that cross a drain, vertical and horizontal separation between water mains and sewer, changing corroding pipes and providing non-return valves at the consumer end (WHO, 2005). Cross connections must either be physically disconnected or have an approved backflow prevention device installed to protect the distribution system (Genivar, 2007).

The rural and urban WDSs in this research are expected to continuously practice the O&M activities discussed in this chapter. The failure to conduct these O&M activities may result in frequent systems breakdowns, poor water quality and premature rehabilitation of the WDSs. This research will reveal and compare the O&M activities performed in the rural and urban WDSs. The research will further suggest which practices need to be incorporated or improved in the O&M regimes of the rural and urban WDSs in order to improve their O&M performances.

2.7.4 Tools, equipment and spares required for operation and maintenance

A list of spares required for a distribution system should be prepared and these spares must be procured and stored. There should be a minimum inventory level for the spares below which new stock should be procured. Suggested spares may include check nuts, spindle rods, assorted bolts, nuts and washers, gaskets, manhole covers and consumables such as grease, thread tape and gland ropes (WHO 2005). In addition, Carlsson (2010) suggests that spares should also include different pipe couplings (cascade clamps, Viking Johnson, short collars, long collars, flange adapters and repair couplings), PVC and HDPE pipes of different sizes, saddles, self-tapping screws and water meters (Carlsson et al., 2010).

Suggested tools required for O&M of distribution systems include key rods, hooks for lifting manhole covers, pipe wrenches of different sizes, double ended spanner sets, ring spanner sets, screw drivers, pliers, hammers, chisels, and excavation tools such as crow bars, spades, buckets and de-watering pumps (WHO, 2005). In addition, other tools that will be required include allen keys, angle grinders, bobbejaan spanners, danger tape, hacksaws, knives, picks, pipe cutters, pressure gauges, rakes, shovels, socket sets, strapping tools, talbot drills, tape measures, thread tapes, traffic cones, temporary traffic signs, trimming tools, calve spanners, vice grips, washers and wrench spanners (Carlsson et al., 2010).

Equipment required to effectively carry out O&M of a water supply system include dump trucks for the transportation of pipes, an air compressor, pavement breakers, air hammers, at least two ditch pumps equipped with 3.6 m hoses for keeping trenches dry during work, electric generators with two floodlights and extension cords for emergency work at night, a small crane, handling up to about 2.5 metric tons equipped with pneumatic tires and a ball-bearing swivel safety hook with a 180 degree turning capacity (WHO, 2005).

2.8 Operation and Maintenance models

2.8.1 Rural water systems

Different models are available for operating and maintaining a WDS. The model adopted by a WDS may affect its performance; it is therefore important to discuss the different O&M models that may be found in both rural and urban areas so that correlations can be made between the models found in these WDSs and their performance. The following is a discussion of the O&M models adopted in rural WDSs.

2.8.1.1 Community management systems

A widely used O&M model in rural water supply systems is the community management system. This model assumes that the user community owns the water supply i.e. the community contributes to the installation, sets and collects tariffs, finances and manages O&M, with support from the implementing agency such as non-governmental organizations (NGOs) or government (Colin, 1999).

This model is popular but it has not delivered anticipated levels of sustainability as communities are not always willing to adopt it. There is an assumption that community management presupposes self-sustainability of systems. However, governments have not facilitated this model effectively and services cannot be managed by communities alone (Colin, 1999).

If a community does not feel a sense of ownership over an asset such as a WDS, it may not effectively operate and maintain the system; this soon leads to its deterioration and eventual failure. It is therefore important to have the support of the implementing agency not only through the planning and implementation stages but also during the operation stage of a WDS when training and skills transfer to a local O&M team can be conducted. The acquisition, stocking and recording of frequently used tools and spares used for O&M may also be done during this period. This is known as the ‘Scaling Up’ approach. ‘Scaling up’ seeks to strengthen community management by advocating continuous support to communities in the management of their water services beyond the installation phase of a water supply system (Schouten & Moriarty, 2003).

Despite community management being mainstreamed in policies and projects, it is often not legally integrated in national institutional frameworks for water service delivery. For sustainable water services to be implemented, a community should be recognized as a legal institutional entity for water service delivery (Davis & Lyer, 2002).

2.8.1.2 Publicly owned and operated systems

In this model, the government fully owns, operates, and maintains the water supply system. Failure of this model may be brought about by insufficient and inefficient use of funds as sometimes governments give low priority to the O&M of social amenities. Failure may also be brought about by inadequate data on O&M associated costs and little documented best practice for ensuring sustainable rural water services. Inappropriate system design may also lead to failure of the O&M process and eventual collapse of the system.

The success of this model is possible despite the above factors; it calls, however, for a restructuring of the water supply utility so that it operates with a certain degree of autonomy. This means that the water utility would operate like a commercial business where it is responsible for recruitment and training of the staff and setting of tariffs, while the government's involvement is limited to setting guidelines and receiving reports from the water utility's management. Successful cases have been reported from the water utilities in Botswana and Singapore (Rukunga et al., 2006).

This model, however, has its limitations as well; the water utilities having adopted a commercial structure will have financial goals and will most likely render better water provision services to areas that are able to pay for the services. Therefore, water provision will often be concentrated in urban areas and disregarded in rural and poor urban areas as these tend to be low income regions and may struggle to pay for these services.

2.8.1.3 Public-private Operation and Maintenance

In this approach, water supply is financed and owned by the user community but operated and maintained by an external organization such as an independent company. This external organization is regulated by the public sector (government) which also provides subsidies for the water provision to the user community (Schouten & Moriarty, 2003).

This model is only feasible if the user community has enough capital to plan and implement a water supply system. It is common to find private organizations such as religious institutions or non-governmental organizations that supply and install a water supply system to remote rural areas with the aim of uplifting the community; this model would be suitable for such a situation.

2.8.1.4 Private ownership, Operation and Maintenance

Privately owned water systems have clear responsibility and an incentive for O&M and can also be sustainable. In this model, water supply is owned privately; the user community pays the owner for water, and the public sector or government ensures price regulation.

This owner of the water supply system may be an individual, a private company or a community church (Colin, 1999). The basis of this model is to make a profit from supplying a community with water. Unless the cost of water is subsidised for the community, the consumers may not be able to afford it. Water provision will then be limited to the few richer members of the community. If the sole purpose of the water supply system is to sell water to the community for profit, this model is not sustainable and may fail. It is therefore not suitable for rural areas.

The rural water systems under investigation in this study are government owned and operated. This research will determine if the government operated model is reaping the desired results; an adequate O&M system. Should the O&M of the rural WDSs prove to be inadequate; the research will suggest adjustments to the current government owned and operated model that will strive to improve the O&M standards.

2.8.2 Urban water systems

Different O&M models found in urban areas are described below.

2.8.2.1 Publicly owned and operated water systems

In this model, government owns and operates the water supply system. Its failure especially in developing country may be caused by constricted budget, lack of capacity, and poor prioritisation and management. A successful government operated water utility requires the utility to operate under 'arm's length' regulation. This means granting the utility a certain degree of autonomy so that it may operate under commercial rules and with exposure to the market while meeting essential economic and social criteria (World Bank, 2007).

The limitation in granting autonomy to a water utility is that the utility will concentrate on providing water to high income areas and will give low priority to poor urban areas where the users may not be able to pay for the service. Therefore government, whilst not paying a major role in the running of the utility, needs to regulate the operations of such a utility and subsidise costs of water provision to poor urban areas.

2.8.2.2 Informal private water providers

Where publicly owned and operated systems have failed, informal private water providers have emerged to fill the gap. These include water vendors, water kiosks, water tanks etc. These suppliers get their water from either private sources such as boreholes and private river extraction points or from the water utilities supply point. In this model, consumers pay much higher rates than the standard water utility rates. The areas mostly served under this model are poor urban areas (Kjellén, 2000).

Although quality and reliability is not assured, these informal private water providers ensure some form of water access where the government has failed (Kjellén, 2000). Government therefore needs to recognize these informal water providers and monitor

the quality of water provided to consumers while at the same time ensuring that the consumers pay reasonable rates for water provision.

2.8.2.3 Civil society organizations

These are Community Based Organizations (CBOs) and Non-Governmental Organizations (NGOs). In this model, the CBOs and NGOs work in conjunction in the water supply process. Typically, the NGOs provide full or partial support in the design and implementation of a water supply system in terms of technical knowhow and financial support. Once this has been established, the NGO then hands over the system to the CBO to operate and maintain the system (Schouten & Moriarty, 2003).

This model assumes that the CBOs have the technical and financial support to run a water supply system; however, as this is not always the case it may result in the eventual collapse of the system if external assistance is not sought. This model can be improved by extending the involvement of the NGOs beyond the implementation phase of the water supply system (Schouten & Moriarty, 2003). This means that it should be actively involved in the O&M process for a few years while building capacity (technical and financial) within the community.

2.8.2.4 Public private partnership (PPP) operators

In this model, the government enters into a long term or lease contract with an organization that specializes in water supply. The external body runs, operates, and maintains the water utility under guidelines provided by the government. This partnership is a high risk model and capital intensive, and both parties (government and the private organization) should exercise due care before entering into such a contract. The government should undertake thorough background checks on the organization it wants to contract to ensure that it has the capacity to undertake the task. When this is not done, it may lead to disappointment on both sides and the consumers may suffer.

An example of such a failure is when the government of Tanzania awarded a 20 year contract to City Water, an international organization (Kjellén, 2000). The lease was terminated in 2005 due to breach of contract. However, where both parties play their part according to contract, such a model can be successful as has been shown by the Karu-Maraba joint venture concession in Nasarawa State, Nigeria. In this case, the private company invested and today still manages the system. In this venture, it gave a 15% share to the government for assisting in the operating process, gaining access to land and overcoming bureaucratic hurdles (Sansom & Scott, 2007).

The urban WDSs in this research are government owned and operated. The study will reveal if the O&M practices are adequate under the government owned and operated model. Should the outcome of the study indicate that the O&M standards are inadequate; the research will suggest adjustments to the government model that may improve the O&M standards of the urban WDSs. These proposed adjustments will be based on the other O&M models discussed earlier in this chapter.

2.9 The legal framework pertaining to water provision in South Africa

The performance of a WDS is based on the structures supporting its operation. It is therefore important to discuss the legal framework that supports water provision in the study area in South Africa. The following is a discussion of the different facets of the South African government and a breakdown of the section in charge of water provisions and the O&M of the WDSs.

The Republic of South Africa is a sovereign, democratic state and is a constitutional democracy with a three tier system of governance and an independent judiciary; national, provincial and local governments (GCIS, 2014).

The national government consists of the national executive and legislature. It forms broad national policies and conducts inter-provincial matters (GCIS, 2014). The Department of Water Affairs (DWA) is the section of government that deals with water service provision matters at national level; it sets policies, norms and standards. The DWA (formerly the Department of Water Affairs and Forestry) performed the function of a Water Service Authority, but in the mid to late 2000's this practice was phased out and responsibilities were transferred to the local governments as they gained administrative capacity (Calfucoy et al., 2009).

Provincial governments have their own provincial executive and legislature. They are bound by the laws and policies passed at national level and can pass their own within a framework that suits their specific needs (GCIS, 2014). The Department of Water Affairs is represented at provincial level but plays a more technical role through regional offices.

Local governments consist of municipalities and are tasked with providing democratic and accountable government to local communities and to provide services to these communities as well as promote social and economic development (GCIS, 2014). Municipalities are responsible for delivering services on behalf of the government as a whole (Roux, 2010).

One of the objectives of local government according to the Constitution of the Republic of South Africa, Chapter 7, is to ensure the provision of services to communities in a sustainable manner. The Constitution further lays out in Section 153 the duties of municipalities, i.e. that municipalities must structure and manage their administration, budget and plan processes to prioritise the basic needs of communities and promote their social and economic development, as well as participate in national and provincial development programmes (SA Govt, 1996_a).

The Constitution therefore charges the local government with the responsibility for community development. It makes them accountable for delivery of services to local communities, including provision of water. Proper operation and maintenance practices are essential to meeting developmental responsibilities (Roux, 2010). The local

government is responsible for the planning and implementing of O&M practices of the existing and proposed WDSs in South Africa.

2.9.1 Categories of Local Government (Municipalities)

There are 278 municipalities in South Africa. Chapter 7, section 155 (1) of the Constitution breaks down the municipalities into three categories (SA Govt, 1996_b):

1. **Category A**: A municipality that has exclusive municipal executive and legislative authority in its area.
2. **Category B**: A municipality that shares municipal executive and legislative authority in its area with a category C municipality within whose area it falls.
3. **Category C**: A municipality that has municipal executive and legislative authority in an area that includes more than one municipality.

Metropolitan municipalities fall under Category A and they administer South Africa's most urbanised areas; they have exclusive municipal executive and legislative authority in their respective areas. There are 8 category A municipalities and 44 district municipalities (Category C). Each district municipality is further subdivided into various smaller local municipalities known as category C municipality (Muller, 2014).

Section 4A and 5B of the constitution lists water and sanitation as one of the matters that municipalities are responsible for (Roux, 2010). The Water Services Act no. 108 of 1997 outlines the right to basic water and sanitation and makes municipalities responsible for supplying water to communities with support from provincial and national government (Conradie, 2009).

According to the Constitution of the Republic of South Africa, local governments assume the responsibility for designing, financing, and maintaining the water supply systems (Calfucoy et al., 2009). Municipalities are mandated to act as Water Service Authorities (WSAs) that must ensure the provision of affordable, economical, efficient and sustainable water services within their areas of jurisdiction. Every WSA must develop and implement a Water Service Development Plan which must be shared with consumers and stakeholders for comment, then be submitted to the DWA for endorsement. Water Service Providers (WSPs) are organizations that provide the water services to a consumer. The WSA can act as a WSP or can appoint a water board, another WSA, a water committee or a private company to act as a WSP (Conradie, 2009).

The five functions of a WSA include planning, infrastructure development to ensure access to basic services, finances and setting of tariffs, service delivery arrangements, which can involve contracting a WSP, monitoring and regulating WSPs, and customer care (Conradie, 2009).

2.10 Benchmarking

AWWA (1996) has defined benchmarking as “a systematic process of searching for best practices, innovative ideas, and highly effective operating procedures that lead to superior performance and then adapting those practices, ideas, and procedures to improve the performance of one’s own organisation” (AWWA, 1996). It is the process where the effectiveness of achieving a particular goal can be compared to a standard set by a number of different organisations. This particular goal is commonly referred to as a Performance Indicator (Du Plessis, 2007).

Benchmarking played a key role in the water industry of the United Kingdom. In England and Wales, the Water Act of 1989 enabled the privatisation of the ten water authorities which saw the appointment of private companies to operate the existing water systems. The water industry privatisation also involved the creation of the economic regulator for water, the director general of water services and the director’s office in the Office of Water Services (Ofwat, now known as the Water Services Regulation Authority) (Bailey, 2002).

The delivery of high standards by the water industry had been a major concern of policy makers, regulators and water companies in the UK since privatisation. It was necessary for regulators to develop ways of measuring performance and for defining targets for the industry to meet (Bailey, 2002).

Ofwat then developed a system of performance measurements by publishing annual reports on service levels for the water industry in England and Wales. These provided the most comprehensive assessment available of the performance of the companies. The data was published in the report along with performance information provided by other regulators such as The Drinking Water Inspectorate that provided information about company performance with respect to the drinking water quality (Bailey, 2002).

A more recent development has been the introduction of the overall performance assessment (OPA) of companies by Ofwat. The main aim of OPA is to assess the overall service provided to customers. Ofwat developed the OPA to enable the director general and customers make comparisons about the overall quality of service provided by the water companies (Bailey, 2002).

One primary objectives of benchmarking is to provide a set of Key Performance Indicators (KPIs) related to a utility’s managerial, financial, operational, and regulatory activities; these KPIs are used to measure internal performance and provide managerial guidance. The other objective of benchmarking is to enable an organization to compare its performance on KPIs with those of other similar utilities; this assists in identifying areas needing improvement, with the expectation of developing more efficient or effective methods to formulate and attain company goals as set forth in its business plan (Van den Berg & Danilenko, 2011).

There are two forms of benchmarking. One is Metric benchmarking which is the systematic comparison of an organization's performance to that of similar organisations (Van den Berg & Danilenko, 2011). It is the quantitative comparative assessment of an organisation's performance that enables comparisons among peer organisations, and by which trending information and target levels of performance can also be established (Parena & Smeets, 2001) A water service provider or water utility can compare its performance to other water service providers of similar size and structure. It can also be time based in that an organisation tracks its performance over a period of time.

The other form of bench marking is the Process benchmarking. This is a tool through with an organization can measure and compare the processes and procedures of its various functions to those of similar organizations (Van den Berg & Danilenko, 2011). It identifies specific work procedures to be improved by comparison of external examples of best practice (Parena & Smeets, 2001). In a water utility, such processes and procedures could include billing and collection systems, customer service management, data recording, collection, and filing systems.

Benchmarking, whether metric or process consists of performance assessment and performance improvement. It is not a single once-off occurrence but a dynamic continuous process of improvement of performance. Performance assessment involves defining benchmarking objectives as well as a performance assessment model. Thereafter tools preparation, participant invitation, data collection, data validation and data analysis is performed. Performance gaps are then identified from the analysis results which are documented and reported. Performance improvement on the other hand involves identifying best practice, preparing a performance improvement plan with targets and priorities, and implementing performance improvement measures and evaluation (EBC, 2014).

There are several benchmarking initiatives in the water industry that have been developed and refined over time. The concept remains the same: identifying, understanding and adapting best practice, but the set of Performance Indicators (PIs) and in their classifications of best practice may vary.

International Benchmarking Initiatives used to gauge water provision performance include:

- Performance Indicators for Water Supply Services by International Water Association (IWA) (Alegre et al., 2006)
- The International Benchmarking Network for Water and Sanitation Utilities (Van den Berg & Danilenko, 2011)
- European Benchmarking Co-operation (EBC, 2014)
- Overall Performance Assessment (Bailey, 2002).

Benchmarking Initiatives developed and used in South Africa include:

- Regulatory Performance Measurement System by the Department of Water Affairs of the Republic of South Africa (DWA, 2013)
- Municipal Services Strategic Assessment (DWA, 2012).

2.10.1 Regulatory Performance Measurement System (RPMS)

The Department of Water Affairs is mandated by the South African Constitution (Act 108 of 1996) to regulate the water service functions of municipalities. In 2008, the Department introduced the National Water Services Regulatory Strategy (NWSRS). The key aspect of this strategy is the measuring and revealing of performance with regard to the achievement of the service delivery quality standards which the Water Services Authorities (WSA) are obliged to comply with. There was therefore a need to define and develop a means of measuring performance across all functions of the institutions that are required to be regulated. In turn, 11 Key Performance Indicators (KPIs) as well as a tool which could enable these KPI's to be measured transparently, consistently and predictably were developed; this tool is the Regulatory Performance Measurement System (RPMS). The RPMS not only measures performance but also tracks the response to non-performance through the issuing of Regulatory Actions (RAs) to WSA whose performance is below the required standards. Once remedial actions according to the RAs are taken, the effectiveness of the actions is measured and reassessed (DWA, 2013). The RPMS used by the Department of Water Affairs is to measure and publicise performance of municipalities against key indicators. The RPMS is a form of Metric Benchmarking that covers the entire business of water service provision in South Africa (Balfour, 2013).

The RPMS can be viewed as a 'living' system that is continuously being adjusted to make it more practical and effective in the performance measurement of water service authorities. The original RPMS was a compliance based regulatory approach and measured 11 KPIs:

KPI 1: Access to water supply
KPI 2: Access to sanitation
KPI 3: Access to free basic water
KPI 4: Access to free basic sanitation
KPI 5: Drinking water quality management
KPI 6: Wastewater quality management
KPI 7: Customer service quality
KPI 8: Institutional effectiveness
KPI 9: Financial performance
KPI 10: Strategic asset management
KPI 11: Water use efficiency.

Any benchmarking initiative is only as good at the data used in the evaluation. This means that unreliable data can render such an initiative redundant. This was the case of

failure of the RPMS at the beginning; the data received for evaluation from the WSAs was not credible or verifiable and therefore the resulting evaluation report was not accurate. There was a need to revise the indicators to reflect the KPIs that the WSAs can provide. The strategy then moved from data gathering to a system of utilizing credible data sources to report performance (Balfour, 2013).

The 11 KPIs were therefore grouped into four categories:

Access:
- To water
- To sanitation
- To free basic water
- To free basic sanitation.

Quality
- Of drinking water
- Of waste water
- Of service.

Efficiency and effectiveness
- Of the institution
- Of national water resource management.

Strategic:
- Finance
- Asset management.

The RPMS was further re-engineered and categories were regrouped. The new categories (KPIs) along with their corresponding areas that are scored are as follows (Balfour, 2013):

Financial Viability
- Cash as a percentage of operating expenditure
- Overspending of original operating budgets
- Underspending of original capital budgets
- Debtors as a percentage of own revenue
- Year on year growth of debtors.

Customer Satisfaction
- Access to services
- Access to subsidises for basic services
- Affordability
- Service delivery protests.

Technical Efficiency
- Average municipal Blue Drop score
- Average municipal Green Drop score
- Water loss percentage.

Effective Institution – Currently not in use due to significant data gaps and queries found on data sources; it is being developed through sector collaboration and targeted audits.

The Blue Drop score measures the technical performance of water supply systems. It has several KPIs that are graded using the score chart shown in table 2.1 below.

