The prevalence of intermittent water supply in Southern Africa

by

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Declaration

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Abstract

The ability to supply potable water by water utilities in Southern Africa is being threatened by several factors including increased population and urbanisation, increased demand, water scarcity, inconsistent sources of energy and deteriorating infrastructure. In this regard, many water utilities in this region have resorted to intermittent water supply (IWS) as a management strategy, in an attempt to meet consumers' basic needs as well as preserve the integrity of the already deteriorated infrastructure. This, over the years, has had a significant impact on the quality and quantity of water distributed. Although most water utilities report improved service delivery, only a statistical demonstration of trends over a period can demonstrate, as well as justify or dispute these performance reports.

This research set out to determine three aspects relating to IWS in 11 countries across Southern Africa over a period of 10 years, between 2008 and 2017. The aspects included the variation in the hours of supply, the leading causes of IWS and the extent of IWS in a Southern African country using the case study of South Africa. Furthermore, the research was based on statistics and incorporated secondary water supply data for Angola, Botswana, Swaziland (Eswatini), Lesotho, Malawi, Mozambique, Namibia, South Africa, Tanzania, Zambia and Zimbabwe. An attempt was made to gather primary data from 252 water utilities across the 11 countries using an emailed questionnaire, but the response rate was only 0.8%. The secondary data used was gathered from annual reports and online databases, and was analysed using Microsoft Excel and mapped using ArcGIS software packages.

The results demonstrate an increase in the population in Southern Africa with access to piped water connections, which was further highlighted by the reduction in the regional connection ratio, which reduced from 53.6 to 40.5 people per connection over the 10 years. The weighted average hours of supply for the region decreased from 21.5 to 18.4 per day between 2008 and 2017, while that for non-revenue water for the region increased from 36.5% to 41.7%. The results also revealed that there are three dominant causes of IWS among water utilities in Southern Africa, which includes maintenance/bursts/failed infrastructure, increased demand and urbanisation, as well as inadequate water resources.

In the case study of South Africa, it was estimated that 39.3% of the South African population is affected by some form of intermittency, with 9.2 million of the affected people being from Gauteng and KwaZulu-Natal provinces. It was also found that of the 54 municipalities that practise IWS, 29 of them probably practise permanent IWS. The results further revealed that the leading causes of permanent IWS in South Africa are increased demand, inadequate pressure/high water loss and vandalism to infrastructure.

The results of this research can be referred to by management teams, policy makers and funding institutions to assist in the allocation of resources. The results can also be used to compare country performances against others in the region.

Opsomming

Die vermoë om drinkwater deur watervoorsieners in Suider-Afrika te voorsien, word bedreig deur verskeie faktore, waaronder toenemende bevolkingsgetalle en verstedeliking, 'n groter aanvraag, waterskaarste, onbetroubare energiebronne en verswakkende infrastruktuur. Baie watervoorsieners in die streek begin gebruik maak van onderbroke watervoorsiening (OWV) as 'n bestuurstrategie, in 'n poging om in die basiese behoeftes van die verbruiker te voorsien en om die integriteit van die reeds verswakte infrastruktuur te bewaar. Dit het deur die jare 'n beduidende invloed gehad op die kwaliteit van en hoeveelheid water wat versprei word. Alhoewel die meeste watervoorsieners verbeterde dienslewering rapporteer, kan slegs 'n statistiese demonstrasie van tendense oor 'n periode hierdie prestasieverslae regverdig of betwis.

Hierdie navorsing het ten doel gehad om drie aspekte rakende OWV in 11 lande in Suidelike Afrika oor 'n periode van tien jaar, tussen 2008 en 2017, vas te stel. Die aspekte sluit in die wisseling in die ure van watervoorsiening, die grootste oorsake van OWV en die omvang van OWV in 'n land in Suider-Afrika, met behulp van die gevallestudie van Suid-Afrika. Die navorsing is verder gebaseer op statistiese en sekondêre watervoorsieningsdata vir Angola, Botswana, Swaziland (Eswatini), Lesotho, Malawi, Mosambiek, Namibië, Suid-Afrika, Tanzanië, Zambië en Zimbabwe. Daar is gepoog om primêre data van 252 watervoorsieners in die 11 lande in te samel, met behulp van 'n e-posvraelys, maar die respons was slegs 0,8%. Die sekondêre data wat gebruik is, is versamel uit jaarverslae en aanlyn-databasisse en is geanaliseer met behulp van Microsoft Excel en gekarteer met behulp van ArcGIS-sagtewarepakkette.

Die resultate toon 'n toename in die bevolking in Suider-Afrika met toegang tot waterkonneksies, wat bewys word deur die streekswaterkonneksieverhouding, wat gedurende die tien jaar van 53.6 tot 40.5 mense per konneksie verminder het. Die geweegde gemiddelde ure van waterlewering vir die streek het tussen 2008 en 2017 van 21.5 tot 18.4 afgeneem, terwyl nie-inkomsgewende waterverbruik (onder andere as gevolg van lekkasies), van 36.5% tot 41.7% gestyg het. Die resultate het ook aan die lig gebring dat daar drie hoofoorsake van OWV in Suider-Afrika is, insluitend instandhouding/pypbreuke/faling van infrastruktuur, verhoogde aanvraag en verstedeliking, asook onvoldoende waterbronne.

In die gevallestudie van Suid-Afrika word beraam dat 39.3% van die Suid-Afrikaanse bevolking geraak word deur een of ander vorm van onderbroke watervoorsiening, met 9.2 miljoen van die geïmpakteerde bevolking afkomstig uit Gauteng en KwaZulu-Natal provinsies. Daar is ook gevind dat van die 54 munisipaliteite wat OWV beoefen, 29 waarskynlik permanente OWV toepas as ‘n formele watervoorsieningstrategie. Die resultate het verder aan die lig gebring dat die mees

algemene oorsake van permanente OWV in Suid-Afrika verhoogde aanvraag, onvoldoende druk gekoppel aan verhoogde waterverliese en vandalisme van infrastruktuur is.

Die resultate van hierdie navorsing kan deur bestuurspanne, beleidmakers en finansieringsinstansies gebruik word vir die toewysing van waterhulpbronne en –infrastruktuur. Die resultate kan ook gebruik word om watervoorsieningstrategieë van lande in die streek met ander in die streek te vergelyk.

Dedication

To my husband Brian Mwitwa Chimbanga and our sons Tubalemye Chimbanga and Mwandama Kantu Chembo Chimbanga, for your immeasurable sacrifices, love and support, without which this master's would not have been possible.

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List of acronyms

CSID	–	Continuous Supply with Intermittent Delivery
CWS	–	Continuous Water Supply
DAWASCO	–	Dar es Salaam Water and Sewerage Corporation
DBPs	–	Disinfection by-products
EPAL	–	Empresa Pública de Águas de Luanda
IBNET	–	International Benchmarking Network
ISCD	–	Intermittent Supply with Continuous Delivery
ISID	–	Intermittent Supply with Intermittent Delivery
IWA	–	International Water Association
IWS	–	Intermittent Water Supply
LWSC	–	Lusaka Water and Sewerage Company
NRW	–	Non-revenue Water
STATS SA	–	Statistics South Africa
SALGA	–	South Africa Local Government Association
THMs	–	Trihalomethanes
WDN	–	Water Distribution Network
ZESCO	–	Zambia Electricity Supply Corporation

Chapter 1
Introduction

1.1. Background of the research

Water sustains vital activities that contribute to the wellbeing of man from a domestic, agricultural and economic point of view. Unfortunately, many people in the developing world do not have access to clean water. In his 2001 World Water day message, the former secretary-general for the United Nations, Kofi Annan, stated that "Access to safe water is a fundamental human need and, therefore a basic human right. Yet even today, clean water is a luxury that remains out of the reach of many. In this new century, water, its sanitation, and its equitable distribution pose great social challenges for our world." Koffi Annan's statement provides a good overview regarding the water situation at that time. Unfortunately, this overview of the water situation that was a reality 18 years ago when this statement was made, still holds true for most developing countries, despite the many efforts, projects, and interventions that are made towards improving water accessibility.

In most countries, the responsibility of distributing water lies with a civic body such as a municipality, a water utility company or a water board. For this dissertation, the institution tasked with this responsibility will be referred to as a water utility. Water Utilities are responsible for ensuring that potable water is distributed to the intended consumers through piped water distribution networks (WDNs). Equally, water utilities have the responsibility of maintaining the proper functionality of the water supply system, particularly the WDN and water treatment facility. The latter mentioned responsibility is critical as through it, the water utility ensures that the consumers connected to the distribution network receive potable water with a supply that is dependable in terms of quantity and availability (The Open University, 2016). In order to give reference to certain aspects of a water supply system that will frequently be referred to in subsequent sections of this dissertation, it is imperative that an overview of its operations, as managed by a water utility, is discussed.

The water supply process begins when raw water is drawn from the source, which could be a river, well, dam or underground reservoir. It is then pumped to a water treatment facility where the water is treated in stages, some of which include the addition of water treatment chemicals. From the treatment facility, it is then pumped to a storage tank or tanks, from where it is distributed to all consumers that are connected via a WDN. The consumers access this water through private residential taps, communal taps, water points, or water kiosks. The whole process, from the water source to where the water is made available to the consumer, is known as a water supply system. **Figure 1.1** shows a schematic diagram of a typical piped water supply system managed by a water utility.