Table 2.1: Score ranges for the different Blue Drop grades (DWA, 2014)

MODERATED COLOUR CODING TO ASSIST WSI WITH CONFIRMATION SESSION PREPARATIONS 2014		
Colour codes		Status description
A+	95-100%	Excellent situation – WSI scored very well, no / limited gap identified
A-	91-94%	
B+	85-90%	Good status, WSI to submit minor additional evidence to move score into blue category
B-	80-84%	
C+	70-79%	Average performance, additional evidence needed to improve on this criteria
C-	50-69%	
D+	40-49%	Poor performance, substantial evidence still required to improve this score
D-	31-39%	
E+	15-30%	Critical state, substantial evidence needed to improve on this score. This score is likely to result in significant reduction of the WSI's Blue Drop / No Drop score
E-	0-14%	
Bonus	*Comment box*	Full, partial or no bonus awarded
Penalty	*Comment box*	Full, partial or no penalty awarded

The KPIs used in the Blue Drop scoring system are; water safety planning; drinking water quality process management and control; drinking water quality compliance; management accountability and local regulation; asset management; and water use efficiency and water loss management (DWA, 2014).

Carden and Armitage (2013) suggest that the RPMS is focused on efficiency and service provision to existing customers and does not take into account service provision to the poor and the resulting impacts when services are non-existent or dysfunctional. The RPMS also does not provide an indication of the potential for overall sustainability of a water system as a whole. For example, the water services in a city may seem to be operating efficiently in terms of the regulatory requirements for drinking water and wastewater treatment, however, if a significant proportion of its residents do not have access to services, the urban water system can be considered as not sustainable

(Carden & Armitage, 2013). While the RPMS has its flaws, it gives a good indication of the areas of a water system that require improvement. However, it should not be the sole indication of the performance of a water system but be used in conjunction with a more integrated approach to reveal the true state of a water supply system

Below is a discussion of the IWA benchmarking initiative that will also be used to measure performance in the rural and urban WDSs in this research.

2.10.2 International Water Association Performance Indicators

The International Water Association (IWA) is a globally recognized organisation dedicated to 'deliver equitable and sustainable water solutions for our world'. It is a global network of water professionals that aims to generate innovative solutions and opportunities to tackle urban and basin related water challenges (IWA, 2014).

Through extensive research of the world's best practices in the water industry, the IWA was able to produce a manual which constitutes a proposed list of performance indicators that can be used in any water organization in the world to gauge its performance against the world's best practices. The main objectives of this system of performance indicators are to provide a robust, consistent, and coherent set of performance indicators; it is to be used universally; it should be useful for all the stake holders playing a role in the water provision undertaking; and its main aim is at the water industry; and its goal is the improvement of services. The aspects that are regarded as particular to each undertaking were left out of the system, such as geographical particularity, institutional framework and internal organisation; the number of performance indicators had to be limited (Alegre et al., 2006).

Performance indicators are grouped into the following categories (Alegre et al., 2006):

- Water resources (WR)
- Personnel (Pe)
- Physical (Ph)
- Operational (Op)
- Quality of services (QS)
- Economic and financial (Fi).

Each of these groups is further divided into subgroups of individual performance indicators. A user is required to identify the PI's that are most suitable to their situation. Some of the indicators are broken down into sub-indicators which are part of the main indicator but can be assessed separately.

Variables are the inputs of a PI system. The Variables in the IWA PI system are divided into the following groups:

- Water volume data
- Personnel data
- Physical assets data

- Operational data
- Demography and customer data
- Financial data.

Contextual information is an important aspect when undertaking a benchmarking initiative. This is information describes a water utility in its context. It describes aspects such as demographics, climate, economy, and system characteristics. This enables the establishment of clusters of comparable undertakings so that a utility may be able to compare its PIs with utilities of a similar structure.

Just like the RPMS, the IWA systems of performance measurement provides efficiency indices for water supply systems without taking into account the consumers with limited or no access to the water services provided by the water system. It does not provide an indication of the potential for overall sustainability of a water system as a whole (Carden & Armitage, 2013).

2.10.3 Municipal Services Strategic Assessment (MuSSA)

By 2005, the Department of Water Affairs in South Africa had used the Municipal Water Management Tool (eWQMS) to assess the local government performance in water and waste water service provision with emphasis on water quality. The DWA realized that each municipality encountered their own unique set of challenges when it came to sustainable, effective and efficient water quality management and that the use of eWQMS alone would not resolve the situation of deteriorating water and waste water services (Wensley, 2011). A risk-based decision support tool, using performance indicators relating to the progressive attainment of the provision of safe drinking water and effective effluent treatment by municipalities, was developed and rolled out nationally (Wensley, 2011).

MuSSA came into effect in 2006 and it conveys an overall business health of municipal water business and serves as a source of information around municipal performance. It identifies key areas of vulnerability that a municipality may be experiencing and exposes these vulnerabilities, allowing a municipality to improve its performance around these weak areas. It is a tracking tool; it allows a municipality to track its current performance and set targets. It also allows a municipality to compare its performance against other municipalities (DWA, 2012),

The key business attributes that municipalities are meant to measure (DWA, 2012), are the following:

1. Water services development planning
2. Management skill level
3. Staff skill level
4. Technical staff capacity
5. Water resource management

6. Water conservation and demand management
7. Drinking water safety and blue drop status
8. Waste water and environmental safety
9. Infrastructure asset management
10. Operation and maintenance of assets
11. Financial management
12. Revenue collection
13. Information management
14. Organisational performance
15. Water service quality
16. Customer care.

MuSSA uses a 'spider diagram' to depict these key attributes; this is shown in figure 2.5 (DWA, 2012).

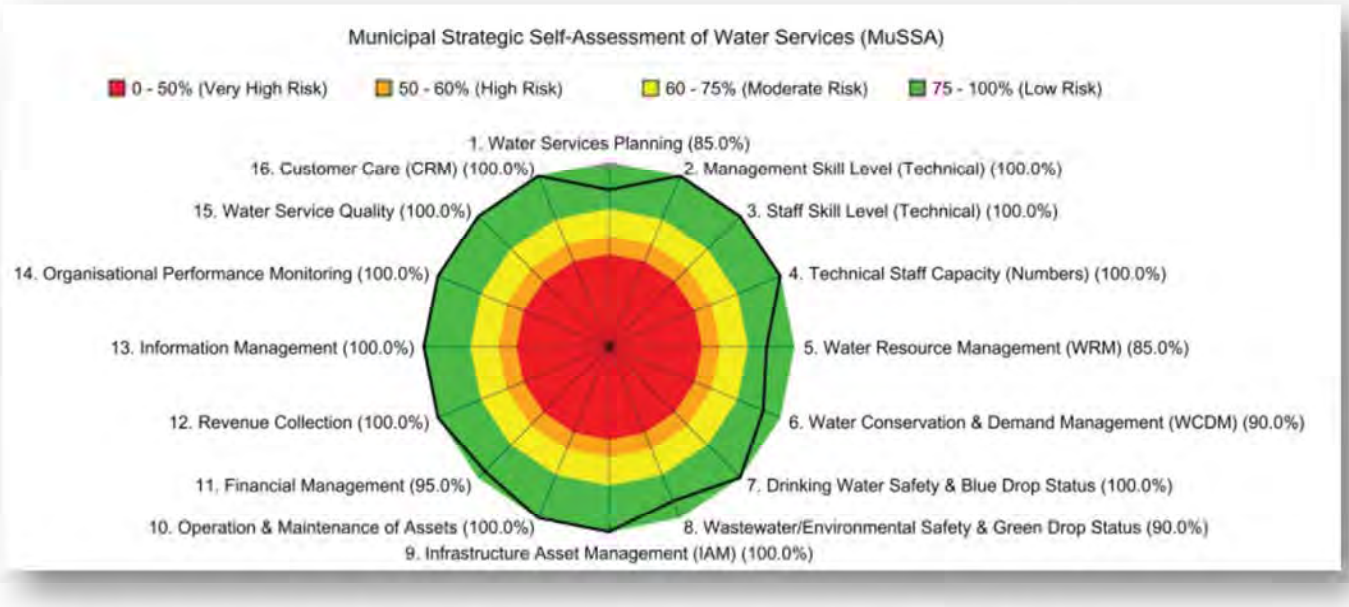

Figure 2.5: MuSSA "Spider-Diagram" output indicating vulnerability (DWA, 2012)

In order to rank municipalities and track their performance, the Vulnerability Index (VI) was developed. In the Spider web diagram, the Vulnerability Index ranking is colour coded as shown in the diagram. The index ranges from 0 – 1, with 1 being extremely high vulnerability while 0 being very low vulnerability (DWA, 2012)

The positive impact of the MuSSAs at a local government level is that water service providers can assess their own performance, identify areas requiring corrective action, benchmark themselves against peers, and monitor their trends (Wensley, 2011). The MuSSA system of performance assessment, however, provides information of the water

provision service in the municipality as a whole. It does not provide information of the individual water supply systems within the municipality like the RPMS. The nature of this research is to retrieve information of different WDSs in the rural and urban areas for comparative purposes, and since MuSSA only provides combined data for the whole municipality, this system of performance measurement will not be suitable for this research.

2.11 Case Studies

Operation and maintenance studies of water supply systems in rural and urban areas have been conducted in the past. The studies were conducted with the aim of understanding the causes of failures of water systems with particular attention to the O&M of the systems. The case studies below were selected not only because they deal with O&M of water systems but also because they were conducted in study areas within developing countries in Africa with similar settings to those for this research. Below are the case studies that highlight the challenges experienced in O&M of rural water supply schemes and urban supply schemes.

Study 1: Operation and maintenance costs of rural water supply schemes in South Africa (Gibson, 2010)

Study Area: Alfred Nzo district municipality and Chris Hani district municipality in the Easter Cape Province, South Africa

Introduction: This was a study aimed at analysing the financial data collected from nine technical support programmes in these municipalities. It identifies the actual costs associated with a comprehensive approach to O&M that included local Community Based Organisations (CBOs) carrying our appropriate tasks at scheme level together with skilled and competent technical institutional support.

Conclusion:

A summary breakdown of the conclusions drawn from the study is as below:

- There is a need for effective technical and management support to rural schemes to maintain functionality of the infrastructure; such support may include highly skilled staff members.
- Costs associated with such technical support represent a large proportion of the overall operational costs.
- Recurrent costs (fuel, spares and material) were found to be proportionally low among the overall cost.
- To reduce maintenance costs and increase reliability, the concept of repair-ability must be given consideration at project design stage.

- Main cost drivers for O&M of rural water schemes are: nature of the infrastructure, particularly mechanical and electrical installations, remoteness of the schemes, number of schemes under consideration.
- Significant variations are observed when different cost estimating tools and methodologies were used to estimate O&M costs.
- Cost models have in-built assumptions that may not apply to the users.
- Percentage of construction cost to estimate cost of O&M should be used with caution (3-6%) as it may have been derived from urban systems.
- Use of metric systems (cost/capita or cost/volume) can lead to inappropriate cost estimates.
- Development of a generic protocol for estimation and prediction of O&M may be difficult if not impossible to create; cost of construction and subsequent O&M may vary widely due to technology choice, scale of scheme and geographic location.
- It is recommended that a realistic 'Actual Based Cost Model' be developed for cost estimation.
- Rural schemes are not necessarily cheaper to operate and maintain than reticulated urban networks. This raises the question of how to allocate the O&M subsidy equitably across urban and rural settlements.

Study 2: Operation and maintenance of small town water supply systems in Ghana (Obuobisa-Darko & Asima, 2008)

Study Area: Oyibi Area amd Abokobi Area Small Towns, Greater Accra Region, Ghana

Introduction: This study analyses the institutional arrangements for the management of small town water systems and highlights how the systems under study are performing financially due to O&M management structures put in place and the commitment of the actors.

Conclusion:

The lessons learnt from this study are summarized below:

- Institutional arrangements put in place for the O&M of water supply systems should ensure sustainable management, and the various stakeholders must be committed, transparent and properly resourced.
- The two schemes have substantial cash inflow; this is attributed to the new water system installed and therefore maintenance costs are low. It is recommended that the schemes invest the excess income in purchase of major parts and also find other reliable measures of investing the excess income against lean periods.
- Pay-as-you-fetch is a sure way of enduring availability of money for prompt O&M community managed systems.

- Standpipes with water meters ensure effective collection of money for actual water consumed.
- Vendors are motivated to carry out their duties as they receive commission.
- Involvement of communities in the management of water systems has created jobs for technical coordinators, vendors and care takers.
- Progress was made in equipping the water boards and their committees to enable them to operate successfully on sound management principles.
- Operating a community ownership and management concept requires time, patience, tact, deployment of a wide variety of participatory mobilisation tools, facilitative skills, and pooling of resources from within and without, particularly with sustainability is the primary objective.

Study 3: Water supply systems in poor urban areas of Addis Ababa, Ethiopia (Sharma & Bereket, 2008).

Study Area: Teklehaimanot, Merkato and Biheretsige, Addis Ababa, Ethiopia

Introduction: In spite of considerable investments in the water supply systems in the city of Addis at different times, the majority of the people living in poor urban areas do not have access to a reliable and safe supply. This study therefore evaluates the water supply situation in selected poor urban areas of Addis Ababa in order to develop strategies to improve the existing situation.

Conclusion:

Below is a summary breakdown of the conclusions drawn from this particular case study:

- The poor urban areas receive low standards of water service provision in terms of quantity and service levels and yet are paying a relatively high price for water.
- The average per capita water consumption of more than 75% of the sample households is less than 20 l/c.d: the majority of the residents can be considered to have no basic access to water supply.
- Most of the poor households are dependent of public taps, water vendors, and water kiosks as a primary source. Only 30% of the respondent households had private household water connections.
- 70% of the unconnected households reported that water vendors and kiosks are not their preferred options because of the high costs of water.
- An innovative financing and cost recovery mechanism should be put in place with the joint effort of the Addis Ababa Water and Sewerage Authority, and the local and national government in order to provide these poorly served areas with safe water supply.

Study 4: Water provisioning in Dar-es-Salaam, Tanzania (Kjellén, 2000)

Study Area: Dar Es Salaam, Tanzania

Introduction:
Residents of Dar-es-Salaam face chronic water shortages and often have to combine several sources of varying cost and quality. This study reviews the role of the public and private actors in Dar-es-Salaam's water system.

Conclusion:

The lessons learnt from this case study are as follows:

- 30% of the households had house connections, 24% yard connections and 45% no connection to a water supply; most houses needed to make use of several alternative sources.
- Other water access modes included households (re)selling water, pushcart distribution and water truck distribution.
- Two main dimensions of 'creep' privatisation are private redistribution of water (vendors and trucks) and 'spaghettisation' of piped water network where individual private service lines are increasing out of proportion to the distribution mains.
- The water utility lags increasingly behind in serving the city's population which has contributed to the 'creep' privatisation.
- New investments in order to improve the present distribution system are sorely needed to replace, repair and extend the distribution lines and thus reduce the need for individually laid and long service lines.
- Distribution vendors should be recognized as an important means of water distribution in Dar-es-Salaam but they sell the water at a much higher price than utility tariffs.
- Structured collaboration between the Dar-es-Salaam Water and Sewerage Authority and water vendors could help lower the prices to end users by applying special lower wholesale prices to the vendors who will in turn sell the water to end users at utility tariff prices.

Lessons learnt from these case studies in relation to this research are discussed below.

O&M of rural water supply schemes is not necessarily cheaper or easier than that of urban water supply systems. The main cost drivers of O&M of rural water systems are the infrastructure, remoteness of the water supply system and the number of water supply systems. With this in mind, the concept of O&M should be considered at the design stage where the repair-ability of the system components is taken into consideration. Furthermore, the water supply systems in rural areas suffer due to the lack of appropriate technical and managerial support; there is therefore a need for effective technical and managerial support for these rural water systems by the water

utility. This can be improved by getting the community involved in the management of the water systems by introducing water board committees. These committees will have to be equipped with the necessary skills to enable them to successfully operate on sound management principles. The management and the various stakeholders must be committed, transparent and properly resourced.

While the O&M issues in rural areas stem from a lack of technical and managerial support, remote locations, and poor design, O&M issues in urban areas seem to be caused by an unprecedented increase in population. The consumers most affected by this are the poor urban residents who receive below standard water services. They are dependent of public standpipes, water vendors and water kiosks for water access and pay a relatively high prices for it. The water utilities lag behind in improving water access in the poor urban areas, leading to increased illegal private service lines. This will cause an increase in demand for water that may lead to decreased pressure and water availability to all consumers of the water system. It will also increase the risk of contamination of water in the distribution system. There is a need to prioritise and action the replacement, repair and extension of distribution lines to these areas to reduce the need for individually laid and long service lines.

2.12 Critical Review

The literature review addressed the components that constitute a WDS. Lack of understanding of these components, their functions, mode of operation and maintenance will lead to the deterioration and eventual collapse of WDS as a whole. Both rural and urban WDSs are expected to have these components; however, their quantities may vary according to the different nature of settlements in these two areas. The rural systems will be expected to have longer pipelines per household, connecting sparsely clustered settlements to the water system and will have fewer meters and valves. In the urban areas, pipelines will be expected to be relatively shorter per household due to the larger and centralized populations they serve. There are expected to have more water meters and valves. The WDSs selected for the purpose of this research should have these components so that their O&M performances can be compared.

The literature review also addresses the O&M of these components; this forms the basis of this research. Each WDS will be expected to practice some form of O&M of these components; the varying degrees of practice in rural and urban systems will be investigated and compared. Below are some of the aspects of O&M practice that will be taken into consideration when undertaking this research:

- The successful maintenance of pipes, valves, hydrants, storage tanks and meters will uphold the physical, hydraulic and water quality integrity of a WDS. Larger WDSs found in urban areas are expected to require more time and resources to undertake maintenance; this can be optimized with an appropriate schedule. An existing maintenance schedule that is regularly updated to

accommodate changes in the WDS will reflect in a system performance. This research will compare the component maintenance routines and the components failure rates of the rural and urban systems and it will try and link this performance to the maintenance routines undertaken in both areas.

- Having accurate meters in a WDS means that accurate water loss management data can be obtained. It is therefore important for any WDS, whether in rural or urban areas, to undertake proper meter maintenance. This study will try and link water loss data to the meter maintenance practices for both rural and urban WDSs and highlight the differences found in the results.

- It is expected that urban areas will practice some form of pressure management especially if they have a remote monitoring and control system. This research will identify performance differences in the WDSs in rural and urban areas; the difference may be an outcome of employing (or not) the pressure management within the WDSs.

The type and availability of spares, tools and equipment will depend on the size of the WDS and resources available to acquire them. Ideally a rural WDS should be well equipped with store with spares, tools and equipment to enable the system be adequately maintained without having to rely heavily on the urban regions. This is because of the large distances between rural regions and urban centres, making acquisition of tools and spare parts difficult. This study will highlight and compare the availability of resources in rural and urban areas and try to account for the differences and similarities.

To obtain optimum levels of O&M of the systems, an appropriate O&M model has to be applied. Community based models with assistance from an external body (government or NGO) would be best for rural systems, while government based utilities with the assistance of a professional service provider would best be adopted by an urban WDS. The existing O&M models of the WDS under investigation will be compared to those proposed in the literature review for both rural and urban systems.

Constitutionally, municipalities (local government) in South Africa are responsible for the provision of water and sanitation services to communities in their jurisdiction with support from provincial and national government. They are mandated to act as Water Service Authorities and may seek assistance from water service providers to ensure the provision of affordable, economical, efficient and sustainable water services within their areas of jurisdiction. For this research, the water systems selected will be from a municipality that has both rural and urban WDSs within its jurisdiction. These systems are exposed to the same resources and governance and hence their performances can be compared.

As described in the literature review, there are several benchmarking initiatives that can be applied. For this research, one international and one local benchmarking program will be selected based on their appropriateness for the purposes of this study, i.e.

access to data required to calculate the performance indicators, and these indicators are in a form that can easily be compared. The International Water Association and the Blue Drop initiative (under the Regulatory Performance Measurement System) will be the benchmarking programs used in this research. These programs will be used to compare the performance of the water systems in rural areas to those in urban areas.

3. RESEARCH METHODOLOGY

3.1 Introduction

The methods employed to accomplish the goals and objectives of this research as outlined in section 1.3 are detailed in this section. The study area is described and a breakdown is provided on how the collected data were analysed.

3.2 Study Area: Kai !Garib Local Municipality

The Kai !Garib local municipality was chosen as a case study for this research because its jurisdiction stretches over rural and urban areas, both of which have water supply systems that can be investigated. Another factor was the researcher's familiarity with the region which made for easier data collection.

Other study area selection criteria include:

a. The water supply systems to be investigated distribute similar water quality: the water supply systems should have similar water sources and also have similar water treatment processes.
b. The water systems to be investigated should have an elaborate WDS: they should have bulk storage tanks, mains and distribution pipes as well as service connections, i.e. either yard standpipes or private service connections.
c. The water supply systems to be investigated are operated by the same WSA.

Below are the details of the study area; they include the location, size, demographics, economy, and the water schemes found in the area.

3.2.1 Location

The Republic of South Africa has nine provinces: Limpopo, Mpumalanga, Gauteng, Kwa Zulu Natal, Eastern Cape, Western Cape, North West, Free State and Northern Cape. Each province has its own premier and executive council and is governed by its own legislature. Figure 3.1 below is a map of South Africa depicting the relative positions of the provinces.

Figure 3.1: The nine provinces of The Republic of South Africa (GCIS, 2014)

The Northern Cape has 5 district municipalities (DM): Namakwa, Pixley ka Sema, ZF Mgcawu, Frances Baard and John Taolo Gaetewe district municipalities.

The ZF Mgcawu District Municipality has 6 local municipalities (LM) under its jurisdiction, namely Mier, //Khara Hais, !Kheis, Tsantsabane, Kgatelopele and Kai !Garib.