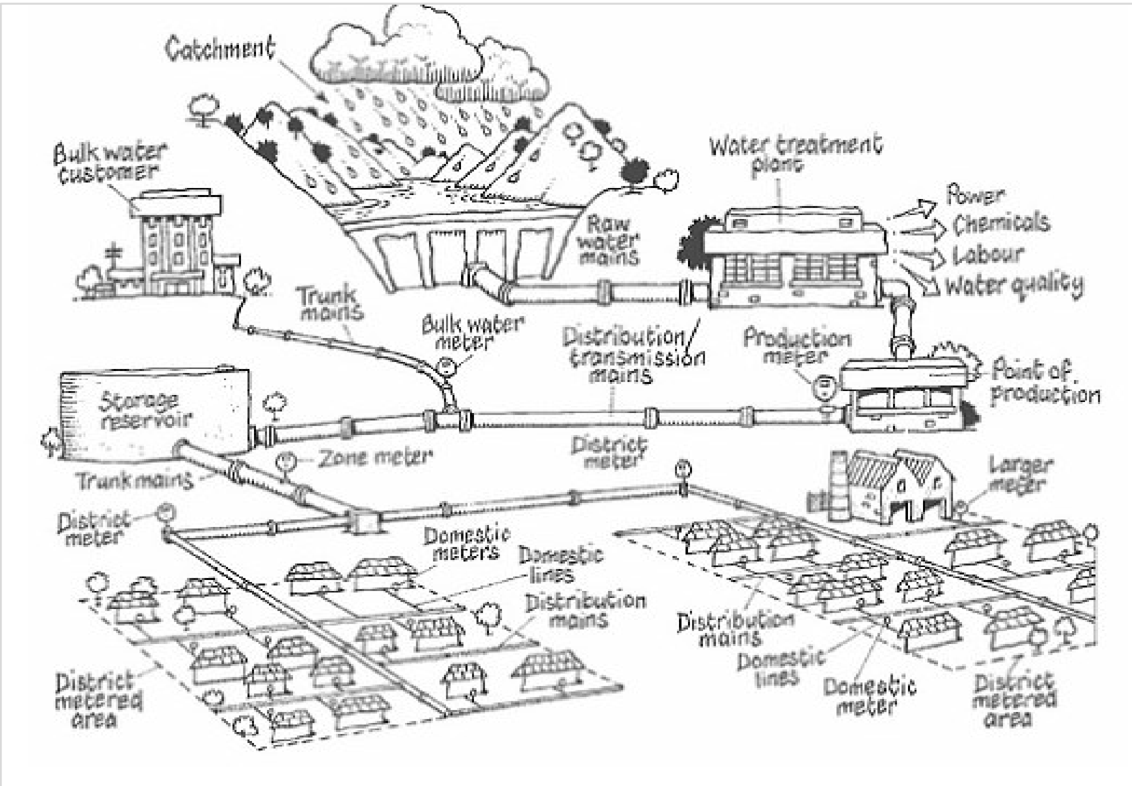

Figure 1.1: A water supply system (Source: The Open University, 2016)

By initial design, water in a WDN should be available to the consumers on a 24-hour basis. This is to enable the consumers connected to that WDN to have access to water whenever they may need it. This type of supply where water is made available to the consumers for the entire 24 hours of the day, is referred to as continuous water supply (CWS). Under CWS, interruptions in water supply that may happen within the 24 hours are generally for pre-determined periods, which allow for maintenance works or upgrades to the network. In such instances, prior notification is sent to the consumers for them to plan their water consumption during the intended period of interruption. Most water utilities in developed countries have achieved and sustained CWS, however, it still remains a challenge in some developing countries.

In many developing countries, continuous water supply is only available in certain areas; what is commonly practised is intermittent water supply (IWS). IWS refers to the provision of water to consumers for less than 24 hours in a day (Agathokleous & Christodoulou, 2016). Under IWS, water is available to consumers in a mode of operation in which the piping system is supplied with water for limited periods. As a result, the piping system is not continuously filled with water under pressure; as was originally provided for in the technical design concept (Klingel, 2012). Although 24 hours of piped water supply remains in some service areas in developing countries, often it is more inclined to locations and communities that earn higher incomes (The Open University, 2016). Several factors, such as increased water demand resulting from the increase in population, urbanisation, aged infrastructure and water scarcity, have made it challenging for the water utilities to supply water for the entire 24 hours.

Many water utilities in the developing world have resorted to IWS, in an attempt to find a balance between water supply and demand (Ameyaw, Memon & Bicik, 2013). The resulting implication of IWS therefore, is that not all consumers connected to the WDN have 24 hours of water supply per day in a day. It has been found that smaller water utilities often supply water for shorter durations, whereas the larger utilities generally supply water for longer durations (van den Berg & Danilenko, 2017). According to Seetharam (2005), as cited by Andey and Kelkar (2007), instead of being implemented in exceptional cases, IWS has become the normal way of operation for many water utilities in developing countries.

The most common reason IWS is implemented is that available water resources fail to meet consumer demand; a situation referred to as water scarcity. However, IWS is implemented even in places which have an abundance of freshwater resources (Sridhar, 2013). According to the United Nations (2014), there should be adequate fresh water on the planet for a human population of seven billion, but it is unevenly proportioned even though most of it is either unsustainably managed, wasted, or polluted. Moreover, water scarcity can be due to the physical absence of water or it can occur as a result of mismanagement, inadequate infrastructure and contamination (Totsuka, Trifunovic & Vairavamoorthy, 2004).

IWS is not only implemented in situations where there is a physical water shortage but also where the hydraulic capacity of the WDN cannot satisfy the demand. Additionally, IWS is implemented where the water supply infrastructure is badly deteriorated (Totsuka *et al.*, 2004). A significant portion of the infrastructure used by water utilities in developing countries is deteriorated and needs to be upgraded. This is because most of it was either installed during colonial eras or just after independence, which is approximately five decades ago for most countries in Southern Africa. As an alternative to network and resource expansion, IWS has been implemented in such places to distribute the available water to as many people as possible, despite the considerable negative impacts of this approach (Totsuka *et al.*, 2004).

The practise of IWS generally varies in the different parts of the world, ranging from piped systems that supply water for a few hours every day, to those that supply water for only a few hours per week. Furthermore, supply durations can also vary based on the location and time of the year (Kumpel & Nelson, 2016). **Figure 1.2**, which is adapted from a study conducted by Kumpel and Nelson (2016) on the prevalence and practises of water utilities under IWS, shows the average hours of water supply per day from a global perspective. The results illustrated in **Figure 1.2** are based on data compiled from water utilities that report into the international benchmarking network (IBNET) database. Although it is not very explicitly illustrated, several countries in **Figure 1.2** that indicate less than 24 average hours of supply, are developing countries. Even though IWS is widely practised, not much research has been done on the effects it has on water quality or quantifying the number of people served by IWS worldwide (Kumpel & Nelson, 2016).

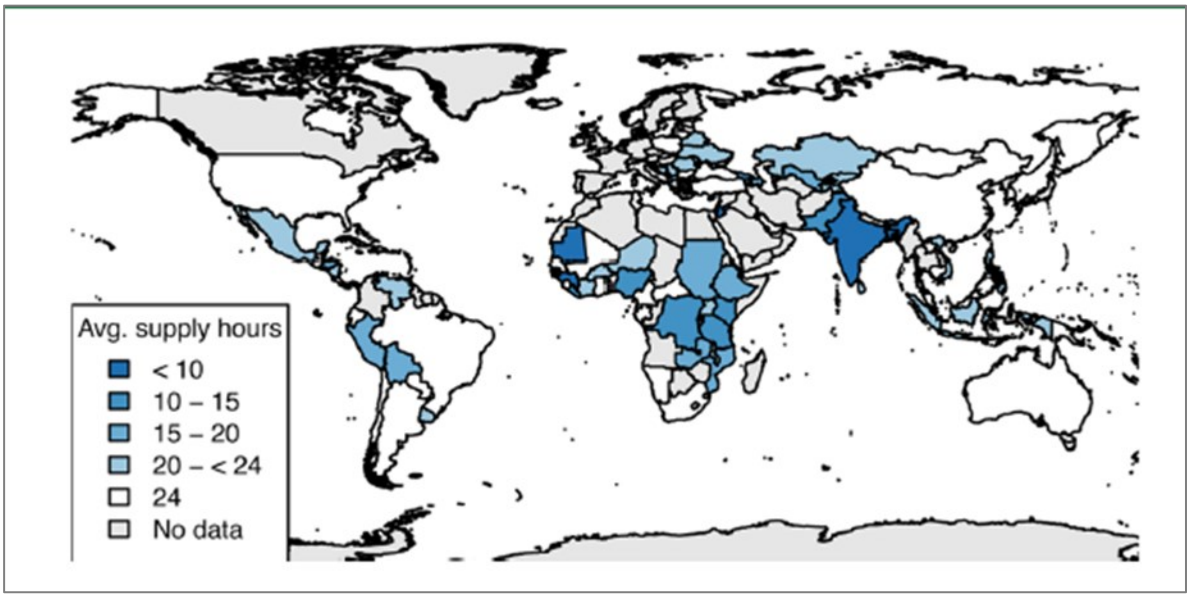

Figure 1.2: Global average hours of water supply per day across all reporting utilities in a country (Source: Kumpel & Nelson, 2016)

Several studies have been performed regarding IWS in developing countries, particularly in Asia and Latin America, however, only a few of these are in relation to Africa. Also, a study performed by the United Nations (2014) revealed that many countries in Africa are faced with water scarcity, particularly economic water scarcity, with a handful of these countries either approaching or experiencing physical water scarcity. As such, several African countries resort to IWS due to economic or physical water scarcity. Like many studies have confirmed, IWS is predominant in developing countries and according to the UN water report for 2012, a global population of 300 million is affected by IWS, of which 30% is in Africa.