The figure 3.2 below indicates the locations of the different district and local municipalities found in the Northern Cape.

Figure 3.2: District and local municipalities in the Northern Cape (DWA, 2011)

The WDSs that will be investigated in this research are located in the Kai !Garib local municipality.

3.2.2 Size, demographics and economy

The Kai !Garib local municipality is a category B municipality located in the ZF Mgcawu District Municipality. It is approximately 26 000 km² in size and is located along the Orange River, characterized by semi-desert conditions with sandy plains and wavy hills (Kai !Garib, 2013).

The Kai !Garib local municipality has a total population of 65 869 and is experiencing a 1.16% per annum population growth, 42% of households have access to piped water either in their dwelling or in the yard (Statistics SA, 2011).

Kai !Garib has 41 human settlements; 8 are located in urban and 33 in rural areas. It also has three town centres, namely Keimoes, Kakamas and Kenhardt. Approximately 43% of the total population live in the rural areas (DWA, 2011).

The main economic activity in Kai !Garib is agriculture which contributed 52% to the economy of the area in 2010. The agricultural sector provides 67% of all formal employment in Kai !Garib. Other economic activities are tourism, mining and manufacturing; solar plant development has recently begun in the region (Kai !Garib, 2013).

3.2.3 Kai !Garib water supply schemes

The water sources used by consumers in the Kai !Garib municipality are summarised in Figure 3.3.

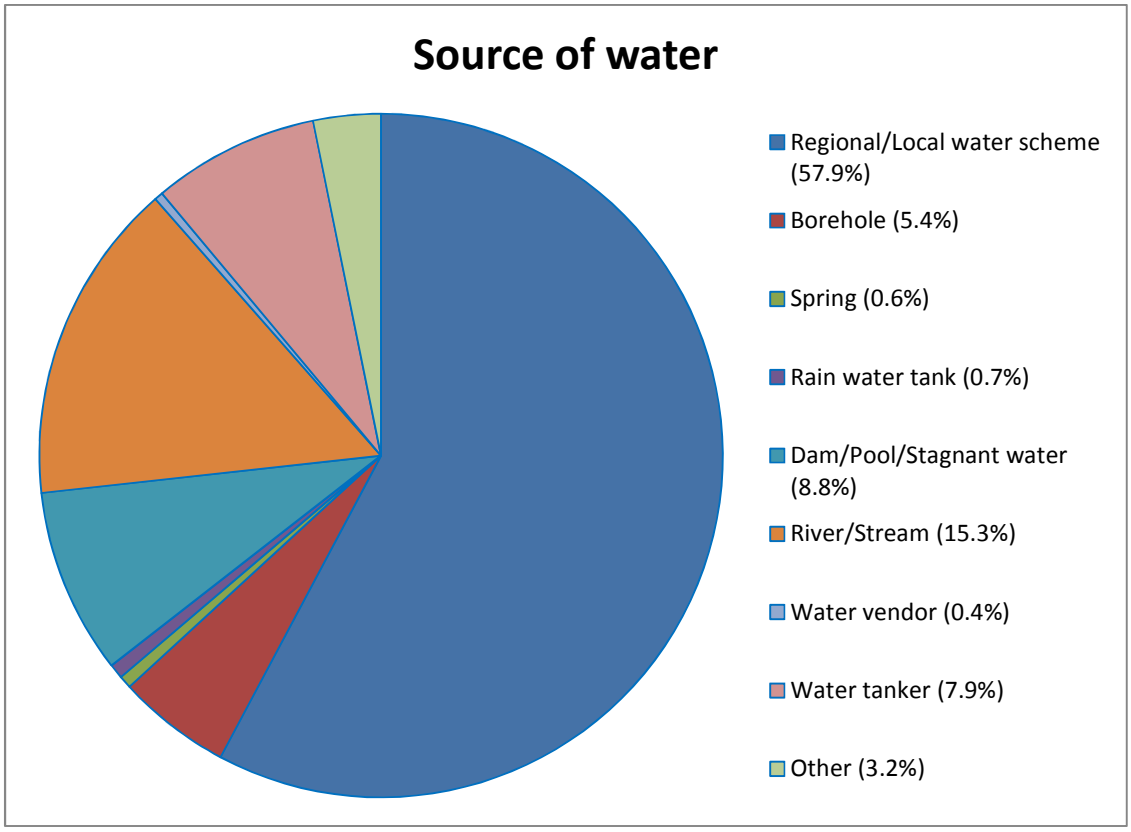

Figure 3.3: Distribution of water sources in the Kai !Garib local municipality (Kai !Garib, 2013)

The graph shows that only 57.9% of the population of Kai !Garib obtain water from formal WDSs, while the remaining 42.1% obtain water from other sources. The low penetration of WDSs is indicative of the low level of economic activity and the relatively small population spread over a wide area.

Kai !Garib has 13 water schemes, each with its own water treatment plant and WDS managed by the Kai !Garib WSA. There are three conventional water treatment plants at Kakamas, Keimoes and Lennertsville. The Lennertsville water treatment plant is also the main water source for the town of Kenhardt. The locations of these water schemes are also shown in Figure 3.4. Ten smaller package water treatment plants are located at Augrabies, Alheit, Marchand, Lutzburg, Cillie, Bloemsmond, Currieskamp, Soverby, Kamkirri and Riemvasmaak.

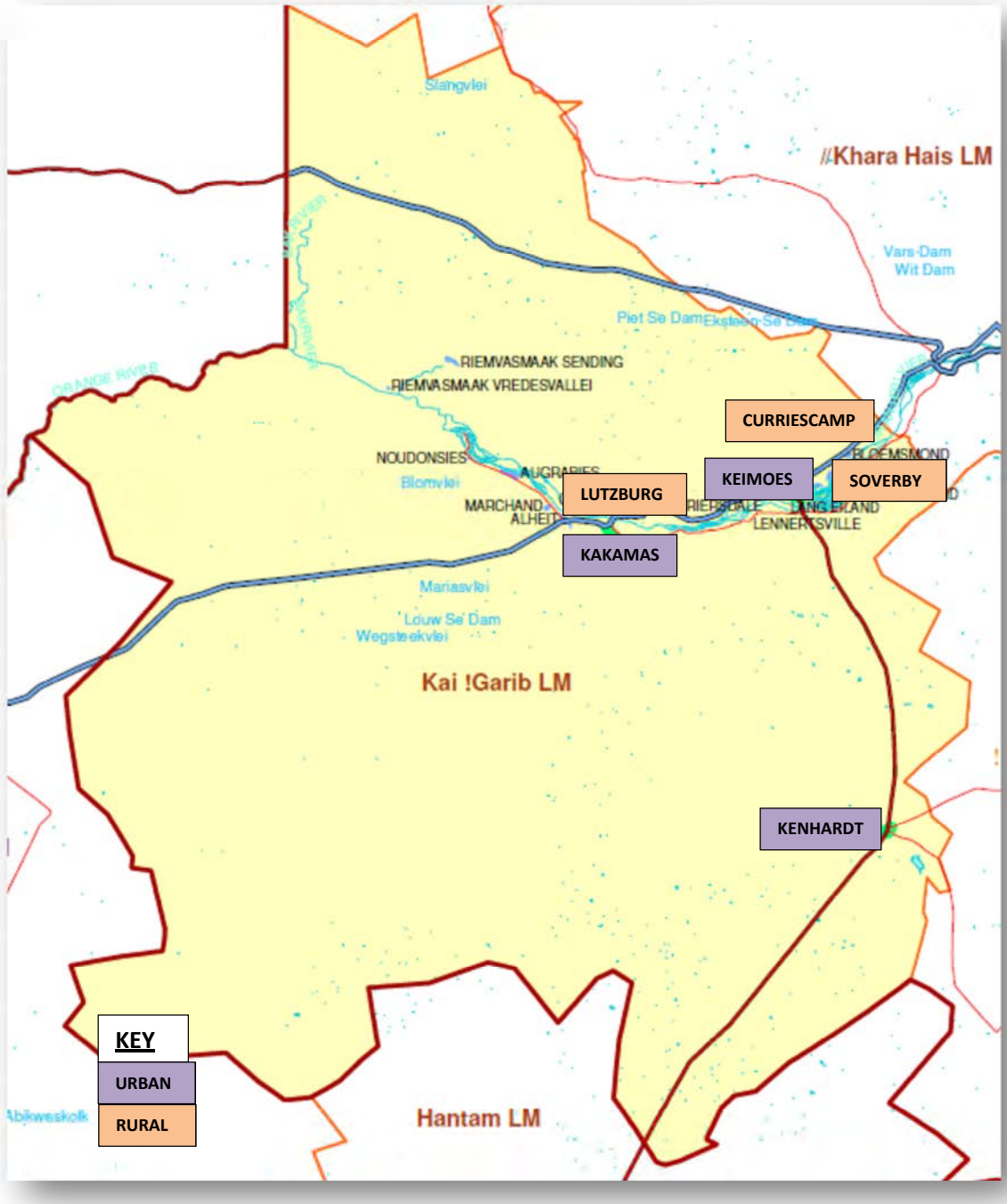

Figure 3.4: Settlements in Kai !Garib that have water supply schemes (DWA, 2011)

Three rural and three urban water schemes were selected for this study: the urban schemes are in Keimoes, Kakamas and Kenhardt, and the rural schemes in Lutzburg, Soverby and Currieskamp. These water schemes were selected because, of data availability required to conduct this research, and their physical locations were such that

they could be located and accessed with ease. The locations of these settlements are also shown in Figure 3.4.

The physical system descriptions of the selected water systems are outlined in the table 3.1 below:

Table 3.1: Physical description of water distribution to be investigated

	Water Scheme	Description				
		Water treatment capacity (m^3/hr)	Total main pipe lengths (m)	Main pipe sizes (mm)	Number of service connections	Number of bulk meters
Urban	Kakamas	260	5 864	200, 160	2 164	2
	Keimoes	200	6 322	200, 160	2 909	3
	Kenhardt	120	41 039	250, 200, 160	1 167	3
Rural	Lutzburg	34	538	160, 110	322	2
	Soverby	30	1 724	160, 110	255	2
	Currieskamp	28	1 263	160, 110	183	2

According to the Kai !Garib Annual Budget Report 2013/2014, the total revenue collected during this financial year was R172 373 000; R12 489 000 of this total was revenue collected from water service provision. The total operating expenditure for the municipality was R152 667 000, and from this R14 318 000 was used for water service provision (Kai !Garib, 2014). No further breakdown of these budgets into revenue and expenditure from the various water schemes was available.

3.3 Desk study

A desk study on the recommended procedures, equipment and staffing required to execute an appropriate operation and maintenance (O&M) programme was conducted. A study of the performance indicators used to gauge the effectiveness of the O&M of a water distribution system was also undertaken.

3.3.1 Data collection

Data required for the desk study was collected from published O&M manuals, International Water Association (IWA) publications of Performance Indicators (PIs), the Regulatory Performance Measurement System (RPMS), as well as from literature reviews of published journal papers, conference proceedings and book chapters. Data was also collected from the Kai !Garib archives. The data collected include:

1. Standard O&M procedures of WDSs that should be undertaken on a daily, weekly, monthly and annual basis

2. Performance indicators to satisfy the set objectives. The number of indicators in the IWA PI system is large; for this reason, only the PIs relevant to this research which could satisfy the objectives outlined in Chapter 1 were reviewed. Below are the IWA PIs used in this study:

   To determine level of O&M practices used in the selected urban and rural WDSs based on relevant performance indicators:

   Op3 – Network inspection (%/year)
   Percentage of mains network inspected per year, assessed in terms of mains length

   Op4 – Leakage control (%/year)
   Percentage of mains length subjected to active leakage control

   Op5 – Active leakage control repairs (no./100km/year)
   Number of leaks detected and repaired due to active leakage control per unit of mains length

   Op6 – Hydrant inspection (-/year)
   Number of hydrants inspected per year

   Op8 – meter replacement (-/year)
   Number of flow meter replacement per year

   Op16 – Mains rehabilitation (%/year)
   Percentage of mains length rehabilitated per year

   Op20 – Service connection rehabilitation (%/year)
   Percentage of service connections replaced or renovated per year

   Op23 – Water losses per connection (m^3/connection/year)
   Total (apparent and real) losses, expressed in terms of annual volume lost per service connection

To determine the level of expertise (skills, both technical and managerial) of staff responsible for O&M in the selected urban and rural WDSs:

Pe1 – Employees per connection (No/1000 connections)
Number of full time equivalent employees per 1000 service connections

Pe3 – General management personnel (%)
Percentage of employees dedicated to directorate, central administration, strategic planning, public relations, other stakeholder relations, legal affairs, internal audits, environmental management, new business development, and general computing support

Pe7 – Technical services personnel (%)
Percentage of employees dedicated to planning, construction, operations and maintenance activities

Pe9 – Operational and maintenance personnel (%)
Percentage of employees of technical services working in O&M

Pe16 University degree personnel (%)
Percentage of employees with university degrees

To determine the resources and equipment dedicated to the O&M of the WDSs in the selected urban and rural regions:

Op15 – vehicle availability (No/100 km)
Number of vehicles available daily, on a permanent basis, on average, for field works in O&M activities per 100km of mains

To determine the level of service and efficiency provided by the O&M methods used in the selected urban and rural areas:

Pe6 – Customer service personnel (%)
Percentage of employees dedicated to accounting and control and to customer relations and management activities

Op30 – Pump failures (days/pump/year)
Average number of days per year that system pumps are out of order

Op31 – Mains failures (No/100 km/year)
Average number of mains failures per 100km of mains and per year

Op38 – Operational meters (%)
Percentage of customer meters installed that are functional

QS14 – Interruptions per connection (No/1000 connections/year)
Average number of interruptions per service connection per year

3. Data from the Department of Water Affairs on the performance of Kai !Garib municipality in the Regulatory Performance Measurement System (RPMS) in the 2013/2014 period.

4. The basic equipment that is required to effectively execute an O&M programme.

5. The personnel required (technical and managerial) in the O&M of water distribution systems, expected level of education and the recommended continuous training required for this personnel.

3.4 Field Work

Field work that was undertaken included interviewing the O&M teams from the WDSs in the six selected water schemes (3 rural and 3 urban). Figure 3.5 below is the organizational structure of the Kai !Garib Technical Department:

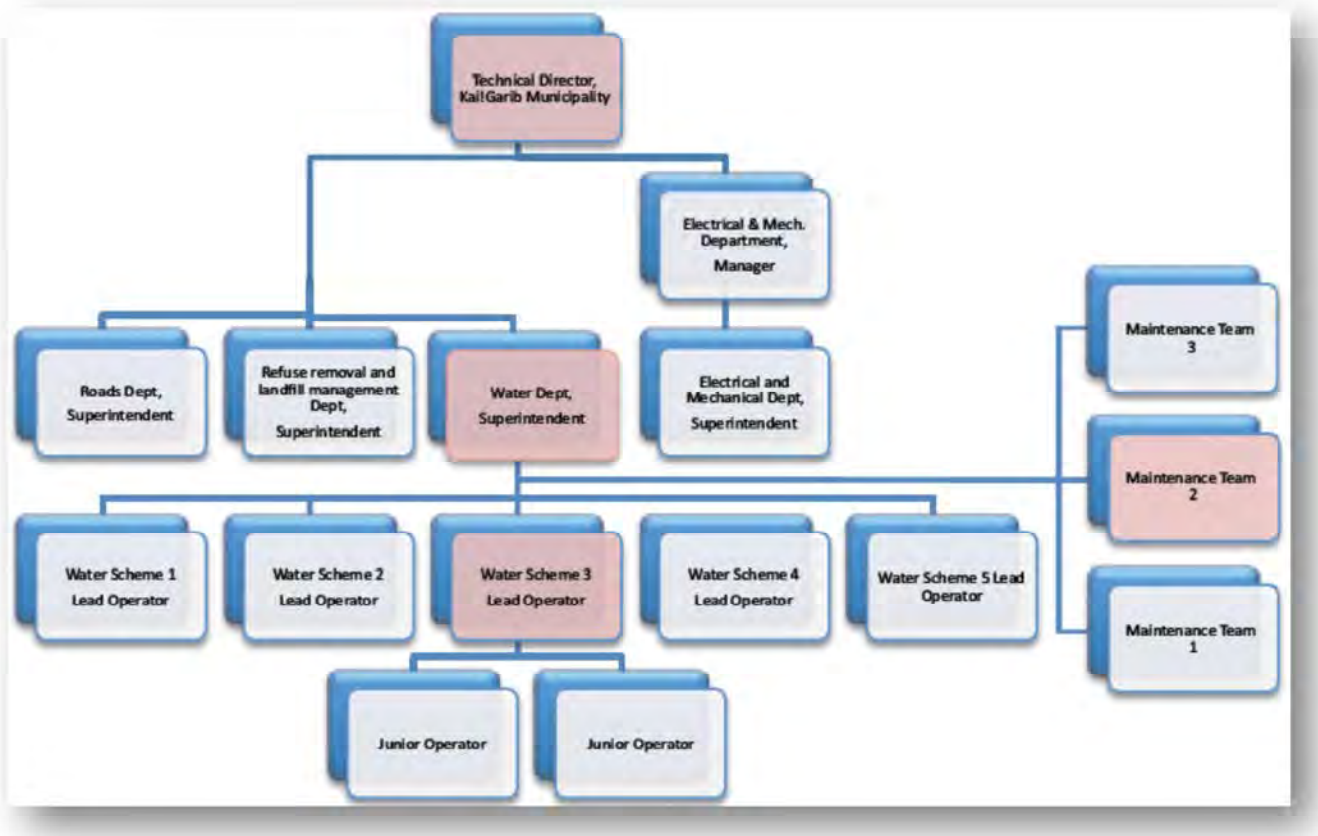

Figure 3.5: Kai !Garib Technical Department Organogram (Kai !Garib Municipality, 2013)

Below are descriptions of the maintenance, operations and management teams that are involved in O&M of Kai !Garib water systems as depicted in Figure 3.5.

Maintenance teams

The Kai !Garib municipality is serviced by three maintenance teams based in the three town centres. These teams service both their respective town's water systems as well as the surrounding rural systems as detailed below:

- Kakamas maintenance team serves: Kakamas, Augrabies, Alheit, Marchand, Lutzburg, Cillie, Kamkirri and Riemvasmaak.
- Keimoes maintenance team serves: Keimoes, Bloemsmond, Currieskamp, Soverby.
- Kenhardt maintenance team serves: Kenhardt and Lennertsville. The water treatment plant is located in Lennertsville rural settlement and water is pumped via a bulk pipeline to the clean water reservoirs in Kenhardt. Water is also pumped to an elevated clean water reservoir at Lennertsville. The WDSs in both areas are gravity fed.

Operating teams

All the water systems located in Kai !Garib have their own operating teams, each with a lead operator responsible for the overall operations of the system. Operating teams in the urban systems, namely Kakamas, Keimoes and Kenhardt, have six to seven junior operators to assist the lead operator in operating the water supply system. The smaller rural water systems, Lutzburg, Currieskamp and Soverby, each has one junior operator whose responsibility is mainly to stand in when the lead operator is off duty.

The urban water systems are much larger in terms of system capacity, network coverage and population served and thus require more operators to manage them adequately.

Management

The staff structure of the municipality is such that most of the employees in the water department are shared between the rural and urban water schemes. The management, customer care and administrative personnel cater for the whole Kai !Garib local municipality region.

Rural and urban water schemes are operated under a single overall management team consisting of a technical director and superintendent, both of whom have the required experience and qualifications to execute their duties in their respective capacities in accordance with The Municipal Systems Act (The Municipal Systems Act, No 32 of 2000 regulation, 2001).

The tools used to attain information were questionnaires and interviews designed from information extracted from the desk study. The tools included:

1. A questionnaire aimed at obtaining information from the lead operators and maintenance team leaders of the selected water schemes. It was used to ascertain their O&M background and understanding of the water schemes that they operate. It also had a section for open ended questions on the O&M practices that they were involved in. A sample of this questionnaire is attached as Appendix 1.
2. A questionnaire aimed at obtaining information from the water department superintendent and the technical director. These were a set of open ended questions (interview) aimed at obtaining detailed information of the O&M practices used. A sample of this questionnaire is attached as Appendix 2.
3. A list of the parameters required to calculate the selected PIs that will give an indication of the performance of the O&M in the selected study areas. This list is attached as Appendix 3. The list of parameters selected for the evaluation of the IWA PIs was attained in the following ways:

    - Scanning data logs from the customer care management system for the January to December 2013 period. These logs were converted and presented on an Excel spreadsheet. The logs for the water schemes under investigation, Kakamas, Kenhardt, Keimoes, Lutzburg, Soverby, and Currieskamp were selected. The customer care system at the Kai !Garib municipality works in the following manner: once a consumer calls with a complaint, the complaint is logged on the system and the responsible maintenance team is alerted and provided with a log reference which is used to open a worksheet. On this worksheet, information on the nature of the job is detailed. For this research, once the appropriate logs were accumulated, the corresponding worksheets filled in by the responsible maintenance team were retrieved from the customer care records and studied. Information regarding the materials used and the length of time between the opening of the log sheet and closing were recorded. This information included data on the type, length, and class of pipes used to repair or replace a pipeline, materials used to repair a faulty pump and the length of time taken to repair the pump and reinstall it.
    - Information regarding the distribution network of the water schemes such as lengths of mains, number of valves, number of meters, number of pumps, number of service connections etc. was extracted from the water schemes feasibility studies of the municipality. This was available from the municipality records.

The first round of surveys targeted the lead operators from each water system; this involved spending 3 to 4 hours with each operator to administer the questionnaire as they went about their daily operations.