This research will review the prevalence and extent to which IWS is practised in Southern Africa. Southern Africa, in the context of this research, includes 11 countries, as per the confines of the Africa Water Atlas of 2010. The countries included are; Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland (now known as Eswatini), Tanzania, Zambia and Zimbabwe. This is taking into consideration the fact that water supply data for Angola remains limited, and most of that which is available, relates to one public water utility, the Empresa Pública de Águas de Luanda (EPAL) which services the capital city, Luanda (African Ministers' Council on Water, UNICEF, 2015). The selection of Africa, particularly Southern Africa, was because the author of this dissertation comes from this region. Furthermore, Southern Africa has for a long time been an area of research interest to the author in terms of water supply practises and accessibility. In the same vein, the research also uses the case study of a country in Southern Africa to explicitly illustrate the extent of IWS in terms of the affected population. The selection of South Africa for the case study was based on the availability of quantitative data.

This research will attempt to identify the main aspects causing water utilities in Southern Africa to persist with practising IWS. The impacts that have resulted from this practise for the water utilities, will be highlighted. This research will also attempt to quantitatively demonstrate the extent to which IWS is prevalent in Southern Africa for both the region as a whole and the individual countries. In order to determine the desired outcomes, the research will take into consideration the following parameters in relation to IWS:

i. Existence of the practise
ii. Number of piped water connections
iii. Connection ratio
iv. Average hours of supply
v. Causes of IWS
vi. Impacts of IWS
vii. Extent of non-revenue water
viii. Population subjected to IWS

A state of African utilities performance assessment was conducted for 2006 and 2009 by a team from the water operators' partnership (Water Operators' Partnerships, 2010). The organisations that were part of that partnership included; Water and Sanitation Programme (WSP), African Water Association (AfWA), Global Water Operator's Partnership Alliance (GWOPA) and United Nation Habitat (UN-Habitat). The assessment covered many aspects of water supply, including IWS. The findings were presented in the State of African utilities performance assessment and benchmarking report of 2010. **Table 1.1** presents the findings of the assessment with regard to IWS for some of the regions in Africa. The findings indicate that Southern Africa performed better than the other regions in terms of the average hours of supply, as well as the percentage of consumers that had access to CWS.

Table 1.1: Continuity of supply and number of consumers with intermittent supply for selected sub-regions in Africa (Adapted from the Water Operators' Partnerships, 2010)

Regions	Population served in millions		Continuity of supply (hours/day)		Number of consumers with intermittent supply in millions		Percentage of consumers with 24 hours supply	
	Year							
	2006	2009	2006	2009	2006	2009	2006	2009
Eastern Africa	10.307	13.099	16.9	17.0	4.441	5.987	57%	54%
Southern Africa	12.888	14.580	21.6	21.7	1.018	0.775	92%	95%
Western and Central Africa	26.402	30.067	20.3	20.4	3.201	3.551	88%	88%
Nigeria	28.969	32.190	12.3	11.4	24.274	27.015	16%	16%
Total	**78.567**	**89.937**	**17.1**	**16.9**	**8.660**	**10.313**	**89%**	**89%**

The aforementioned assessment report summarised its findings by stating that up until 2009, twenty-six percent of the African population (equating to 244 million) had a piped connection on their premises, while in Northern and Southern Africa almost two-thirds (equating to 166 million) had piped connections. It also presented the possible causes and consequences of IWS in Africa, as shown in **Table 1.2**.

Table 1.2: Possible causes and consequences of IWS in Africa (Adapted from the Water Operators' Partnerships, 2010)

Possible causes	Consequences
Inadequate water resources and lack of production capacity.	The negative network pressures created by discontinuous supply can compromise water quality and damage assets (especially water meters).
	Intensive rationing programs that are likely to disproportionately affect the poor as the utility focuses on high consumers.
High water losses due to poor condition and performance of the assets.	Customer dissatisfaction and reduced willingness to pay for the services.
	Vandalism in areas of the network where this occurs affects continuous water supply.
Poorly designed transmission, storage, and distribution and infrastructure with a strong reliance on pumping and energy.	Utility is at risk of becoming redundant as customers (domestic and non-domestic) look for alternative sources.
	Increasing number of domestic storage tanks that further exacerbate the problem as they increase demand.

During this assessment, only five of the eleven countries in the Southern African context of this research were included. Besides, not all the water utilities in the five countries were considered, implying that the results obtained may not have been representative for Southern Africa. This research aims to address this shortfall concerning IWS and will attempt to determine estimated values that will be more representative for Southern Africa by including all the countries in the region.

Furthermore, the research will consider a period of 10 years, from 2008 to 2017, in order to establish trends and subsequently present average values that are more representative of Southern Africa using quantitative data.

1.2. Problem statement

Supplying water continuously to consumers within a water supply system is by operation and design of water supply infrastructure the intent of a water utility. Unfortunately, many water utilities have over the years resorted to supplying water intermittently to consumers, which has resulted in negative impacts to both the consumer and the water utility. Kumpel and Nelson (2016) predicted that the practise of IWS was likely to escalate because of climate change and the rapid population increase in urban areas, both negatively impacting on the ability of water utilities to adequately meet the demand for potable water.

A significant body of research has been performed to determine and highlight the impacts that IWS has had on the consumer, on water quality and on the water supply infrastructure. However, not much has been done to determine whether this undesirable type of water supply scenario is increasing or decreasing. Additionally, there has not been much research on the dominant factors that have caused water utilities within a specified region to keep practising IWS. This research will attempt to contribute to this knowledge gap for Southern Africa analysing historical (from 2008 to 2017) quantitative data from various sources.

1.3. Significance of the research

A significant amount of research has been done to determine and highlight the impacts IWS has on the consumer, water quality and water supply infrastructure. There appears to be opportunity to determine whether IWS is improving or becoming worse, by for instance, studying trends in the hours of supply. Similarly, not much research has been done to determine the leading causes of IWS within a specific region. Trends that have been observed from field studies and data reported by utilities reveal that despite the wide prevalence of IWS, there is a decrease in the supply duration in many developing countries (Kumpel & Nelson, 2016). As it stands, not enough studies have been performed to conclusively determine how IWS impacts on the outcomes of a water service. (McDonald, 2016). For example, there is limited research that quantifies the population receiving water through IWS and the effects it has on water quality, despite how extensive the practise is (Kumpel & Nelson, 2016).

To establish potential effective measures towards the improvement of water supply conditions in view of IWS, urban water managers need to understand the trends in water access and water losses (Kumpel, Woelfle-Erskine, Ray & Nelson, 2017). Existing statistics often availed on public platforms portray actual supply situations of WDNs as more optimistic than realistic (Lee & Schwab, 2005). The availing of performance data on a public platform enables consumers to make comparisons between their water providers and those in other locations. More specifically, it enhances aspects of transparency and accountability on the part of water providers (McDonald, 2016). On one hand, better management of data can assist WUs to improve water supply and cost recovery. On the other hand, improved data management may not have a meaningful impact in cases where all-encompassing water management is undermined by corrupt practises within a government, or where one part of the population has more privilege than the other (Galaitsi, Russell, Bishara, Durant, Bogle & Huber-Lee, 2016).

This research uses the ideas and recommendations from previous studies as the guiding context, particularly those that were done by Kumpel and Nelson (2016) as well as Kaminsky and Kumpel (2018). By so doing, the research contributes to the highlighted knowledge gap by quantitatively illustrating the performance of Southern African countries in relation to IWS from a 10-year historical context. While most of the previously conducted studies on IWS focus on the consumers, the main focus of this research is IWS with respect to water utilities. The research identifies the common causes of IWS amongst water utilities in Southern Africa. It also establishes country trends in the hours of supply, Non-revenue water (NRW) and the population affected by IWS within a defined geographical location. Estimates of the affected population could provide an insight into how many people are likely to be affected by waterborne diseases (caused by exposure to contaminated water) or water-related diseases (resulting from having insufficient water quantity for personal hygiene purposes), both which can result from IWS.

The significance of this research is paramount as it gives valuable insight into the performance of countries in Southern Africa in the light of IWS. This research highlights the leading causes and impacts of IWS among water utilities in Southern Africa. The areas that need resources and major interventions towards the improvement of supply hours, NRW and the reduction of potential impacts resulting from IWS, can thus be identified. The results and graphs from the analysis could, therefore, provide meaningful data for the region that can be used in making decisions regarding water supply, as well as the allocation of resources for water supply operations. With the trends of IWS known, government water departments and regulators in the various countries will be in a position to make more informed decisions. Moreover, individual countries included in the research will be able to benchmark their performance against the other countries within the region.

1.4. Definitions

In order to avoid the misinterpretation of some key terms that are frequently used in this dissertation, their definitions are provided in this section. The definitions are provided in the context of this research.

i. **Consumer** is the end user who receives water supply from a water utility via a piped connection linked to a WDN.
ii. **Intermittent water supply (IWS)** refers to a type of water supply in which the consumers receive water from a water utility connection for less than 24 hours in a day (Agathokleous & Christodoulou, 2016).
iii. **Non-revenue water (NRW)** is the difference between water supplied into the distribution system and the amount of water billed to consumers (van den Berg, 2015).
iv. **Water supply system** refers to interconnected hydraulic and hydrological elements purposefully designed to deliver water from a water source to an end-point user, in this case a consumer (The Open University, 2016).
v. **Water distribution network (WDN)** refers to all the interconnected components of the water supply system after the water treatment plant, that is, all the components after the point of production, starting with the distribution transmission mains as illustrated in **Figure 1.1**.
vi. **Water utility** is a civic body within a defined jurisdiction tasked with the responsibility of managing the water supply system.

1.5. Research goals

The research has three goals which are to:

i. Determine whether there is an improvement in the supply durations to domestic consumers affected by IWS in Southern Africa, between 2008 and 2017
ii. Determine the causes and impacts of IWS in Southern Africa
iii. Estimate the population affected by IWS in a Southern African country using the case study of South Africa

1.6. Research questions

To determine solutions that would adequately contribute to this knowledge gap pertaining to IWS, the following research questions are addressed:

i. Was there an improvement in the water supply duration to consumers affected by IWS in Southern Africa, between 2008 and 2017?
ii. What are the leading causes and impacts of IWS among water utilities in Southern Africa?
iii. To what extent is the population in a Southern African country affected by IWS?