Thereafter, approximately one hour was spent with each of the leaders from the three maintenance teams to administer the questionnaire. Their schedules were more

stringent than those of the operators as they spend most of their time travelling to different water systems to attend to urgent maintenance issues, so less time was spent with them.

Sessions with the superintendent and the technical director were by appointment and each interview session was between 1 and 2 hours long. Where some aspects needed clarification or deeper discussions, a second interview session was conducted.

The whole process of gathering data from the lead operators, maintenance team leaders, superintendent and technical director took approximately 6 weeks.

Based on the available data, the IWA Performance Indexes (PIs) were also calculated. Those PIs that did not have data to be collected such as water loss PI were not calculated. In this way only reliable PIs were used in the analysis.

Information on the Regulatory Performance Measurement System of the water schemes under study for the 2013/2014 period was obtained from the Department of Water Affairs (now the Department of Water and Sanitation). This was used to work out the PIs under this system.

3.5 Data analysis

3.5.1 Quantitative data preparation

The raw data collected as described in section 3.3 (field work) required refinement and presentation in a form that could easily be analysed. This was done as indicated in Figure 3.6.

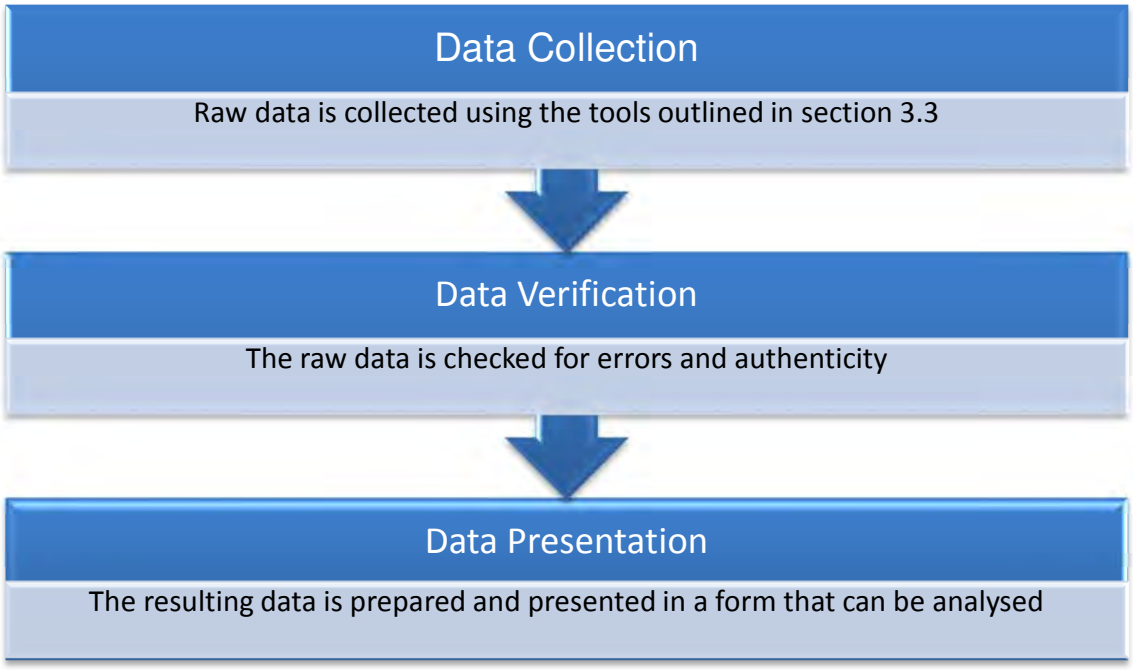

Figure 3.6: Proposed approach for quantitative data preparation

This research compares performances of rural WDSs to urban WDSs; therefore, the collected data had to be prepared in a structured format that could easily highlight patterns, similarities and differences in the WDSs. A data presentation template was prepared which was used to present data for easy comparison. The results are presented in chart format for comparison.

3.5.2 Data analysis

Once the data had been refined and presented, the following data analysis was undertaken: The two sets of data collected (from the rural and urban regions respectively) are presented in a predetermined presentation format that will allow both sets of data to be compared on the same basis as shown in figure 3.7.

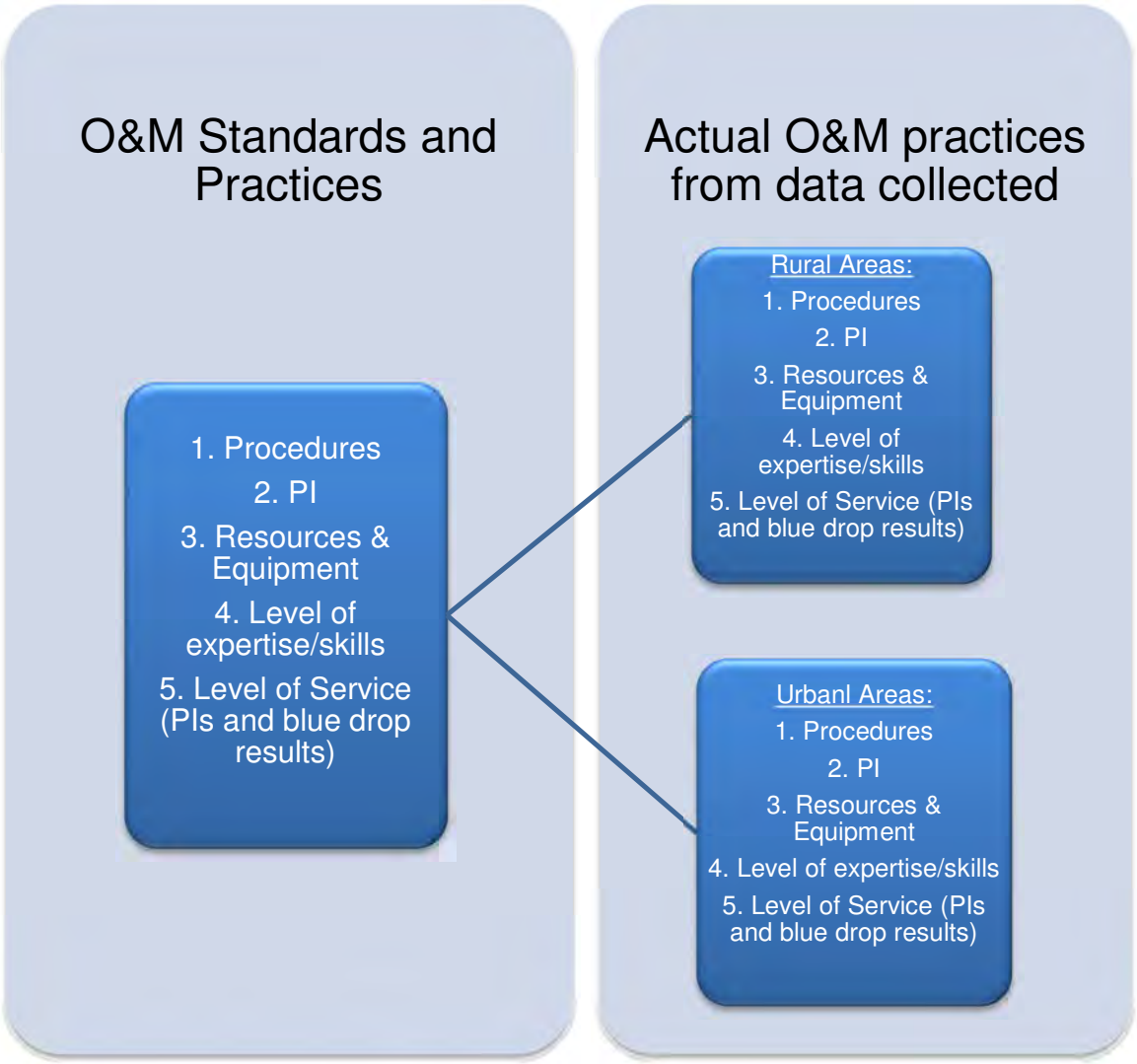

Figure 3.7: Data analysis approach 1

The actual O&M standards in rural areas were then compared to those in urban areas as depicted in Figure 3.8:

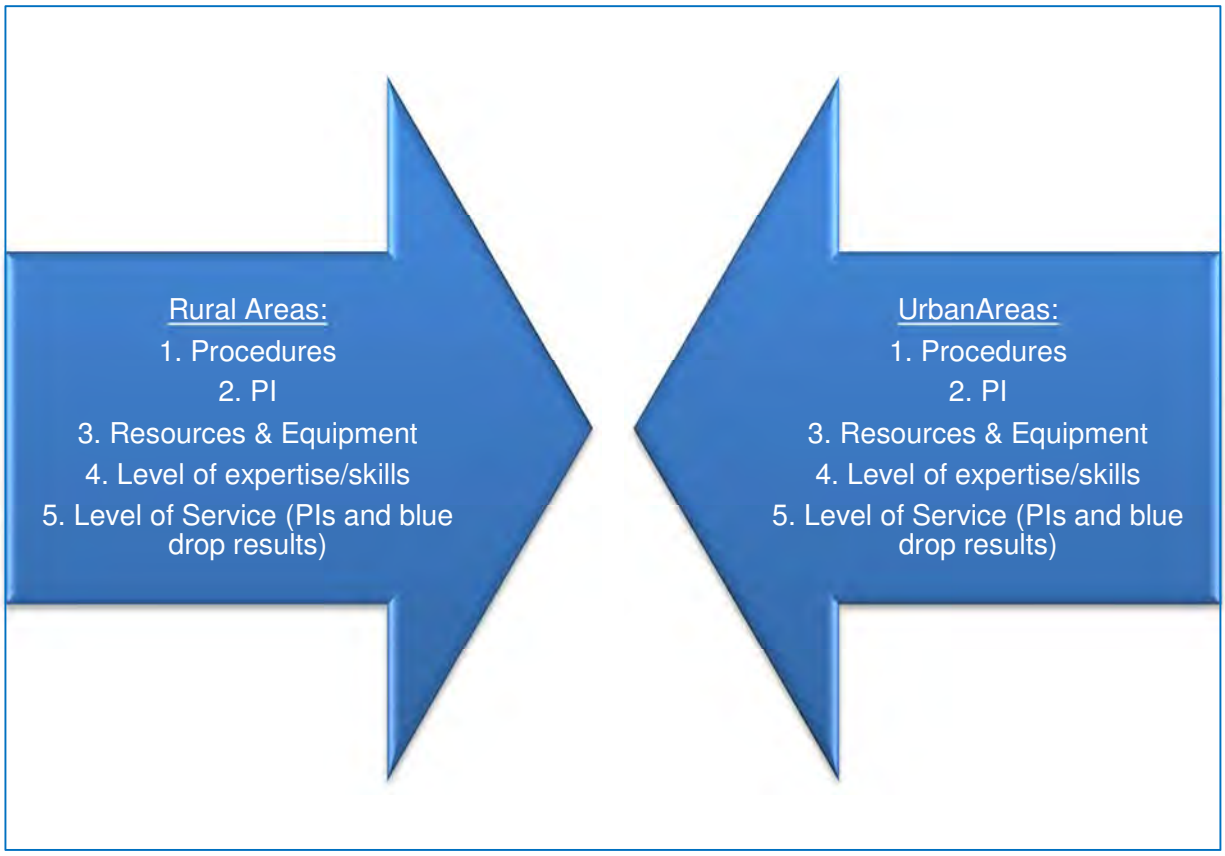

Figure 3.8: Data analysis approach 2

The results extracted from this analysis were combined with information retrieved from the structured interviews to draw up the conclusions of this study, satisfy the objectives outlined in Chapter One, and make recommendations.

4. ANALYSIS AND DISCUSSION

4.1 Introduction

This chapter deals with the analysis and discussions of the findings obtained from the desk study and field work. The data collected was sorted, refined and prepared in a format that could be analysed in a comparative manner.

The chapter describes the analysis of three sets of data; the International Water Association Performance Indicators, the Regulatory Performance Measurement System (Blue Drop) Key Performance Indicators, and data retrieved from questionnaires and interviews. It further discusses the analysed data under each set.

4.2 Analysis using the International Water Association (IWA) Performance Indicators

The performance indicators (PIs) evaluated in this section are outlined in the methodology chapter (Chapter 3). Each objective had a number of PIs that were calculated and used for comparative purposes. The PIs calculated were based on the availability and reliability of the data. Data with low reliability (such as approximations as opposed to documented data) were not analysed.

4.2.1 Mains Rehabilitation

This PI compares the length of pipe mains rehabilitated during the year to the total length of mains found in a WDS (1st January to 31st December 2013). The results are shown in table 4.1.

The total length of mains was retrieved from the Kai !Garib water supply schemes feasibility study report, while the length of pipe used for rehabilitation was extracted from the worksheets for pipework replacements conducted in each water scheme for the period January - December 2013.

Table 4.1 Mains rehabilitation PI

Mains Rehabilitation PI				
Region		Length of mains rehabilitated (m)	Total length of mains (m)	Percentage of mains rehabilitated per year (%/year)
Urban	Kakamas	1250	5864	
	Keimoes	450	6322	
	Kenhardt	0	41039	
	Total	**1700**	**53225**	**3.2**
Rural	Lutzburg	75	538	
	Soverby	12	1724	
	Currieskamp	0	1263	
	Total	**87**	**3525**	**2.5**

The table shows that the urban WDSs had higher rates of mains rehabilitation than the rural WDSs.

4.2.2 Bulk meter replacement

This PI compares the number of bulk meters replaced during the year to the total number of bulk meters found in a WDS (1st January to 31st December 2013). The results are shown in table 4.2.

The total number of meters was retrieved from the Kai !Garib water supply schemes feasibility study report (Stabilis Development, 2012), while the number of meters replaced was extracted from the worksheets for meter replacements conducted in each water scheme for the period January - December 2013.

Table 4.2 Bulk meter replacement PI

Bulk Meter Replacement PI				
Region		Total number of bulk meters (No.)	Number of bulk meters replaced (No.)	Number of bulk meters replaced per year (%/year)
Urban	Kakamas	2	1	
	Keimoes	3	0	
	Kenhardt	3	1	
	Total	**8**	**2**	**25.0**
Rural	Lutzburg	2	0	
	Soverby	2	0	
	Currieskamp	2	1	
	Total	**6**	**1**	**16.7**

The data indicate that the urban areas had higher rates of meter replacement than the rural areas.

4.2.3 Service connection rehabilitation

This PI compares the number of service connections rehabilitated to the total number of service connections found in a WDS during the period 1st January to 31st December 2013. The results are shown in table 4.3.

Service connections include private connections, yard connections and public standpipes. The total number of service connections was retrieved from the Kai !Garib water supply schemes feasibility study report, while the number of service connections rehabilitation was extracted from the worksheets for service connections rehabilitation conducted in each water scheme for the period January - December 2013.

Table 4.3 Service connection rehabilitation PI

Service Connection Rehabilitation PI				
Region		Total number of service connections (No.)	Number of service connection rehabilitated (No.)	Number of service connections rehabilitated per year (%/year)
Urban	Kakamas	2164	250	
	Keimoes	2909	70	
	Kenhardt	1167	150	
	Total	**6240**	**470**	**7.5**
Rural	Lutzburg	322	5	
	Soverby	255	10	
	Currieskamp	183	0	
	Total	**760**	**15**	**2.0**

The table indicates that the urban WDSs underwent more frequent service connection rehabilitation than the rural systems. Rehabilitation of service connections entailed replacement or repair of the service connections when consumers complained of leakage or faulty tap connection.

Data on leakage control and water loss along the distribution system was not available; therefore leakage control, active leakage control repairs and water loss per connection PIs could not be evaluated.

4.2.4 Employees per connection

This PI is calculated as the total number of full time employees dedicated to a system per 1 000 connections in that system during the year (1st January to 31st December 2013). The results are shown in table 4.4.

The number and details of the personnel in the municipal technical department was retrieved from the departmental organogram that was provided by the department for the purpose of this research.

Table 4.4 Employees per connection PI

Employees per Connection PI				
Region		Number of employees (No.)	Total number of connections (No.)	Number of employees per 1 000 connections (No/1 000 conn.)
Urban	Kakamas	20	2164	
	Keimoes	19	2909	
	Kenhardt	13	1167	
	Total	**52**	**6240**	**8.3**
Rural	Lutzburg	15	322	
	Soverby	14	255	
	Currieskamp	14	183	
	Total	**43**	**760**	**56.6**

The figures in the table above indicate that there were more employees dedicated to the rural WDSs than the urban WDSs. The total number of employees in the water department constituted employees in management, O&M, customer care and administration. The employees in management, customer care and administration catered for the whole Kai !Garib local municipality which include the rural and urban WDS. For the purposes of calculating this PI, the number of employees in these categories was divided 50/50 between the rural and urban WDSs. The amount of time the management, customer care and administration employees dedicated to the urban and rural systems was further investigated and discussed in the interview and questionnaire sections.

4.2.5 General management personnel

The general management PI compares the number of personnel in management to the total number of employees dedicated to a WDS for the period 1st January to 31st December 2013. The results are shown in table 4.5.

The structure, number, and details of the personnel in the municipal technical department were retrieved from the departmental organogram provided by the department for the purpose of this research.

Table 4.5 General management PI

General Management Personnel PI				
Region		Total number of employeers (No.)	Number of employees in management (No.)	Percentage of employees in Management(%)
Urban	Kakamas	20	1	
	Keimoes	19	1	
	Kenhardt	13	1	
	Total	**52**	**3**	**5.8**
Rural	Lutzburg	15	1	
	Soverby	14	1	
	Currieskamp	14	1	
	Total	**43**	**3**	**7.0**

The data in the table indicate that there were more employees in management dedicated to rural areas than in the urban areas. As discussed in 4.2.4, management was a shared resource and time dedication allocated to the rural and urban would provide a better reflection on which systems got more dedication from the management team. This will be brought out in the interviews discussion section.

4.2.6 Operation and maintenance personnel (%)

This PI compares the number of technical personnel involved in O&M to the total number of employees found in a WDS for the period 1st January to 31st December 2013. The results are shown in table 4.6.

The structure, number and details of the personnel in the municipal technical department were retrieved from the departmental organogram that was provided by the department for the purpose of this research.

Table 4.6 Operation and maintenance personnel PI

Operation and Maintenance Personnel PI				
Region		Total number of employeers (No.)	Number of employees in O&M (No.)	Percentage of employees in O&M (%)
Urban	Kakamas	20	16	
	Keimoes	19	15	
	Kenhardt	13	11	
	Total	**52**	**42**	**80.8**
Rural	Lutzburg	15	11	
	Soverby	14	10	
	Currieskamp	14	10	
	Total	**43**	**31**	**72.1**

The data in this table indicate that there were more people dedicated to O&M in the urban than in the rural systems. The maintenance teams, however, were shared resource between the rural and urban regions while the operators are not (refer to section 3.4). Each system had its own team of operators. The question of time dedication of the maintenance teams to the rural and urban systems was investigated further by use of questionnaires which are analysed later in this chapter.

4.2.7 Tertiary qualification (%)

This PI compares the number of personnel with tertiary qualifications to the total number of employees dedicated to a WDS for the period 1st January to 31st December 2013. The results are shown in table 4.7.

Tertiary qualifications in this case include an accredited degree or diploma. The structure, number, and details of the personnel in the municipal technical department were retrieved from the departmental organogram that was provided by the department for the purpose of this research.

Table 4.7 Tertiary qualification PI

Tertiary Qualification PI				
Region		Total number of employeers (No.)	Number of employees with degree or diploma (No.)	Percentage of employees with tertiary qualification%
Urban	Kakamas	20	1	
	Keimoes	19	1	
	Kenhardt	13	1	
	Total	**52**	**3**	**5.8**
Rural	Lutzburg	15	1	
	Soverby	14	1	
	Currieskamp	14	1	
	Total	**43**	**3**	**7.0**

This table indicates that there were more personnel with tertiary qualifications in rural than in urban WDSs. However, it was the personnel in management positions that possessed these tertiary qualifications and they were shared between the two areas. For this reason, the number of managers in these categories was divided 50/50 between the rural and urban WDSs for the purposes of calculating this PI. This however may not provide an accurate estimation of managerial dedication to these systems. Time dedication was therefore further investigated and is discussed in the interview section of this research.

4.2.8 Vehicle availability

This PI compares the total number of vehicles dedicated to O&M per 100 kilometres of pipes found in a WDS for the period 1st January to 31st December 2013. The results are shown in table 4.8.

Table 4.8 Vehicle availability PI

Vehicle Availability PI				
Region		Total number of vehicles (No.)	Total length of mains (m)	Number of vehicles per 100 km (No/100km)
Urban	Kakamas	2	5864	
	Keimoes	1	6322	
	Kenhardt	1	41039	
	Total	4	53225	**0.01**
Rural	Lutzburg	2	538	
	Soverby	1	1724	
	Currieskamp	1	1263	
	Total	4	3525	**0.11**

Vehicles were used by the maintenance teams, so when compared to the length of mains, the areas with longer mains exhibited lower vehicle availability. The question of time dedication of the maintenance teams (and hence vehicle availability) to the rural and urban systems was investigated further and discussed in the interview and questionnaire section.

4.2.9 Customer service personnel

This PI compares the number of personnel in customer care to the total number of employees found in a WDS for the period 1st January to 31st December 2013. Personnel information was retrieved from the departmental organogram. The results are shown in table 4.9.

Table 4.9 Customer service PI

Customer Care Personnel PI				
Region		Total number of employees (No.)	Number of customer care employees (No.)	Percentage of employees in customer care (%)
Urban	Kakamas	20	2	
	Keimoes	19	2	
	Kenhardt	13	2	
	Total	**52**	**6**	**11.5**
Rural	Lutzburg	15	2	
	Soverby	14	2	
	Currieskamp	14	2	
	Total	**43**	**6**	**14.0**

The above table indicates that the rural WDSs had more customer care personnel than the urban systems. However, the customer care centre catered for all the service departments in Kai !Garib local municipality and therefore time allocated to the rural and urban systems was further discussed in the questionnaire section below.

4.2.10 Interruptions per connection

This PI compares the number of water supply interruptions as logged in the customer care data base per 1000 connections found in a WDS system for the period 1st January to 31st December 2013. The results are shown in table 4.10.

Information on the number of water supply interruptions was retrieved form the customer care system logs.

Table 4.10 Interruptions per connection PI

Interruptions per Connection PI				
Region		Total number interruptions during the year (No.)	Total number of service connections (No.)	Number of interruptions per 1 000 connections per year (No./1 000 connections /year)
Urban	Kakamas	46	2164	
	Keimoes	68	2909	
	Kenhardt	24	1167	
	Total	**138**	**6240**	**22.1**
Rural	Lutzburg	10	322	
	Soverby	7	255	
	Currieskamp	7	183	
	Total	**24**	**760**	**31.6**

The table indicates that the rural WDSs had higher rates of interruptions than the urban WDS. This could be due to the urban region receiving better O&M services than the rural area and hence had a higher rate of interruption.

4.2.11 Pump failures

This PI expresses the average number of days a water system pump was out of order (as per customer care data logs) per year (1st January to 31st December 2013). The results are shown in table 4.11.

The total number of pumps was retrieved from the Kai !Garib water supply schemes feasibility study report, while the number of pump failures and time it took to repair and replace the pumps were extracted from the worksheets for pump failures at each water scheme for the period January - December 2013.

Table 4.11 Pump Failures PI

Pump Failures PI				
	Region	Total number days system pumps were out of order (No.)	Number of pumps (No.)	Pump failure days per pump per year (days/pump/year)
Urban	Kakamas	12	15	
	Keimoes	4	11	
	Kenhardt	4	9	
	Total	**20**	**35**	**0.6**
Rural	Lutzburg	7	5	
	Soverby	3	3	
	Currieskamp	8	2	
	Total	**18**	**10**	**1.8**

The above table indicates that rural WDSs had significantly higher pump failure days than the urban WDSs.

4.2.12 Discussion

The PIs analysed under the IWA system of performance measurement are discussed in this section. The results above were first combined in chart form then discussions regarding the differences and similarities in the resources used in O&M and O&M activity levels in the rural and urban WDSs were undertaken.

The PIs calculated above are summarized and represented in figure 4.1.

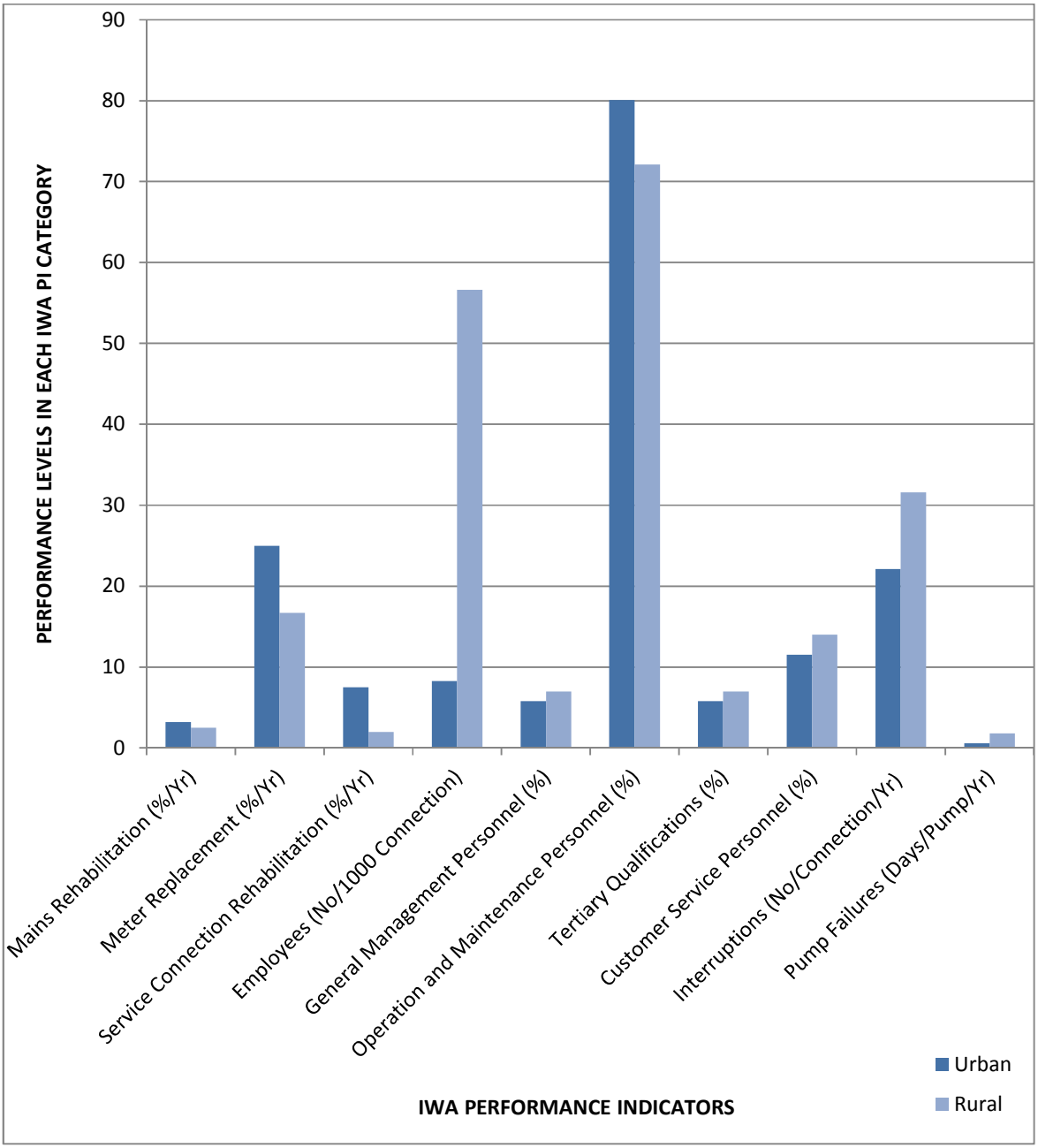

Figure 4.1: Comparison of urban and rural O&M PIs using the IWA system of performance measurement

Resources

Figure 4.1 shows that the rural WDSs had considerably more employees from the water department than the urban WDSs. There were also more employees in management and customer service attending to the rural areas than the urban areas.

However, a proportion of the total number of employees was shared among the rural and urban WDSs, namely; management, customer care and administrative personnel. The total number of connections in the urban systems was considerably higher than in the rural systems. The time allocation that the shared employees dedicated to the rural and urban systems would provide better insight of the situation on the ground. If it is assumed that time allocation was 50% to rural and 50% to urban; then the urban systems indeed had lesser employees per connection attending to the systems due to the large number of consumers.

The general management team constituted of the technical director and water superintendent; while the superintendent was wholly responsible for the water department, the technical director was responsible for other departments as well, including; roads and storm water, sanitation, disaster management and electrical departments. Therefore it was difficult to allocate the proportion of time given to the water department let alone the rural and urban WDSs by the technical director.

The customer service also catered for all service departments (water, roads and storm water, sanitation, and electrical departments). Customer care time allocation between the rural and urban systems was therefore also difficult to deduce.

The only human resource that was not shared were the operators of the different water schemes and therefore the O&M personnel PI provided a more realistic picture of the employee status of both regions. There were more O&M employees in urban than in rural areas; this could be accounted for by the relatively larger WDSs and population served by the O&M personnel in the urban WDSs.

The PI on vehicle availability was too small to fit in the chart above; however, it indicates that there was higher vehicle availability in the rural areas (0.11) than in the urban areas (0.01). It needs to be noted that the vehicles in this case study were used by the maintenance team for mobilisation to the different water schemes and the issue of prioritisation had to be taken into consideration; this was investigated in the questionnaire section of this research.

The vehicles were centred at the major towns and only used to attend to the rural areas when emergency maintenance was required to be undertaken. The distances from the towns to the rural areas were large, this would deterred the maintenance staff from using their vehicles to reach the rural areas to undertake proactive maintenance as it was both time consuming and expensive.

O&M activity PIs

The percentage of mains replacement, meter replacement and service connection rehabilitation was significantly higher in urban than in rural areas. This could have been as a result of the relatively larger WDSs sizes in the urban areas as well as better O&M practices, particularly proactive maintenance in urban areas.
Reasons could also be older infrastructure in some of the urban systems experienced frequent breakdowns hence frequent replacement or rehabilitation. However, the PIs of system interruptions and pump failures were significantly lower in urban than in rural water system. This supports the argument that better O&M practices existed in the urban systems leading to fewer system interruptions and pump failures.

4.3 Analysis using the Regulatory Performance Measurement System (RPMS) benchmarking system

4.3.1 Introduction

The Department of Water Affairs (now the Department of Water and Sanitation) initiated and executes the RPMS benchmarking system. This system is still being refined and this analysis is based on available data from the 2013/2014 Blue Drop scorecard (DWA, 2014). The Blue Drop scoring concentrates mainly on water quality and water treatment processes; however, some key performance indicators (KPIs) directly affect the water distribution system as well.

This analysis will first define the scoring system used in the RPMS. It will then display the results each WDSs scored for the January 2013 – December 2013 period and represent these scores in chart form.

The RPMS uses Blue Drop scoring system to measure performance. The score ranges for each grade are broken down in Table 2.1 in the literature review chapter (Chapter 2). The KPIs used in the is scoring system are: water safety planning; drinking water quality process management and control; drinking water quality (DWQ) compliance; management accountability and local regulation; asset management; and water use efficiency and water loss management. Table 4.12 depicts these KPIs and the grading of each KPI for each study water system.

Table 4.12: Blue Drop score card grading (DWA, 2014)

		Key Performance Indicators					
	Region	Water Safety Planning	DWQ Process Management & Control	Drinking Water Quality Complience	Management Accountability and Local Regulation	Asset Management	Water Use efficiency & water loss management
Urban	Kakamas	A+	A+	C+	D-	D-	E-
Urban	Keimoes	A-	C+	E-	D-	C-	E-
Urban	Kenhardt	B+	C+	E-	D-	C-	E-
Rural	Lutzburg	C+	C+	E+	D-	D-	E-
Rural	Currieskamp	C+	C+	D-	D-	E+	E-
Rural	Soverby	C+	C+	C+	D-	E+	E-

The desired situation for any water system is to score A+ in all the KPI's. Table 4.12 indicates the KPI grading for the different urban and rural regions. The average KPIs were calculated and expressed in form of a chart in figure 4.13.

Table 4.13: Blue drop score card grading using averages for each grade (DWA, 2014)

		Key Performance Indicators				
	Region	Water Safety Planning (%)	DWQ Process Management & Control (%)	Drinking Water Quality Complience (%)	Management Accountability and Local Regulation (%)	Asset Management (%)
Urban	Kakamas	**97.5**	**97.5**	**74.5**	**35**	**35**
Urban	Keimoes	**92.5**	**74.5**	**7**	**35**	**59.5**
Urban	Kenhardt	**87.5**	**74.5**	**4**	**35**	**59.5**
Urban	Average	**92.5**	**82.17**	**28.5**	**35**	**51.33**
Rural	Lutzburg	**74.5**	**74.5**	**22.5**	**35**	**35**
Rural	Currieskamp	**74.5**	**74.5**	**35**	**35**	**22.5**
Rural	Soverby	**74.5**	**74.5**	**74.5**	**35**	**22.5**
Rural	Average	**74.5**	**74.5**	**44**	**35**	**26.67**

The corresponding chart is shown in Figure 4.2:

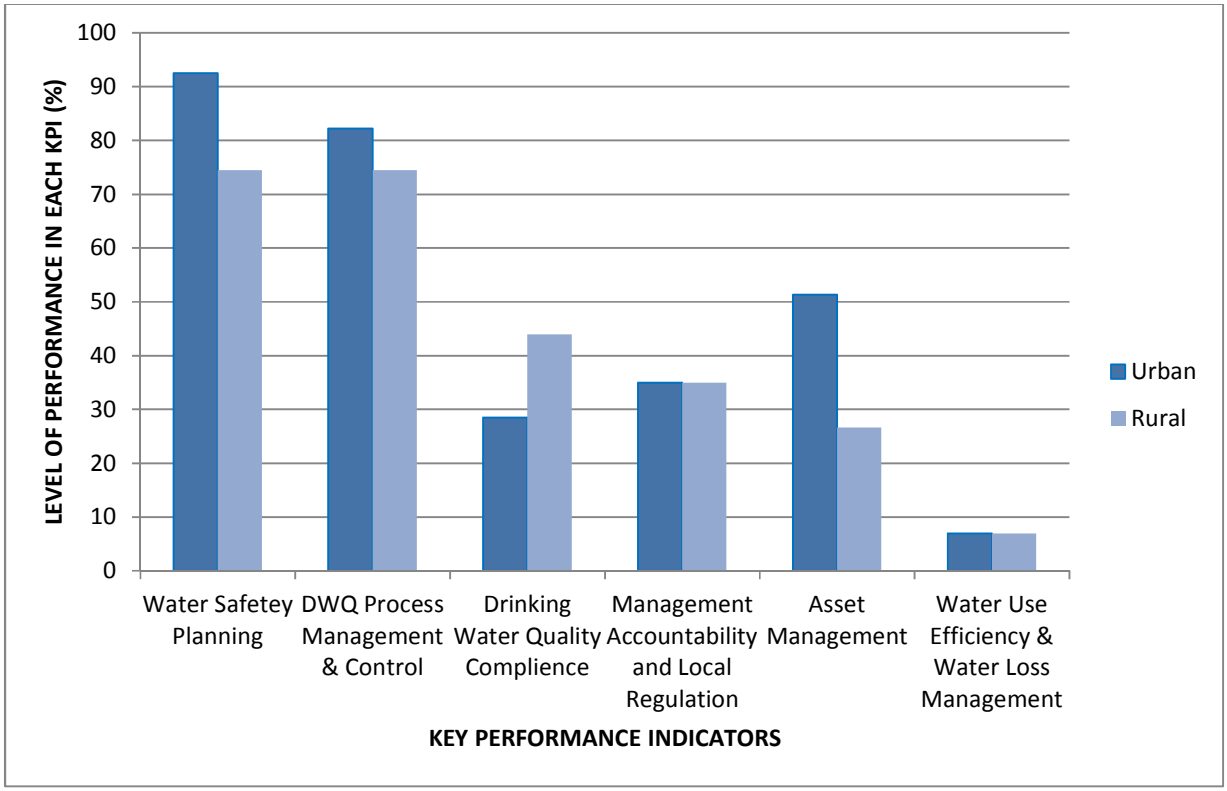

Figure 4.2: Blue Drop KPI analysis for water systems in urban and rural areas

The results shown in figure 4.2 indicate that the urban WDSs had better scores in water safety planning, DWQ process management and control and asset management. Both areas displayed similar performance in management accountability and local regulation KPI and water use efficiency and water loss management KPI. The rural WDSs performed better in the drinking water quality compliance. Both areas performed well in the water safety planning and DWQ process management and control KPIs. They however performed poorly in the water use efficiency and water loss management KPI.

All the KPIs mainly deal with the water treatment processes except for the asset management KPI which has aspects that are directly related to WDSs. It is broken down into the following subcategories; annual process audit; asset register; availability and competence of maintenance team; O&M manual; O&M budget and expenditure; and design capacity vs operational capacity. Table 4.14 depicts the performance of each WDS under these sub categories.

Table 4.14: Scorecard on asset management categories (DWA, 2014)

	Performance Indicators					
Region	Annual Process Audit (%)	Asset Register (%)	Availability and competence of maintenance team (%)	O&M manual (%)	O&M budget and expenditure (%)	Design capacity vs operational capacity(%)
Kakamas	E+	A+	C-	E-	E-	C+
Keimoes	A+	A+	C-	E-	E-	C-
Kenhardt	A+	A+	C-	C+	E-	C+
Lutzburg	E+	A+	C-	E-	E-	E+
Currieskamp	E-	A+	C-	E-	E-	E-
Soverby	E-	A+	C-	E-	E-	E+

The average of each grading was calculated and used for comparative analysis in the table 4.15. A corresponding chart displaying the comparative performance of the WDSs in these subcategories is shown in figure 4.3.

Table 4.15: Score card on asset management sub categories indicating the averages of the different grades (DWA, 2014)

		Performance Indicators					
	Region	Annual Process Audit (%)	Asset Register (%)	Availability and competence of maintenance team (%)	O&M manual (%)	O&M budget and expenditure (%)	Design capacity vs operational capacity (%)
Urban	Kakamas	**22.5**	**97.5**	**59.5**	**7**	**7**	**74.5**
	Keimoes	**97.5**	**97.5**	**59.5**	**7**	**7**	**59.5**
	Kenhardt	**97.5**	**97.5**	**59.5**	**74.5**	**7**	**74.5**
	Average	**72.5**	**97.5**	**59.5**	**29.5**	**7**	**69.5**
Rural	Lutzburg	**22.5**	**97.5**	**59.5**	**7**	**7**	**22.5**
	Currieskamp	**7**	**97.5**	**59.5**	**7**	**7**	**7**
	Soverby	**7**	**97.5**	**59.5**	**7**	**7**	**22.5**
	Average	**12.2**	**97.5**	**59.5**	**7**	**7**	**17.3**

The corresponding chart is shown in figure 4.3:

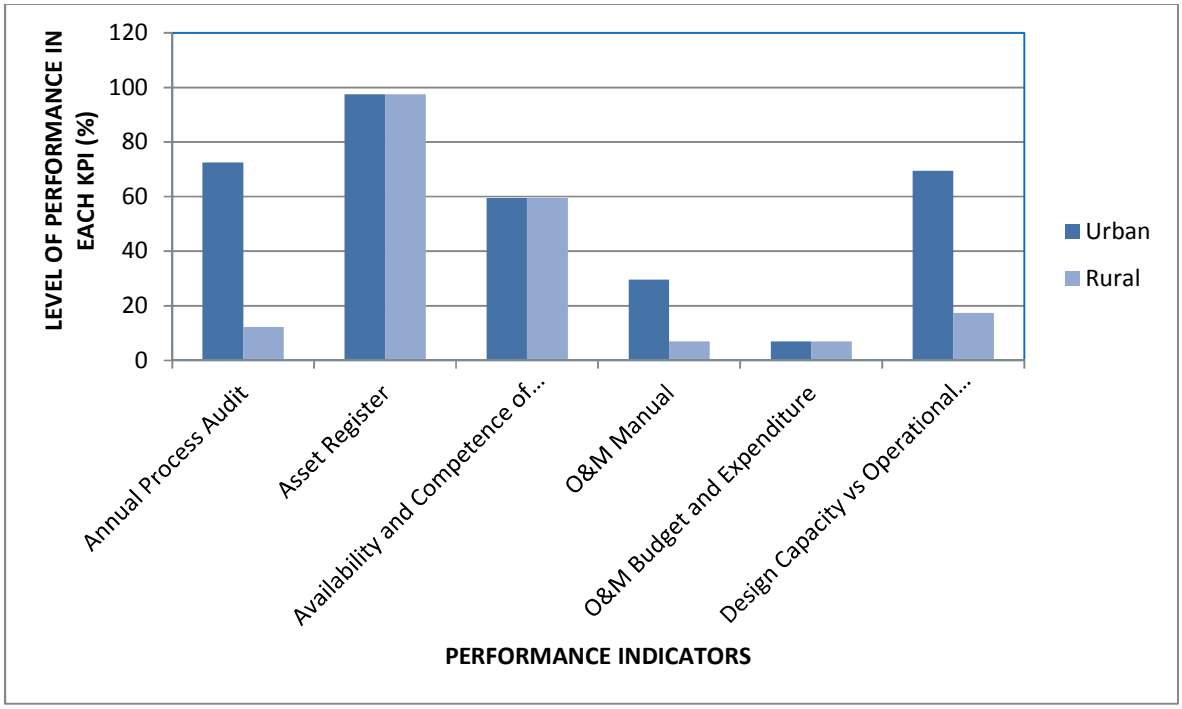

Figure 4.3: Asset management sub-category performance indicators

Overall, the urban systems performed better on asset management (51.3%) than the rural systems (26.7%). This was because they performed better in annual process audit, O&M manual and design capacity vs operational capacity sub categories. Both systems had similar scores in asset register, availability and competence of maintenance team and O&M budget and expenditure. The sub category performances that stand out are asset register in which both areas performed very well (98%) and the O&M budget and expenditure in which both areas performed poorly (7%).

4.3.2 Discussions

The section below discusses the main Blue Drop KPIs individually and then expands on the Asset Management KPI as it has aspects that directly deal with WDS performances.

Water safety planning

According to the RPMS guidelines, this KPI is a combined score of the following requirements: water safety planning process, risk assessment, monitoring programme, credibility of drinking water quality data and incident management. Bonus points were given for sampler training and incident management protocol communication.

The urban water systems scored better (92.5% compliance) than the rural (74.5% compliance) in this section. This KPI is heavily dependent on the management of water

safety processes, and the urban areas could have had better exposure and experience in this than the rural areas.

Drinking water quality process management and control

This KPI is a combined score of works classification compliance, process control registration compliance, availability of water treatment works logbooks and bonus points on process control training and process control excellence. This KPI mainly encompasses the water treatment process activities and has little to do with the WDSs. It is also a KPI of compliance to regulations in which the urban systems (82.17% compliance) performed better than the rural areas (74.5% compliance).