1.7. Research objectives

Based on the goals of this research, the objectives of the research are to:

i. Quantify the average number of water supply hours for the years 2008 to 2017 and establish a trend for each country in Southern Africa,
ii. Determine whether a correlation exists between NRW and continuity of supply,
iii. Identify the causes and impacts of IWS among water utilities in Southern Africa,
iv. Demonstrate the extent to which the population of a country in Southern Africa is affected by IWS, using the case study of South Africa.

1.8. Limitations

In the earlier mentioned assessment of the African Water Utilities report, van den Berg and Danilenko (2017) pointed out that a comprehensive volume of data is required in order to adequately illustrate the performance of water utilities. Collection of such data is complicated and involves downturns not only relating to the expenses involved but that, water utilities, regulators and stakeholders are generally not enthusiastic about availing information relating to their operational performance. Specifically, this research is limited by the following:

i. This research intended to gather data from as many water utilities in Southern Africa as possible, so that the outcomes would be representative for the region. Instead of having comprehensive datasets comprising of both primary and secondary sources, all the analyses done, and results obtained are based on secondary data.
ii. Regarding the collection of secondary data, not all water utilities and countries have water-related statistical data and annual reports available on online open-access platforms.
iii. Limited co-operation from water utilities

1.9. Chapter overview

The overall structure of this dissertation takes the form of five chapters, including this introductory chapter. This first chapter provided an overview of IWS through the background of the research highlighting critical aspects that form the basis of this research from a global, African and Southern African perspective. It also covered the problem statement, significance of the research, the research goals, questions, and objectives as well as definitions and limitations of this research.

The second chapter incorporates a literature review. It incorporates several studies conducted by other researchers as well as some of the different ideologies proposed regarding IWS. Several aspects of IWS from its causes, types, impacts on the water utility as well as on the consumer, to highlighting possible interventions as proposed by other researchers are discussed.

The third chapter presents the methodology used for this research. The fourth chapter presents the results obtained from the data analyses in the form of charts, tables and maps, all relating to the four objectives of this research. The results are also discussed as part of this chapter.

Finally, Chapter Five draws upon the entire dissertation, connecting the various theoretical and empirical outcomes of this research in the conclusion, and provides clarity on whether the objectives and goals of this research were achieved. Additional recommendations and proposed areas for future research are also included in this chapter.

Chapter 2
Literature review

2.1. Introduction

Water supply that is readily accessible, dependable, reasonably priced and of good quality is vital for sustaining good human health. However, for a number of decades, almost a billion people in the developing world have lacked water supply that is safe and sustainable (Hunter, MacDonald & Carter, 2010). Many people in developing countries who do have access to water supply, are serviced through IWS. It is estimated that approximately 300 million people worldwide receive their water through IWS (Kumpel & Nelson, 2016). Approximations that were made using data from IBNET suggest that in Sub-Sahara Africa alone, a population close to 18.8 million is affected by IWS, with supply durations varying between one and 23.5 hours per day (Kumpel & Nelson, 2016). This approximation was based on data from 19 countries in Sub-Sahara Africa covering 249 water utilities. The 249 water utilities returned an average supply duration of 12.8 hours (Kumpel & Nelson, 2016).

Although there have been significant international efforts towards improved water supply in most developing countries, centralised water distribution continues to suffer inadequacies, the main one being IWS (Klingel, 2012). Despite the efforts to transition from IWS to CWS systems, IWS may eventually become a common phenomenon because of underinvestment in water supply infrastructure (Kumpel & Nelson, 2016). This is notwithstanding the anticipation on how urbanisation, an increase in population numbers and climate change will affect the quantities of water that will be accessible to cities (Kumpel & Nelson, 2016). Climate change and urbanisation may lead to an increase in the population that will be serviced through IWS (Kumpel & Nelson, 2016). It is therefore not apparent how reverting to CWS will be achieved in developing countries. This is because, as it stands, rationing and a decrease in the duration of supply is the current trend. Hence, IWS may potentially be accepted as permanent (Simukonda, Farmani & Butler, 2018).

The distribution of water in urban areas during a shortage is often resolved by the introduction of a service that is intermittent. Many developing countries have adopted this approach for solving short term water scarcity situations that may arise from unforeseen phases of drought. Even though an intermittent supply may be seen as a short term solution, the network operating conditions it leads to are not in line with the intended design conditions (Fontanazza, Freni & La Loggia, 2007). Most of the WDNs in the urban areas of developing countries that are operated on an intermittent basis, have been designed for CWS (Andey & Kelkar, 2007).