Drinking water quality compliance

This is a combined score of microbiological, chemical and operational compliance, and a bonus on aesthetic compliance. This KPI affects both the water treatment and the water distribution systems; samples tested for compliance are both from the water treatment site and at several points of the distribution.

The chart above indicates that both areas were struggling to achieve acceptable levels of water quality compliance. The rural area however had a higher level of water quality compliance (44%) than the urban areas (28.5%). This indicates that the rural systems had less contamination along the distribution and there were adequate levels of residual chlorine compared to the urban systems. Rural water systems tend to be smaller and therefore easier to manage; any causes of water quality anomalies can be traced and rectified more easily than in urban systems.

To obtain a complete picture, the number of sample sites has to also be taken into account. Numbers of sample sites are displayed in the table 4.16:

Table 4.16: Number of water quality sampling points

	Region	Number of Sample Points
Urban	Kakamas	4
	Keimoes	4
	Kenhardt	5
	Average	**4.3**
Rural	Lutzburg	2
	Soverby	2
	Currieskamp	2
	Average	**2.0**

The information provided from the urban systems provides a better picture of the distribution system as it takes into account more sampling points (approximately 4), one immediately after the water treatment process and the others at the furthest points of the distribution system. This means that there were definitely water quality issues along the distribution lines caused by either contamination or low residual chlorine.

On the other hand, the information extracted from the rural regions may not necessarily provide a complete picture of the WDSs. With only two sample points (one at water treatment and the other in the distribution system), poor compliance levels could mean a failure at treatment level or at distribution level, and it is difficult to draw a conclusion on the 'health' of the WDS with only one sample from the furthest part of the system being tested.

Management, accountability, and local regulation

This indicator is a combined score for management commitment, publication of performance, performance agreement and submission of drinking water quality data, with bonus points for procurement processes.

All water schemes at Kai !Garib municipality are run by the same water service authority and the same management. This is the reason for the uniform score on this KPI. For both areas, management, accountability and local regulation were issues that needed to be investigated and worked on for improvement (35%). Poor management and accountability will inevitably affect the overall O&M performance of a water system. Successful O&M, just like any other managerial function, requires planning, organizing, controlling, coordination and commanding. The end consumer has to be involved in the O&M process and the water service provider needs to be accountable to the consumers. O&M has to be carried out within the local by-laws and regulations especially when it comes to supply chain processes. Acquisition of equipment, spares and chemicals can affect the performance of O&M. When the appropriate procurement processes are adhered to, preventative and reactive maintenance can be effectively carried out.

Water use efficiency and water loss management

This KPI is a combined score on water balance, water demand management strategy, business plans and implementation, compliance, performance, and bonus points on availability and competence of the water loss manager and team.

Both rural and urban areas had very low compliance levels and reasons cited for this is lack of water loss data and no business strategies. Water loss data is required to score the compliance and performance category and seeing that this data is not available, this too was scored quite low for both areas. Lack of data could be caused by poor recording and filing systems, non-functional measuring equipment, incompetent personnel in charge of water loss management or a combination of these. It could also be caused by a lack of a water loss management system altogether. Without knowledge

of the water loss levels exhibited by a water scheme, it is difficult to know the efficiency levels of that scheme and draw up its water balance chart.

Asset management

This KPI was further broken down into its sub category PIs as some of these are a direct reflection of the performance of O&M of the WDSs. Below are the discussions under each sub category:

- **Annual process audit:** This indicator pertains to the water treatment process only and does not apply to this study as it does not include the water distribution systems.

- **Asset register:** This register includes the detailed relevant equipment and infrastructure, asset description, location, condition, and replacement value. A proper asset register forms the basis of an adequate O&M plan because a utility needs to first know its existing equipment and infrastructure as well as their status before embarking on an O&M exercise.

  Both rural and urban systems exhibited excellence in this indicator (98% compliance); this is because the municipality had employed an external consultant (Total Geo-spatial Information Solutions) to assist with the asset register.

- **Availability and competence of the maintenance team:** Competence is measured in terms of qualifications and experience. The maintenance team at Kai !Garib local municipality was shared by both urban and rural systems and therefore exhibited similar performances in both regions. A compliance level of 59.5% is above average but there is room for improvement.

- **Operation and maintenance manual:** This manual mainly pertains to the water treatment processes but also includes aspects that affect the water distribution system such as maintenance schedules and fault finding procedures.

  Both regions are not doing well on this aspect, with the urban systems exhibiting better compliance at 29.5% while the rural areas were at only 7%. The urban areas had larger water schemes that were monitored using a telemetric system. For this reason, it was expected that the schemes would have O&M manuals to assist in the operation, maintenance and troubleshooting of the telemetric system; it was noted that there were O&M manuals in all the urban systems however the contents of the manuals needed much improvement. The rural systems were manually operated and monitored and were expected to have a O&M manual to assist the operators operate the different components of the water scheme; however this was not the case, it was noted that all the rural water schemes did not have manuals.

These competency levels are however expected to increase in time when the asset register is complete and the data is used to draft out appropriate O&M manuals.

- **O&M budget and expenditure:** Budget and expenditure for O&M is an element that is initiated at management level. Any decisions made at this level will have the same impact on the urban and rural areas; this accounts for similar performance of this indicator in both rural and urban areas. At 7% compliance, the O&M of all the water systems was bound to suffer. The reason for non-compliance sited was lack of data (O&M budget for each water scheme not provided). This could have been caused by lack of a proper filing system and of communications systems or even the non-consideration of O&M of water services in the municipal budget planning process. The reasons for lack of financial data pertaining to O&M should be investigated and rectified.

- **Design capacity vs operational capacity:** This is scored on the documented design capacity for the plants, documented daily production rates and the annual meter calibration certificates. In this section the urban systems excelled (69.5% compliance) and it was because they had documented operational data downloaded directly from the telemetric systems including production rates. The rural systems however fell short (17.3) because daily production rates had to be manually monitored and recorded, a tedious and time consuming exercise that was highly dependent on the measuring instruments (meters) and the operators' competence. The one section that both regions fell short was the submission of meter calibration certificates; this could have been as a result of poor filing systems or the complete failure of meter calibration. The latter would result in flawed readings which could in turn have affected other aspects of the water system such as measured water losses.

4.4 Information from questionnaires

This section analyses and discusses the results from the interviews and questionnaires. It describes the respondents' perception of what O&M entails. The description is broken down into analysis of the resources available and the O&M activities that are carried out in the water schemes.

4.4.1 Resources

4.4.1.1 Human Resources

This information was retrieved from an organogram the manager provided during the interview session (refer to Figure 3.5). A breakdown of the human resources involved in the O&M process at the rural and urban WDSs is shown in table 4.17:

Table 4.17: Breakdown of human resources at the rural and urban regions of Kai !Garib

	O&M sections				
Regions	Management	Operators	Maintenance Team	Customer Care	Admin
Kakamas	1	7	9	2	1
Keimoes	1	6	9	2	1
Kenhardt	1	7	2	2	1
Average	**1**	**7**	**7**	**2**	**1**
Lutzburg	1	2	9	2	1
Sorverby	1	1	9	2	1
Currieskamp	1	1	9	2	1
Average	**1**	**1**	**9**	**2**	**1**

Management: The technical director and water superintendent formed the management of the Water Services Department at Kai !Garib local municipality. They oversaw the O&M operations of the water department and consequently of all the water schemes. It was initially assumed that management divided their time between the rural and urban systems equally; therefore the number of managers was split equally between the rural and urban areas pending the interview process that would try and provide a more realistic estimation of time dedication.

The water superintendent was responsible for the O&M of the water supply systems and reported to the technical director. The technical director on the other hand was responsible for provision of civil services in the municipality which include roads and storm water, sanitation, water, electricity supply as well as disaster management. They both had tertiary qualifications and experience in their different capacities; the technical director had extensive experience (approximately 7 years) in management and administration of government departments while the water superintendent had more than 3 years' experience in a similar position in another municipality.

They both highlighted that the main challenges in the O&M of the WDSs was understaffing, personnel with limited experience and training, as well as a restricted budget for O&M. The issue of training the existing personnel was always included in their annual planning reports but the limited funds did not allow them to realise this goal.

Both of them explained that while they strived to provide the best services to all the water schemes, they dedicated more time to the urban water schemes due to the large consumer base and the large complex water schemes that require frequent attention. Should the urban areas suffer water related issues, it not only affected the residential consumers but the industries and commercial businesses; it directly affected the economy of Kai !Garib local municipality. For this reason, they attended to the urban schemes more regularly than the rural schemes.

Operators: Each water supply system had its own operating team headed by a lead operator. The lead operator reported to the water superintendent on the operational and maintenance issues experienced in the water supply system. The operating teams in the urban systems were much bigger than those in the rural systems, some have only one operator. This may have been due to the size of the water schemes; the urban regions had much larger water schemes in terms of capacity (average of 220 m^3/hour) and the size of the distribution network (pipe sizes, lengths and number of site connections).

The duty of the operating teams was to operate and maintain the water supply systems. Their time and resources were spent more on the water treatment section of the supply system than in the distribution section. When interviewed, the operators in the urban areas seemed to have a better understanding of the water supply systems they operated than the operators in the rural areas. They could approximate the system capacity, knew the operating parameters that the system should run within, and they could easily locate the main system components such as the bulk meters, hydrants, and main valves.

The operators in the rural water supply schemes could not estimate the system capacity and did not understand the importance of observing system parameters. They could all locate the location of the bulk meters but rarely got to read and document the readings. Where readings were recorded, the values were sometimes not consistent due to either operator error or a faulty meter.

Maintenance Team: This was a partially shared resource. Kai !Garib was broken down into 3 maintenance areas, namely the Kakamas maintenance team that served Kakamas and the surrounding 6 settlements, the Keimoes maintenance team that served Keimoes and the surrounding 4 settlements, and the Kenhardt maintenance team that served Kenhardt town. Each team had a team leader who reported to the superintendent. Their main function was to attend to system breakdowns that could not be handled by the operating teams. They were also responsible for the proactive maintenance of the water systems, especially the WDSs that the operators did not frequently have contact with. The Kakamas and Keimoes maintenance teams served a large area in terms of square kilometres and population, while the Kenhardt maintenance team only served Kenhardt town, hence the lower personnel number in their team. Lutzburg was served by the Kakamas maintenance team, while Soverby and Currieskamp were served by the Keimoes maintenance team.

The maintenance teams spent most of their time and resources in the urban areas and only attended to the rural areas in emergency situations. When interviewed, the maintenance team leaders explained that in a typical week they would visit on average two of the rural water systems for approximately two to three hours each, depending on the emergency. They explained that this was a result of the distance between the towns where the teams are located and the rural settlements and that the urban system already had a large number of maintenance related issues to attend to so they had

limited time spared for the rural systems. Attending to the rural systems was time consuming and expensive.

Customer care department: Kai !Garib local municipality has a Customer Care Centre (CCC) through which any water related issues are logged into the Integrated Municipal Information System (IMIS). Once logged, the maintenance team in charge is informed, a job card is opened with a corresponding worksheet. On the worksheet, the team provides details of the problem, the cause, spares required to fix it and time taken to fix it.

The CCC was found to be a shared resource that served the whole Kai !Garib municipality jurisdiction. Just like management, the number of staff was divided equally between the rural and urban regions. The centre gave consumers the option to call it directly if a problem is encountered or send a text message and the operators returned the call. Consumers could also make use of other short message service platforms such as the WhatsApp messaging services to contact the CCC, and an operator would call back to obtain details of the problem. The CCC was used by all the civil service departments (water, roads and storm water, sanitation and electrical) to log consumer complaints and pass them through to the responsible maintenance teams. They attended to all calls that came into the centre and so availability to both rural and urban areas was the same.

Administration: This was a supporting function to assist with the administrative issues of the whole department. One is under the technical director while the other is under the superintendent. This function was important in the O&M process as they were directly responsible for the recording and filing systems of the department which is a necessity in undertaking O&M of any services.

4.4.1.2 Vehicles

Maintenance vehicles were a shared resource. Table 4.18 is a breakdown of the number of vehicles dedicated to each region:

Table 4.18: Number of vehicles dedicated to O&M in the rural and urban regions

Region	Kakamas	Keimoes	Kenhardt	Lutzburg	Soverby	Currieskamp
No. of Vehicles	2	1	1	2	1	1
Average	**1**			**1**		

Similar to the maintenance teams, the vehicles served specific areas of Kai !Garib: 2 vehicles were dedicated to Kakamas and the surrounding settlements including Lutzburg, 1 vehicle was dedicated to Keimoes and the surrounding settlements including Soverby and Currieskamp, and 1 vehicle was dedicated to Kenhardt. There was a mismatch of resources especially for the Keimoes region because there were 9 maintenance personnel and only one vehicle dedicated to maintenance serving 4

settlements and one town. The maintenance team may therefore struggle to keep up with both reactive and proactive maintenance in the town and the 4 surrounding settlements.

4.4.1.3 Workshops

In the Kai !Garib region, there was only one workshop dedicated to repairs and servicing of major equipment related to water service such as pumps, bulk meters and valves. The workshop was in Keimoes where major spare parts were also stored and repair equipment was available. Repair of key equipment such as pumps in rural areas would take time due to time spent in transporting the equipment to the workshop, repair, and transport it back to site. This does not take into account that the equipment may not have been a priority when compared to similar equipment from towns or bigger settlements, besides the obstacles experienced with the limited number of maintenance vehicles.

4.4.2 Operation and maintenance activities

This section describes and compares the O&M activities undertaken by the rural and urban O&M teams as emerged from the questionnaires posed to the O&M team leaders. They are summarised in table 4.19 below that highlights the O&M activity and how it was undertaken as reported by the operators during the questionnaire sessions. These activities were further grouped into different and similar activities in the discussion section.

Table 4.19: O&M activities undertaken in the rural and urban regions

	Region	
Activity	**Urban**	**Rural**
Preventative pipe replacement program	No	No
Flushing	Yes	Yes
Average frequency	twice a year	as needed/emergency
Check for efficiency of flushing	Yes, test for Cl residual	Yes, test for Cl residual
Average no. number of valves in system	Many, unknown	4
Routine inspection	Yes, twice a year	No
Routine valve servicing	Yes, once in 5 years: involves bolt and gland packing of the valve	No
Average no. of fire hydrants	20	None
Routine hydrant inspection	No	N/A
Routine hydrant servicing	No, only on emergency: involves replacing of o-rings	N/A
Tank cleaning	Yes, once a year: Community is informed of water interruption, tank is completely drained, filled, then drained again before filling it up again	Yes, once a year: community is informed of water interruption, tank is completely drained, filled, then drained again before filling it up again
Check for tank cleaning efficiency	Yes, water quality test	Yes, water quality tests
Average no. of bulk meters	3	1
Average no. of domestic meters	Many, unknown	None
Average frequency of meter inspection	Yes, Bulk - daily, domestic monthly	N/A
Averave frequency of meter servicing	Bulk - never, domestic - when customer complains	N/A
Average frequency of meter calibration	Never - too costly	Never
Average number of pumps in the system	12	4
Routine pump inspection	Yes, everyday: check noise levels and leakage	Yes, everyday: check noise levels and leakage
Routine pump servicing	Major, when pump fails. Lack of workshop prevents them from undertakeing minor routine maintenance. One urban system has work shop but only service when pump fails	Major, when pump fails. Lack of workshop prevents them from undertakeing minor routine maintenance
Water quality tests	Turbidity, pH, Total Chlorine, Residual Chlorine - done monthly at the distibution level with Blue Drop test kit	Turbidity, pH, Total Chlorine, Residual Chlorine - done weekly at the distibution level with Blue Drop test kit
Average number of sampling points	4 - one after clean water reservoir before distribution, 3 at the furthers ends of the distribution systems	2 -one after the clean water reservoir before distribution, one at the furthest end of the distribution system
Procedure undertaken during main break	Isolate affected area by valve or/and pump action; log call with call centre	Isolate affected area by valve or/and pump action; log call with call centre
Average time it takes to fix a main break	4hrs - 12hrs	2days - 1 week
Spare parts store	No, have a general store that couples as a spare part store	No, depend on the near towns for spares
Equipment/spares commonly kept	Pipes & fittings; usually 75mm &50mm	N/A
Monitoring and control	Semi-automated using telemetric system	Manual
Relevant training undertaken in the past 3 years	Non	Non
Emergency Response Plan	Yes	No
O&M Manual	Yes	No

4.4.3 Discussion

Table 4.19 highlights the differences and similarities in the O&M carried out in urban and rural WDSs. These are discussed in the sections below.

4.4.3.1 Similarities

The activities that were similar in both areas are the following:

- Both areas did not actively participate in preventative pipe replacement programs. Deteriorated pipes were only replaced when they failed completely.
- Both urban and rural WDSs conducted pipe flushing. Flushing effectiveness was checked by testing for chlorine residual.
- Tank cleaning was also conducted in both areas at the same frequency, i.e. once a year. Tank cleaning effectiveness was checked by testing for chlorine residual.
- Pump inspection was conducted in both areas by observing the noise levels and unusual leaks from the pumps. Bear-shaft pumps were expected to have some leakage but if it was excessive, the maintenance team was notified.
- The pump servicing was undertaken only when the pumps failed, then the maintenance team was informed. They would then take the failed pumps to a central workshop where the pumps were fixed, serviced, then taken back to site and re-installed.
- Water quality tests within the WDSs were undertaken in both areas using the same testing technology, i.e. a Blue Drop test kit.
- Emergency responses to pipe bursts were similar in both areas.
- Both areas did not have dedicated spare parts store rooms or spares inventory systems that indicated levels of stock and which spare parts were used frequently and hence should be stocked regularly.
- The O&M teams had not undergone any relevant training in the past 3 years.
- Bulk meter servicing and calibration was not undertaken in the urban or rural WDS.

4.4.3.2 Differences

The differences detected were:

- Frequency of flushing programs: twice a year in the urban systems and in emergency situations in rural areas. Flushing in the rural systems was only undertaken when there are persistent water quality issues, i.e. when water quality tests constantly fail, especially chlorine residual tests, or when consumers continuously complained of foul taste, smell, or discolouration of the water.
- From the number of valves, hydrants, meters, and pumps as well as mode of operations of the WDSs in both areas it can be deduced that the systems in rural areas were smaller than in urban areas. Those in urban areas seemed much

larger and complex; monitoring and control of these systems were however simplified by the use of a telemetric system.

- Routine inspection and servicing of valves was undertaken in the urban WDSs but not in the rural systems.
- Routine inspection and servicing of hydrants was not undertaken in either WDS, only emergency repair of hydrants was conducted in urban systems. The rural WDSs did not have any known hydrants.
- Routine inspection of meters was undertaken in the urban WDSs, daily for bulk meters and monthly for domestic meters. This was not done in the rural WDSs and there were no domestic meters in the rural areas.
- Domestic meters were only serviced when there was a consumer complaint in the urban WDSs. The rural WDSs did not have domestic meters.
- When conducting water quality tests, urban areas had 4 sampling points while rural regions only had 2. The tests were undertaken monthly in the urban WDSs and weekly in the rural areas.
- Average time to fix a main break was 4 - 12 hrs in the urban systems and 2 - 7 days in rural areas.
- Urban systems did not have a dedicated spare parts store or inventory system but had a general store in which some spares are stored, e.g. uPVC pipes and fittings, 75mm and 50mm. The rural areas depended on the bigger towns to provide spares when needed.
- The controlling and monitoring of the urban WDS was semi-automated by the use of Spectrum Telemetric systems. This means that the hydraulic characteristics of the system could be monitored remotely. The telemetric system could pick up changes in the distribution system that would disrupt supply of water; this gave the maintenance team time to rectify the situation on the ground before it became an emergency. Controlling and monitoring of the rural systems was done manually. The operators had to look out for physical changes in the system such as low tank levels, burst pipes and customer complaints to know that there had been a change in the water system hydraulics that had caused a disruption in the water supply.
- The urban water systems all had an Emergency Response Plan under the Water Safety Plan. A risk analysis was conducted for all 3 urban systems; the risks however focused on water quality with little mention of other water operating qualities such as pressure and flow. Below are the points mentioned in the plan:

    - Contamination via the reservoirs due to open gaps and aging of pipes
    - Contamination via vandalism or sabotage
    - Inadequate disinfection or flushing of new mains
    - Contamination during flooding and at points close to storm water or sewage pipes
    - Insufficient flushing points and flushing of network
    - Low residual chlorine in network
    - Contamination during repair and maintenance
    - Increase in temperature may contribute to growth of some micro-organisms

- Interruption of water supply due to pipe bursts and leaks (only mention of interrupted water supply).

There was no Water Safety Plan or Emergency Response Plan for the rural systems.

- All urban water systems had O&M manuals. The manuals mainly concentrated on the water treatment works' O&M. They gave detailed descriptions of how to operate the different components of water treatment systems with emphasis on water quality as a measure of performance of the systems. Not much attention was given to the reticulation systems. Below are the points mentioned on the WDS:

    - Point of Use (PoU) must be checked on a weekly basis to ensure that the water quality remains within the required turbidity and chlorine residuals standards as per South African National Standards.
    - It included a network sampling log sheet for sampling water quality properties of water within the distribution system.
    - The monthly summary sheet made provision for water losses but only within the treatment plant. No water loss measurement guidelines within the system were outlined.
    - Water quality was the only parameter that could be used as an indication of the WDS performance. This was done by testing the water quality at the plant and comparing the results to those at the sample points; a difference in quality could be an indication of contamination within the WDS. The O&M manuals did not address the reticulation systems adequately. Water treatment works may be in working order but with a poorly performing WDS, the whole water supply system may be deemed a failure.

From the list above, it can be deduced that there was more routine maintenance being undertaken in the urban systems than the rural systems. These included regular pipe flushing, valve servicing, inspection of meters, tank cleaning, pump inspection and water quality testing. The rural systems only undertook tank cleaning, pump inspection and water quality testing. This trend could be attributed to the urban systems possessing O&M manuals that have maintenance schedules.

There were however maintenance activities that are vital in ensuring that the water systems meet their objectives that were not practiced in either area. These included preventative pipe replacement and inspection and servicing of hydrants. Even with the O&M manuals, the urban system still had room for improvement of O&M of their water systems.

The rural systems further suffer in the quality of O&M provided due to the lack of spares stores, workshops, O&M manuals, Emergency Response Plans and telemetric systems; all of which the urban systems have. This is the primary cause of the differences in O&M exhibited by rural and urban WDSs.

4.5 Summary

This section summarises the differences and similarities in O&M between the rural and urban WDSs under each study objective below:

4.5.1 To determine O&M practices used in the selected urban and rural WDSs based on appropriate performance indicators.

Table 4.20 details the O&M practice indicators as scored by the urban and rural WDSs under the different systems of performance measurement:

Table 4.20: O&M practice performance indicators

O&M Performance Indicators		WDS area	
		Urban	Rural
IWA	Mains rehabilitation (%)	3.2	2.5
	Meter replacement (%)	25.0	16.7
	Service connection rehabilitation (%)	7.5	2.0
RPMS	Water safety planning (%)	92.5	74.5
	Drinking water quality management and process control (%)	82.17	74.5
	Annual process audit (%)	72.5	12.17
	O&M manual (%)	29.5	7
O&M activities from questionnaires	Scheduled pipe flushing	√	**x**
	Valve inspection and servicing	√	**x**
	Hydrant inspection and servicing	√	**x**
	Tank cleaning	√	√
	Pump inspections	√	√
	Routine water quality testing	√	√
	O&M manuals and emergency response plans	√	**x**
	Water loss management practices	**x**	**x**

Both rural and urban WDSs were found to undertake some level of O&M practices. The urban WDSs however exhibited higher levels of O&M activities than the rural WDSs in most indicators. The only indicator in which the rural WDSs displayed higher scores was the meter replacement.

The WDSs in both areas could not be scored on water loss, active leakage control, water use efficiency and water loss management PIs due to lack of data. It was revealed that indeed the WDSs do not undertake water loss management practices within the distribution systems.

4.5.2 To determine the level of expertise (skills, both technical and managerial) of staff responsible for O&M in the selected urban and rural WDSs.

Table 4.21 details the level of expertise indicators as scored by the urban and rural WDSs under the different systems of performance measurement:

Table 4.21: Level of expertise performance indicators

Level of expertise PIs		WDS area	
		Urban	Rural
IWA	Overall no. employees/1000connections	8.3	56.6
	Employees with tertiary qualifications (%)	5.8	7.0
	Employees dedicated to O&M (%)	80.8	72.1
RPMS	Management, accountability, and local regulation (%)	35	35
	Availability and competence of maintenance team (%)	59.5	59.5
	Annual process audit (%)	72.5	12.17
	O&M manual (%)	29.5	7
Questionnaires	5+ years technical experience	√	**x**
	Any technical training	√	**x**
	Attended training in the past 3years	**x**	**x**

Both areas are operated under the same management with one technical director and one superintendent. The technical director was in charge of all civil services departments and so it was difficult to apportion time dedicated to rural and urban areas by management. The management however attended to the urban systems more frequently than the rural systems due to the large consumer base and large complex water systems found in the urban areas.

The maintenance teams were shared between the rural and urban WDSs; they were based in the town centres and only attend to the rural WDSs when required. Each WDS had its individual team of operators; there were more operators in the urban systems (average of 7 per system) than in the rural systems (average of 1 per system). The urban systems were much larger in terms of capacity, network coverage and population served, so there was a need for more operators to manage the system adequately.

All the lead operators in the urban water systems had adequate experience in the fields they worked and had tertiary technical training while only one operator from the rural water systems has had tertiary training. All three lead operators from the rural systems had less than 5 years' experience in water system operation. None of the operators from WDSs in both areas had attended technical training in the past 3 years.

The operators in the urban water systems displayed in-depth knowledge of the systems they operated while the operators in the rural water supply schemes could not estimate the system capacities and did not understand the importance of observing system parameters.

4.5.3 To determine the resources and equipment dedicated to O&M of the water distribution systems in the selected urban and rural areas.

Table 4.22 below details the resources and equipment dedication indicators as scored by the urban and rural WDSs under the different systems of performance measurement:

Table 4.22: Resources and equipment performance indicators

O&M Performance Indicators		WDS area	
		Urban	Rural
IWA	Vehicle Availability No./100km	0.01	0.12
RPMS	Asset Register (%)	97.5	97.5
Questionnaires	Average time spent in WDS per week (hrs) by maintenance team	32	6
	Workshop dedicated to O&M repairs	x	x
	Store for spares	√	x
	Telemetric system	√	x

The vehicles dedicated to O&M were used by the maintenance team who were based in the urban areas and only come out to the rural WDSs during emergency maintenance. The maintenance team on average visited two of the rural water systems for approximately two to three hour per week in each system. This translates to spending at most 6 hrs in the rural WDSs during a 40 hour working week.

There was only one workshop dedicated to O&M repairs in the Kai !Garib local municipality centred at an urban town centre; any equipment that could not be fixed on the site by the maintenance team was brought to this workshop for repairs. The rural areas were not prioritised owing to the distances to the town centre, so they did not get the full benefit of having a workshop and a maintenance team.

Even though there was no dedicated store for O&M spares, all three urban areas did have general stores that kept pipes and fittings frequently used for repairs. None of the rural WDSs had a store and they are dependent on the urban WDSs for spares.

4.5.4 To determine the level of service or efficiency provided by the O&M method used in the selected urban and rural WDSs

Table 4.23 below details the level of service or efficiency indicators as scored by the urban and rural WDSs under the different systems of performance measurement.

Table 4.23: Level of service performance indicators

Performance Indicators		WDS area	
		Urban	Rural
IWA	Customer care personnel (%)	11.5	14.0
	Number of interruptions per connection	22.1	31.6
	Number of pump failure days	0.6	1.8
RPMS	Drinking water quality compliance	44	28.5
Questionnaires	Maximum time to fix a main break (days)	0.5	7

The customer care centre was a shared resource for the whole of the Kai !Garib local municipality. Its purpose was to log any complaints regarding service delivery in the region and pass on the complaints to the respective maintenance teams to attend to them. In terms of employee proportion, the rural WDSs scored higher in the customer care personnel PI. Time dedication for each WDS on the other hand was difficult to deduce as the customer care centre attended to numerous departments in the municipality. They however attended to all the calls and complaints that came to the centre without bias; the centre was therefore equally available to the rural and urban systems.

When all indicators are taken into account, it can be deduced that the urban areas had substantially higher levels of service when it came to O&M of WDSs than the rural areas.

5. CONCLUSION

This study strived to understand the O&M carried out in rural and urban WDSs in Kai !Garib local municipality by investigating the differences and similarities experienced in rural and urban WDSs. By understanding these differences and similarities, the strengths and weaknesses of the O&M practice in both areas were brought out and reasonable changes were suggested that would make O&M of these systems more efficient.

This chapter draws conclusions based on the results of this research; it groups the findings under each objective. The chapter further discusses the possible reasons for the disparities or similarities in O&M performance between the rural and urban WDSs. Finally, the suggestions for further research are made.

5.1 Main findings

The goal of this study is to compare O&M in the rural and urban WDSs of the Kai !Garib local municipality. Below are the overall findings of this study:

5.1.1 O&M practices

The urban WDSs evaluated as part of this research were served by better scheduled O&M practices than the rural systems. Both systems however, did not undertake water loss management which is an important O&M practice. The sizes and characteristics for the WDSs that were investigated are outlined in table 3.1 (Chapter 3).

5.1.2 Staffing

While both urban and rural areas were operated under the same management, the maintenance teams were grouped in zones; each team was centred in an urban centre and attended to surrounding rural WDSs as required. This resulted in proactive maintenance not being actively practiced in the rural WDSs.

The urban WDSs were found to have larger operating teams (average of 7 operators) and their lead operators had substantial experience and tertiary training in their area of expertise. The rural WDSs, on the other hand, were found to have only one operator each who had less experience and little to no tertiary training. None of the members of the rural maintenance and operating teams undertook formal technical training in the previous three years.

5.1.3 Resources and equipment

The vehicles dedicated to O&M in the Kai! Garib local municipality were all allocated to the maintenance teams based in the urban areas. The maintenance teams were found to spend most of their time in the urban WDSs – on average they only spent 6 hrs in the rural WDSs during a 40 hour working week.

The Kai !Garib local municipality was found to have only one major workshop dedicated to O&M centred in an urban town centre. The rural areas were not prioritized in attending to their faulty equipment owing to the distances to the town centre.

All three urban WDSs had general stores that kept pipes and fittings frequently used for repairs and a telemetric system that assisted in the control and monitoring of the WDSs. In contrast, none of the rural WDSs had a store and they are dependent on the urban WDSs for spares. The rural systems also did not have telemetric systems and were manually monitored and controlled.

The WDSs in the urban areas all had O&M manuals as well as Emergency Response Plans. None of the rural WDSs had these documents.

5.1.4 Level of service and efficiency

It was found that Kai !Garib local municipality had a customer care centre that catered for all the municipality's civil departments (water, roads and storm water, sanitation and electrical). For this reason time dedication to each WDSs was difficult to assess. However, the centre attended to all the complaint calls so it was equally available to both rural and urban areas.

The urban WDSs however had lower number of interruptions and pump failure days and it had significantly shorter main failure repair times. The urban WDSs therefore had better levels of service when compared to the rural WDSs.

The rural systems exhibited better levels of drinking water quality compliance; they undertook water quality tests in accordance to the RPMS guidelines (weekly) while the urban systems undertook them monthly hence the lower score in this PI.

5.1.5 Discussion

Taking all objectives into consideration, it may be concluded that while both rural and urban WDSs were provided with O&M services by the Kai !Garib local municipality, the urban WDSs exhibited better scheduled O&M practices. The main findings can be summarised as follows:

- The urban systems had telemetric systems that assisted in monitoring and controlling the WDSs while the rural regions undertook these processes manually.

- The urban WDSs had larger operator teams with higher levels of expertise and experience than the rural WDS operators, with as few as one operator per system.
- O&M workshops, stores and maintenance teams and vehicles were shared between the urban and rural WDSs. These facilities and resources were however based in the urban regions, and rural WDS tapped into these resources only when the need arose. This resulted in a lack of proactive maintenance in the rural WDSs.

It may be concluded that the rural WDSs in Kai !Garib local municipality were found to have consistently lower levels of O&M service provision compared to those in urban areas.

5.2 Recommendations

To increase the O&M efficiency in both rural and urban WDSs with limited shared resources, suggested changes are recommended for the Kai !Garib local municipality. These are:

- The operating teams' structures need to be revised. This is because the urban WDSs had remote monitoring and controlling or telemetric systems and also had larger teams with more experience and expertise while the rural WDSs were manually monitored and controlled by a single inexperienced operator in each system. It would be more efficient to select an experienced operator from an urban water system and transfer him/her to a rural water system; this urban WDS operator will assist in operating the WDS while imparting skills to the existing rural WDS operator.
- The distance between the rural and urban areas was cited as a major reason that deterred the maintenance team from undertaking proactive maintenance in the rural regions. To improve maintenance performance, an experienced maintenance staff member should be appointed to assist the operator in the rural WDS to undertake proactive and reactive maintenance and only call for assistance from the urban based maintenance teams in emergency cases (as is currently the case). This however will be a cost factor for the municipality and it may not be able to afford such a change. It is then advisable to widen the scope of the existing operator to include proactive and some reactive maintenance. In this case, the operator has to be well trained to be able to execute his or her duties effectively. The operator can then receive support and assistance form the maintenance team in case of emergencies that are beyond his or her scope.
- An operator who undertakes proactive and reactive maintenance will work more efficiently if there is a small store and workshop for spares and repairs in the rural area. This will be an initial cost to the municipality especially if they are to implement this in every rural WDS; however, it will save costs in future as the maintenance teams will visit the rural regions less often as a result of fewer water service interruptions due to increased proactive maintenance. Fewer water service interruptions will further translate to fewer customer complaints.

- O&M in rural WDSs would further be enhanced if there was a sense of ownership of the system by the community. This can be achieved by forming community based committees within the rural settlements that will assist the Kai !Garib water service authority (WSA) with operating the water systems. This devolution of authority means that the community will be actively involved in the O&M of the WDS with the support from the local municipality concerning management, financial accountability, training and technical support. The operators appointed for these WDSs have to be from the community and will report to the local committees on matters to do with the O&M of the WDSs.
- O&M manuals and Emergency Response Plans have to be written with regards to each WDS. They have to be specific to the system, and the respective operators have to be adequately trained in translating the information in these documents into the appropriate actions, i.e. flushing procedures, equipment inspection and servicing, tank cleaning etc. Documentation, filing and reporting of these actions also has to be emphasised; this will form the basis of any changes or adjustments to be undertaken to enhance the O&M efficiency. A reward system may be put in place to motivate the operators to undertake their tasks. This could include awarding operators whose systems show improved performance in terms of reduced consumer complaints and increased performance in the Blue Drop rating systems.

5.3 Recommended Research

While the findings of this study are only valid for the Kai !Garib local municipality, it is likely that the situation in other municipalities in South Africa is similar. The findings therefore provide an insight and better understanding of O&M of WDSs in urban and rural areas in South Africa. However, on their own, they cannot be used to make solid decisions pertaining to O&M of other rural and urban water systems that are governed by common water service providers. More research in other key areas that affect O&M may have to be conducted as outlined below:

- A separate study is required that will analyse and revise the O&M staff and resources structures in order to bring a balance to the O&M practices in the rural and urban WDSs while at the same time improving these practices in both areas.
- Financial research entailing an O&M budget and expenditure study of rural and urban WDS is also recommended. This will bring a better understanding to the finances involved in the operating of WDSs, especially within a WSA that caters for both rural and urban regions. The findings of this research can be used together with those of the financial research to make sound and economical decisions for the O&M of rural and urban WDS that share resources.
- Customer care centres are key structures in retrieving information pertaining to O&M as seen in this research. This means that the reliability and precision of this information is only as accurate as the customer care management system. It is therefore important to conduct research on the use, impact, and importance of this customer care system for rural and urban water system consumers.

References

Alegre, H., Baptista, J.M., Cabrera, E., Cubillo, F., Duarte, P., Hirner, W. & Parena, R. (2006) *Performance indicators for water supply* services, 2nd ed. London, UK: International Water Association (IWA) Publishing.

Alperovits, E. & Shamir, U. (1977) Design of optimal water distribution systems. *Water resource research.* vol 12(6): 885-900. DOI: 10.1029/WR013i006p00885.

American Water Works Association (AWWA). (1996) *Performance Benchmarking for Water Utilities* Denver, Colorado: American Water Works Association Research Foundation.

American Water Works Association (AWWA). (1983) *Automation and instrumentation, AWWA Manual M2*. Denver, Colorado: American Water Works Association.

Ayanshola, A.M., Sule, B.F. & Salami, A.W. (2013) Evaluation of willingness to pay for reliable and sustainable household water use in Ilorin, Nigeria. *Ethiopian journal of environmental studies & management.* vol 6(6):754-762. DOI: 10.4314/ejesm.v6i6.6S.

Babić, B., Dukić, A. & Stanić, M. (2014) Managing water pressure for water savings in developing countries. *Water SA.* vol 40(2): 221-232. ISSN 1816-7950 .

Bailey, P. (2002) *Regulation of the UK water industry*. Bath, UK: Jan Marchant.

Balfour, F. (2013) *Municipal water services performance measurement and risk profiling* [Presentation]. Department of Water Affairs, Pretoria. 9 July 2013.

Brandt, K., Carbaugh, B., Abbott, D., Wellman, T., Gold, L., Alper, R., Ford, L., Bair, J. et al. (2000) *Drinking water and wastewater handbook for local officials*. Maryland, USA: Environmental Protection Agency.

Calfucoy, P., Cibulka, J., Davison, J., Hinds, T. & Park, M. (2009) *Improving free basic water provision in South Africa* [workshop Report]. Madison, USA: La Follette School of Public Affairs, Spring 2009.

Carden, K. & Armitage, N.P. (2012) Assessing urban water sustainability in South Africa – not just performance measurement. *Water SA*. vol 39(3) 2013.

Carlsson, B., Van Dyk, G., Esterhuyse, C. & Meiring, G. (2010) *O&M Handbook for Water Supply Services – Water Resources in the Northern Cape*. Kimberley, South Africa: Department of Housing & Local Government - Northern Cape, Department of Water Affairs & Forestry - Northern Cape, and Swedish Institute of Public Administration (SIPU) International.

Chase, D.V. (2000) *Operation of water distribution systems* – Water distribution systems handbook, ed. L.W. Mays (Chapter 15). New York, USA: McGraw-Hill.

Colin, J. (1999) *Lessons learned from village level operation and maintenance.* Loughborough University, UK: Water, Engineering and Development Centre.

Conradie, B. (2009) *O&M handbook on legal & environmental issues - an introduction to water and roads, streets and storm water legislation*. Kimberley, South Africa: Department of Housing & Local Government - Northern Cape, Department of Water Affairs & Forestry - Northern Cape, and Swedish Institute of Public Administration (SIPU) International.

Council for Scientific and Industrial Research (CSIR). (2000) *Guidelines for human settlement planning and design, chapter 9: water supply, (Red Book).* Pretoria, South Africa: Department of Housing, CSIR Building and Construction Technology.

Davis, J. & Iyer, P. (2002) *Taking sustainable rural water supply services to scale: a discussion paper*. Nairobi, Kenya: Water and Sanitation Program – Africa.

Deb, A.K., Momberger, K.A., Yakir, J.H. & Frank, M.G. (2000) *Guidance for management of distribution system operation and maintenance*. Denver, USA: American Water Works Association Research Foundation.

Department of Water Affairs (DWA) (2014) *Blue Drop/No Drop Audit Scorecards; Kai !Garib Local Municipality, Jan 2013 – Dec 2013.* Kimberley, South Africa: Department of Water Affairs.

Department of Water Affairs (DWA) (2011) *Water backlog eradication strategy, Northern Cape Province, Kai !Garib Water service authority report.* Pretoria, South Africa: Department of Water Affairs.

Department of Water Affairs (DWA) (2012) *Municipal strategic self-assessment (MuSSA) of water service authorities in the Northern Cape 2012/2013 report*. Pretoria, South Africa: Department of Water Affairs.

Department of Water Affairs (DWA) (2013) *Municipal water services performance assessment (MWSPA) report*. Pretoria, South Africa: Department of Water Affairs.

Department of Water Affairs and Forestry (DWAF) (2005_a) *A history of the first decade of water service delivery in South Africa 1994 to 2004*. Pretoria, South Africa: Department of Water Affairs and Forestry.

Department of Water Affairs and Forestry (DWAF) (2005_b) *National water services infrastructure asset management strategy*. Pretoria, South Africa: Department of Water Affairs and Forestry.

Department of Water Affairs and Forestry (DWAF) (2008) *Water for growth and development in South Africa*. Pretoria, South Africa: Department of Water Affairs.

Du Plessis, J.A. (2007) Benchmarking water use and infrastructure based on water services development plans for nine municipalities in the Western Cape. *Journal of the South African Institution of Civil Engineering*, vol 49 (4): 19-27.

European Benchmarking Co-operation (EBC) (2014) *EBC's benchmarking process*. Netherlands: European Benchmarking Co-operation. Available: http://www.waterbenchmark.org/content/benchmarking.html [Accessed 20 March 2014].

Gagnon, J.L. & Bowen, P.T. (1996) Supply safety and quality of distributed water —a contradiction overcome by the use of high performance models. *Proceedings of the American Water Works Association Computer Conference:* Chicago, USA.

GENIVAR (formerly Cochrane Engineering) (2007) *Best Practices Manual for Small Drinking Water Systems.* Manitoba, Canada: Manitoba Water Stewardship.
Geyer, H., Schloms, B., du Plessis, D. & van Eeden, A. (2011) Land quality, urban development and urban agriculture within the Cape Town urban edge*. African Journals Online.* vol 59(2011). Available: http://www.ajol.info/index.php/trp/article/view/77220/67674 [23 April 2014]

Gibson, J. (2010) *Operation and maintenance costs of rural water supply schemes in South Africa.* The Hague, The Netherlands: IRC Symposium 2010 - Pumps, Pipes and Promises, 16 – 18 November 2010.

Government Communications and Information Systems (GCIS) (2014), *Pocket Guide of South Africa 2013/2014*. Pretoria, South Africa: Government Communications and Information Systems

Harvey, P.A. & Reed, R.A. (2004) *Rural water supply in Africa: building blocks for hand pump sustainability.* Loughborough University, UK. Water, Engineering and Development Centre.

Huisman, L., Hofkes, E.H., Sundaresan, B. B., De Azevedo, J.M. & Lanoix, J.N. (1983) *Small community water supplies: technology of small water supply systems in developing countries*. London, UK: John Wiley & Sons.

International Water Association (IWA) (2014) website. Available: http://www.iwa-network.org [Accessed12 April 2014].

Kai !Garib Municipality (2013) *Integrated Development Plan (IDP) 2013 – 2014 report.* Kakamas, South Africa: Kai !Garib Municipality.

Kai !Garib Municipality (2014) *Annual Budget of Kai !Garib Municipality 2013/2014 to 2013/2016. Medium Term Revenue and Expenditure Forecasts*. Kakamas, South Africa: Kai !Garib municipality

Kibue, S. & Craven, A. (2000) *Traditional and cultural aspects in rural and urban housing in Kenya*. School of Architectural Studies, University of Sheffield: European Network for Housing Research (ENHR) 2000 Conference, June 2000

Kjellén, M. (2000) *Water provisioning in Dar Es Salaam, Tanzania: the public – private interface*. Department of Human Geography, Stockholm University, Sweden.

Lallana, C. & Thyssen, N. (2003) *Water use in urban areas*. Copenhagen, Denmark: European Environment Agency.

Lambert, A. & Fantozzi, M. (2010) *Recent Developments in Pressure Management*. Llandudno, UK: ILMSS Ltd.

Landman, K. (2010) *A home close to opportunities in South Africa: top down vision or bottom up demand.* Pretoria, South Africa: Department of Town and Regional Planning, University of Pretoria.

Lawless, A. (2008) *Numbers and needs in local government*. Association of Municipal Electricity Utilities (AMEU) convention, October 2008. Available: http://www.ameu.co.za/Portals/16/Conventions/Convention%202008/Papers/7.%20Allyson%20Lawless.pdf [Accessed 14 October 2014].

Lewis, L. (2010) *Rural and urban water issues in Africa*. Concord, USA: The Water Project Organization. Available: http://thewaterproject.org/water-in-crisis-rural-urban-africa [25 March 2014].

Lockwood, H. (2002) A strategy for operation and maintenance of rural water supplies, Dominican Republic. *Water Lines Magazine*. vol 21(2): 22-24.

Lottering, J.G. & Maritz, G. (2009) *O&M handbook for water supply services – O&M of pumps*. Kimberley, South Africa: Department of Housing and Local Government - Northern Cape, Department of Water and Forestry - Northern Cape, and Swedish Institute of Public Administration (SIPU) International.

Matji, M.P. (2003) Investigation of water supply issues in typical rural communities: case studies from Limpopo province. *Water Resource Commission*. WRC Report No. 1271/1/03

Mays, L.W. (2006) *Water resources engineering*. Singapore: John Wiley & Sons (Asia).

McKenzie D. & Ray I. (2009) *Urban water supply in India: status, reform options and possible lessons*. Washington, USA: Developing Research Group, World Bank.

Ministry of Health, New Zealand (2010) *Operation and maintenance of a small drinking water supply*. Wellington, New Zealand: Resources for drinking water assistance programme, New Zealand.

Momba, M.N.B., Tyafa, Z., Makala, N., Brouckaert, B.M. & Obi, C.L. (2006) *Safe drinking water still a dream in rural areas of South Africa. Case Study: The Eastern Cape Province.* Pretoria, South Africa: Water Care Department, Tshwane University of Technology.

Moriarty, P., Nyarko, K.B., Dwumfour-Asare, B., Obuobisa-Darko, A. & Appiah-Effah, E. (2012) *Life-cycle costs in Ghana*. [Report] Uses and sources of water in rural areas. Hague, Netherland: IRC International Water and Sanitation Centre.

Muller, D. (2014) *The local government handbook, South Africa – a complete guide to municipalities is South Africa. 4th ed*. Cape Town, South Africa: Yes! Media.

Muller, M. (2002) *The national water and sanitation programme in South Africa: turning the 'right to water' into reality – water and sanitation program.* Nairobi, Kenya: Water and Sanitation Program – Africa

Nnadozie, R.C. (2011) Access to adequate water in post-apartheid South African provinces: an overview of numerical trends. *Water SA*. vol 37(3) 2011.

Nyarko, K., Awuah, E. & Ofori, D. (2008) *Ghana, self-supply schemes for community water supply in Ghana*. Accra, Ghana: 33rd WEDC International Conference. 7 April 2008

Obuobisa-Darko, A. & Asima, S.E. (2008) *Operation and maintenance of small town water supply systems in Ghana.* Accra, Ghana: 33rd WEDC International Conference. 7 April 2008

Okun, D.A. & Emst, W.R. (1987) *Community pipes water supply in developing countries.* [The World Bank technical paper no. WTP 60]. Washington, USA: The World Bank.

Parena, R. & Smeets, E. (2001) Benchmarking initiatives in the water industry. *Water Science and Technology*. vol 44 (2-3):103-110

Roodie, G. (2009) *O&M handbook for water supply services – O&M of water supply networks and fittings.* Kimberley, South Africa: Department of Housing and Local Government - Northern Cape, Department of Water and Forestry - Northern Cape, and Swedish Institute of Public Administration (SIPU) International.

Roux, J. (2010) *Handbook for management of O&M – management of services and O&M.* Kimberley, South Africa: Department of Housing & Local Government - Northern

Cape, Department of Water Affairs & Forestry - Northern Cape, and Swedish Institute of Public Administration (SIPU) International.

Royal Haskoning D.H.V. (2013) *Operation and maintenance manual. Kakamas Water Treatment Works, Kai !Garib Municipality, Northern Cape.* Kakamas, South Africa: Royal Haskoning D.H.V.

Rukunga, G., Kioko, T. & Kanyangi, L. (2006) *Operation and maintenance of rural water services in Kenya: sustainable solutions.* Loughborough University, UK: Water, Engineering, and Development Centre.

Sansom, K. & Scott, R. (2007) *Improving urban water services: government engagement with non-state providers*. Loughborough University, UK: Water, Engineering, and Development Centre.

Schouten, T. & Moriarty, P. (2011) *Community water, community management - from system to service in rural areas.* London, UK: ITDG Publishing

Stabilis Development (2012) *Feasibility Study: Water Supply Systems – Kai !Garib Municipality*. Upington, South Africa: Stabilis Development

Statistics South Africa (Stats SA) (2011) *National statistics: Kai !Garib municipality*. Available: http://beta2.statssa.gov.za/?page_id=993&id=kai-garib-municipality [Accessed 15 March 2014].

Sharma, S.K. & Bereket, B.W. (2008) *Water supply systems in selected urban poor areas of Addis Ababa, Ethiopia*. Accra, Ghana: 33rd WEDC International Conference, 7 April 2008.

South African Government (SA Govt), Constitution of the Republic of South Africa (1996_a) *Developmental duties of municipalities*. Act No. 108 of 1996, Chapter 7 - Local Government: section 153.

South African Government (SA Govt), Constitution of the Republic of South Africa. (1996_b) *Establishment of Municipalities*. Act No. 108 of 1996, Chapter 7 - Local Government: section 155.

Sundaravadivel, M. & Vigneswaran, S. (2004) *Rural water supply system*. Paris, France: Encyclopedia of Life Support Systems (EOLSS). Available: http://www.eolss.net/Sample-Chapters/C07/E2-14-03-03.pdf [Accessed 30 March 2014]

The Municipal Systems Act, No 32 of 2000 (2001) *Government gazette. 21776(1187). 01 March. Government notice no.1497*. Cape Town: Government Printer

Thematic Group (2005) *Scaling up rural water services: sustainability through support for community management. A joint vision*. Loughborough University, UK: Water, Engineering, and Development Centre

Trifunovic, N. (2006) *Introduction to Urban Water Distribution*. Leiden, Netherlands: Taylor & Francis Group.

United Nations (2014). Millennium development goals report 2014. Available: http://www.un.org/millenniumgoals/2014%20MDG%20report/MDG%202014%20English%20web.pdf [Accessed 12 March 2014].

Van den Berg, C. & Danilenko, A. (2011) *The* International Benchmarking Network for Water and Sanitation *(IBNET) water supply and sanitation performance blue book*. Washington, USA: The World Bank.

Van Zyl, J.E. (2011) *Introduction to integrated water meter management.* 1st ed. Pretoria, South Africa: Water Resource Commission.

Van Zyl, J.E. (2014) *Introduction to operation and maintenance of water distribution systems.* 1st ed. Pretoria, South Africa: Water Research Commission.

Wagner, E.G. & Lanoix, J.N. (1959) *Water supply for rural areas and small communities*. Geneva, Switzerland: World Health Organization.

World Bank (2002) *The national water and sanitation programme in South Africa: turning the 'right to water' into reality.* Nairobi, Kenya: Water and Sanitation Program, The World Bank - Africa.

World Bank (2007) *Managing urban water supply and sanitation: operation and maintenance*. Prepared by the World Bank, Department of Operations Evaluation. Available: http://www.gdrc.org/uem/water/wb-urbanwater.html [Accessed 24 July 2014].

World Bank (2012) *Improved water source, rural.* The World Bank. Available: www.worldbank.org/data/indicators/infrastructure/Improvedwatersource [Accessed 27 Nov 2012].

World Health Organisation (2005) *Manual on operation and maintenance of water supply systems*. New Delhi, India: World Health Organisation in collaboration with Ministry of Urban Development, New Delhi, India.

World Health Organization & United Nations Children's Fund (UNICEF) (2012) *Progress on drinking water and sanitation*. New York, USA: United Nations Children's Fund.

Wensley, A., Mackintosh, G. & Delport, E. (2011) A vulnerability-based municipal strategic self-assessment tool enabling sustainable water service delivery by local government. *On The Water Front*. vol 2(2010):21-31

Younkin, C.S. & Huntley, G. (1996) Unattended facilities offer competitive advantage. *Proceedings of the AWWA Computer Conference.* 1996. Chicago, IL.

Appendix 1

COMPARATIVE STUDY OF URBAN AND RURAL OPERATION AND MAINTENANCE PRACTICES OF WATER DISTRIBUTION SYSTEMS AT KAI !GARIB MUNICIPALITY

This questionnaire has been formulated to assist in the research of the mentioned project as part of a Master's Degree in Civil Engineering. Participation is voluntary and participants will remain anonymous

QUESTIONNAIRE FOR WATER DISTRIBUTION SYSTEM OPERATOR AND MAINTENANCE PERSONNEL

General

Town/Region……
……..

☐ Urban Region ☐Rural Region

Number of Water Distribution System operators…….

Section A

a. Highest level of education of lead operator
   ……..

b. What O&M responsibilities does the operator have?
   .....
   .....
   .....
   .....
   .....

c. Number of years in service as an operator with above responsibilities?
   …….....
   .....

d. What was previous work or O&M task?
   .....
   .....
   .....
   .....
   .....

e. How long did operator do this work or task for?
.....
.....

f. Number of formal training sessions attended in the past 3years in regards to your responsibilities/tasks as an
operator…….....

g. Main topics of training
……..
……
……

Section B

a. What is the source of the water……..
b. Size and approximate length of raw water pipe……..
c. Number of households being supplied by the WDS……
d. Size of distribution pipes……..
e. Approximate lengths of the distribution pipes……..
f. No of clean water reservoirs & Capacity……
……
g. No of water reservoirs & Capacity……..
……
h. System pressure operating limits/range……
i. System velocity operating limits/range……..
j. Actual/current system operating pressure……
k. Actual/current system operating velocity……..
l. Residual Chlorine Limits……..
m. Actual/current levels of Residual Chlorine (delivery line)……
n. Turbidity Limits……..
o. Actual/current levels of Turbidity……

p. Methods of monitoring system hydraulic characteristics:
☐Pressure gauge
☐Flow meters
☐Water Storage tank levels
☐Automated monitoring equipment
☐Customer complaints
☐Other, specify
……
……

q. How much water is pumped into the distribution system…….m^3/day

SECTION C

a. Do you conduct routine system flushing programs?
☐Yes ☐No

If yes, how Frequent?

☐ Once a year
☐ Once in 5 years
☐ Once in 10 years
☐ As needed only

b. Do you check for effectiveness of flushing? .....

How?

☐Chlorine residual tests
☐Turbidity tests
☐Coliform tests
☐Number of customer complaints after flushing
☐In emergency only; check if crisis has been resolved
☐Other, specify
……
……

c. Do you undertake water storage tank cleaning programs?
☐Yes ☐No

If yes, how frequent?
☐ Once a year
☐ Once in 5 years
☐ Once in 10 years
☐ As needed only

d. Do you check for effectiveness of water tank cleaning?

How?
☐Chlorine residual tests
☐Turbidity tests
☐Coliform tests
☐Volume of water available for fire protection/community usage
☐In emergency only; check if crisis has been resolved
☐Other, specify
……
……

e. How often do you check if valves are operable? .....

f. How many valves do you have in the system? Fill answer in the table below

	No of operable valves	No of inoperable valves
Municipal/butterfly valves		
Non Return Valves		
Other Valves		

g. Frequency of servicing of valves
☐ Once in 6 months
☐ Once in 1 year
☐ Once in 5 years
☐ Emergency only

h. What procedure do you undertake when servicing valves?
……
……
……
……
……

i. How many fire hydrants do you have in the system? Fill answer in the table below

	No of operable hydrants	No of inoperable hydrants
Fire hydrants		

j. Frequency of servicing of hydrants
☐ Once in 6 months
☐ Once in 1 year
☐ Once in 5 years
☐ Emergency only

k. What procedure do you undertake when servicing hydrants?
……
……
……
……
……

l. How many meters do you have in the system? Fill answer in the table below

	No of operable meters	No of inoperable meters
Bulk Meters		
Domestic Meters		

m. Frequency of servicing meters
☐ Bulk Meters……
☐ Domestic Meters……...

n. What procedure do you undertake when servicing meters?
……
……
……
……
……

o. How frequently do you measure water loss/leakage in the system?
☐ Once a year
☐ Once in 5 years
☐ Once in 10 years
☐ Emergency only (pipe burst)

p. Current approximate water loss; ……m^3/day
……% of total water volume

q. How do you measure water loss:
☐ Use of meters
☐ Use of night flows
☐ Automated systems
☐ Independent consultant/another department
☐ Other,
specify……
……
……
……

r. How many pumps do you have in the system?

No of Pumps with automatic operations	No of pumps with manual operations

s. Frequency of minor pump servicing (oil changes, bearing tightening etc):
☐ Once in 6 months
☐ Once in 1year
☐ Once in 5 years
☐ Emergency

t. Frequency of major pump servicing:
☐ Once in 1 year
☐ Once in 5 years
☐ Once in 10 years
☐ Emergency

u. What procedure do you undertake when servicing Pumps?

Minor Servicing	Major servicing

v. How do you check for effectiveness of pump servicing
☐Power consumption
☐Frequency of pump tripping
☐Noise & Vibration levels
☐Pump characteristics (flow and pressure)
☐No of pump breakdowns (in the case of emergency)
☐Other,
specify……
……

w. Which water treatment tests do you undertake

	Test	Frequency
☐	Chlorine residual	
☐	Total chlorine	
☐	Turbidity	
☐	Coliform	
☐	Total organic content	
☐	Metals (Fe, Mn, FL etc.)	
☐	Others……	

x. Points where water samples for testing are extracted
☐ After water treatment process
☐After clear water reservoir, before distribution
☐Within the distribution; how many sample points…….

y. How many main breaks did you experience in the past year……

z. Average time taken to restore system into working order……..

aa. What procedure do you undertake in the case of a main break……
……
……
……

bb. Cause(s) of main breaks:
☐Faulty valves
☐Deteriorated pipe material
☐Pressure surges; cause……
☐Increased water treatment systems capacity/undersized system pipes
☐Accidental breaks by contractors working in the area
☐Other, specify…….

cc. Approximately how many customer complaints have you received in the past year…….

dd. Nature of the complaints
☐Colour of water
☐Taste of water
☐Smell of water
☐Water pressure issues (low pressure)
☐Periodic loss of water
☐Billing issues & water meter
☐Other, specify……

ee. Average response time for customer complaint
☐Immediately
☐In an hour
☐Within a day
☐Within a week
☐Within a month

ff. Where do you source for spare parts for repairs?
……
.....

gg. How often are spare parts available…….....

hh. What spare parts are often stored

……
……
……
……
……

Do you have a standard O&M guidebook? Copies please…

Appendix 2

COMPARATIVE STUDY OF URBAN AND RURAL OPERATION AND MAINTENANCE PRACTICES OF WATER DISTRIBUTION SYSTEMS AT KAI !GARIB MUNICIPALITY

This questionnaire has been formulated to assist in the research of the mentioned project as part of a Master's Degree in Civil Engineering. Participation is voluntary and participants will remain anonymous

QUESTIONNAIRE FOR WATER DISTRIBUTION SYSTEM TECHNICAL MANAGER

General

Town/Region……
……...

☐ Urban Region ☐Rural Region

Number of Water Distribution System operators…….

Section A

h. Highest level of education
……..

i. What O&M responsibilities do you have as a manager?
.....
.....
.....
.....
.....

j. Number of years in service as a manager with above responsibilities?
…….....
.....

k. What was previous work or O&M task?
.....
.....
.....
.....
.....

l. How long did the manager do this work or task for?
.....

m. Number of formal training sessions attended in the past 3years in regards to your responsibilities/tasks as a manager…….....

n. 3 main topics of training

……..
……
……

Section B

r. How much water is pumped into the distribution system…….m^3/day

Consumption breakdown

Water use	Appx. Volume, m^3/day
Domestic	
Industrial	
Agriculture	
Commercial	
Others	

s. Staff composition

Total	Management	Professional	Admin	O&M team	Finance	Others

What is the structure of the technical team responsible for O&M? Indicate who you report to and personnel that report to you.

t. What parameters (pressure, velocity etc.) do you monitor in the WDS that give an indication of its performance? Give operating limits/range, how they are monitored and frequency of monitoring.

u. What is the source of the water……..
v. Size and approximate length of raw water pipe……..
w. Number of households being supplied by the WDS……
x. Size of distribution pipes……..
y. Approximate lengths of the distribution pipes……..

z. No of clean water reservoirs & Capacity……
……
aa. No of raw water reservoirs &
Capacity…….

SECTION C

1. Water Loss:
   i. What procedure do you undertake to measure system water loss? Frequency?
   ii. What is the current estimated total water loss?
   iii. What is the current estimated water loss due to unmetered unauthorised use?

2. Pipe repair and replacement:
   i. Do you undertake preventative pipe replacement program? If yes, what is the procedure and frequency of this program?
   ii. Do you conduct routine pipe flushing programs? If yes, what it the procedure and frequency?
   iii. What is the emergency response procedure undertaken in the case of pipe burst?

3. Valves: How many valves are in the system?
   i. Do you undertake routine valve inspection to check if they are operable? Frequency?
   ii. Do you undertake routine valve servicing? What is the procedure & frequency?

4. Hydrants: How many hydrants are in the system?
   i. Do you undertake routine hydrant inspection to check if they are operable? Frequency?
   ii. Do you undertake routine hydrant servicing? What is the procedure & frequency?

5. Tanks:
   i. How often do you undertake routine water tank cleaning? Procedure and frequency?

6. Meters: How many bulk and domestic meters are in the system?
   i. Do you undertake routine meter inspection to check if they are operable? How often do you check for domestic and bulk meters?
   ii. How often do you service the bulk and domestic meters? Procedure?
   iii. How often do you calibrate the bulk and domestic meters? Procedure?

7. Pumps: how many pump stations do you have in the WDS?
   i. Do you undertake routine pump inspection to ensure it is working to specification? Procedure and frequency?

ii. Do you undertake routine pump maintenance (minor & major)? Procedure and frequency?

8. Water Quality:
   i. What parameters (Chlorine, turbidity etc.) in the water do you test within the distribution network? Procedure for each test and frequency.
   ii. How do you determine sampling points and how many sampling points does this system have?

9. Customer Management:
   i. What is the procedure of handling a customer complaint
   ii. How many customer complaints have been recorded in the past 12months?
   iii. Of these complaints, what were the major ones and how were they handled?

10. Spare Parts?
   i. Do you have a spare parts store for this distribution system?
   ii. What equipment/spares are commonly stored?
   iii. How do you select which spares will be kept in storage?

11. Emergency response programs (ERP):
   Do you have ERPs? What procedures do they entail?
   Do you have ERP training for the O&M staff? Frequency and when was the last conducted?

12. Benchmarking:
   i. Do you undertake benchmarking as a method of monitoring and improving operations of the WDS?
   ii. If Yes, describe the procedure.
   iii. If No, what methods do you employ to monitor & improve operations of the WDS? Describe the procedure.

Do you have a standard O&M guidebook? Copies please…

Appendix 3

PARAMETERS REQUIRED TO CALCULATE PERFORMANCE INDICATORS

Water Scheme……

Urban or Rural……

PI	Variable	Value	Accuracy band	Reliability of the data source
Op3	Total Lenth of network (m)			
Op3	Lenth of network inspected per year (m)			
Op4	Lenth of network subjectd to active leakage control per year			
Op5	Number of leaks detected & repaired due to active leakage control			
Op6	Number of hydrants in the network			
Op6	Number of hydrants inspected per year			
Op7	Number of flow meter in the network			
Op7	Number of flow meters replaced per year			
Op16	Length of network rehabilitated per year			
Op20	Total number of service connections in the network			
Op20	Number of service connections replaced/renovated per year			
Op23	Total water losses in the network (m3)			
P31	Number of full time employees dedicated to the water dist system			
Pe3	Number if employees in management			
Pe7	Number of employees in technical team			
Pe9	Number of employees dedicated to O&M			
Pe16	Number of employees with university degrees			
Pe17	Number of employees with basic education			
Op15	Number of vehicles that are available daily on permanent basis for O&M			
Pe6	Number of employees dedicated to accounting and control and to customer relations and management activities			
Op30	Total number of pumps in the network			
Op30	Number of days the pumps are out of order per year			
Op31	Number of main failures per year			
Op38	Total number of customer meters			
Op38	Number of customer meters that are out of order			
QS14	Number of interruptions per year			