According to Kumpel and Nelson (2016), IWS yields undesirable effects on water quality, water supply infrastructure, and adds a financial burden on a water utility. Charalambous and Liemberger (2016), pointed out that even though IWS is inevitable in certain situations, the benefits of its implementation, if any, were minimal. It is also stated that, these benefits do not substantiate IWS as a viable method for operating WDNs in the long term. Although many water utilities implement IWS as a solution during water scarcity situations with great ease and without giving serious consideration to alternative solutions, it should not be part of a lasting solution (Charalambous & Liemberger, 2016). In this regard, IWS is generally regarded as a form of supply that is not ideal (Charalambous & Liemberger, 2016).

This chapter includes a discussion of the literature that was reviewed in relation to IWS. The knowledge gap and the contribution this research is expected to make is highlighted. Thereafter the different types of IWS and the main causes are discussed. Subsequently, the mode of operation of a WDN during IWS and the roles of water utilities in this regard are discussed. The impacts of IWS on the water utility and consumer are subsequently reviewed. The chapter is concluded by listing, possible interventions to IWS.

2.2. Intermittent water supply (IWS)

Different researchers define IWS using different terms and phrases. For example, Solgi, Haddad, Seifollahi-aghmiuni & Loáiciga (2015), described IWS as the discontinuation of water supply to a location at specific times within a day. Kumpel and Nelson (2016) defined it as the provision of piped water during restricted intervals in a day. In other terms, Florian and Pandit (2018) defined it as the mode of water supply in which consumers are supplied with piped water for hours that do not amount to 24, within a day. In essence, the meaning is the same and relates to the inconsistency of piped water supply within a day. It is normally used as a way of reducing the amount of water consumers use within a location by interrupting the supply when there is less demand for water (Solgi *et al.*, 2015). Water supply interruptions are either done manually by shutting off the valves or electronically, through equipment that is configured to automatically lock and unlock the valves at pre-set timeframes and frequencies (Solgi *et al.*, 2015).

The frequency with which most WDNs in developing countries receive water supply varies from a few hours in a day to a few days in a week (Abu-Madi & Trifunovic, 2013). This is ascribed to an increase in the demand for water, excessive levels of NRW, inadequate financial resources and the dependence on international assistance to restore existing projects as well as implement new ones (Abu-Madi & Trifunovic, 2013). As a result, many water utilities in developing countries have resorted to the implementation of IWS. Other factors which lead to IWS include insufficient storage capacity, treatment or distribution networks, or an increase in population that surpasses the rate of infrastructure and water resources development (Rosenberga, Talozib & Lundc, 2008). Climate change and population increase in some instances increase the gap between supply and demand. As a result, the water resources are becoming limited (Charalambous, 2012), subsequently leading to situations of water scarcity.

Notably, IWS is not only implemented in situations of water scarcity or when the WDN has a hydraulic capacity that cannot meet the demand, but also where the network has a high leakage rate resulting from excessive deterioration (Charalambous & Liemberger, 2016). Charalambous and Liemberger (2016) found that water utilities that had implemented IWS as an intervention to reduce excessive leakage in their networks, encountered additional challenges. They reiterated that the implementation of IWS unquestionably prevented such water utilities from maintaining a constant pressure within their respective networks, thereby resulting in detrimental consequences. One of the main elements that accompanies IWS is consistent pressure fluctuations. The water loss from a piped network effectively creates another form of demand (Kumpel & Nelson, 2016). Commonly reported about IWS systems are profuse leakages that can reduce pressure within the network as well as offer a point of entry for the intrusion of contaminants. Despite the scarcity of dependable data on intermittent systems, estimates indicate that they lose between 30 and 50 percent of the water within the WDN (Kjellén, 2006). As a result, IWS causes severe challenges in the functionality and operation of many WDNs (Charalambous & Liemberger, 2016).

By design, WDNs are supposed to operate without disruptions in supply, except during instances when repairs or planned maintenance is required on the system (Charalambous & Liemberger, 2016; Klingel, 2012). In addition to the normal operating costs of CWS systems, IWS systems normally involve additional costs due to constant operational adjustments (Florian & Pandit, 2018).

When operating under IWS, the areas serviced by a WDN are typically grouped into zones, into which water is supplied at different timeframes that follow a defined timetable (Klingel, 2012; de Marchis, Fontanazza, Freni, La Loggia, Napoli & Notaro, 2010). These timeframes may vary depending on the specific challenges that led to IWS being implemented in the first place. Variations may stretch from being a few hours apart to even being weeks apart (Klingel, 2012). This view is supported by Abu-Madi and Trifunovic (2013) who report that the duration between one supply period and the next does however depend on the underlying conditions with which the water utility may be operating in that area or zone. These typically include the available resources, topographical conditions, state of and capacity of infrastructure and water demand.

During IWS, the pipes in the WDN are exposed to periods of intermittent filling and emptying, which do have negative impacts (Fontanazza *et al.*, 2007). For instance, situations of reduced pressure may have impacts on water quality resulting from stagnation and the intrusion of pollutants within the pipelines (Klingel, 2012). Other consequences of IWS include water losses in infrastructure which has been impacted by the underrunning and overrunning of stress limits during pressure surges (Klingel, 2012). **Table 2.1** provides a summary of the impacts of IWS on a water utility.

Table 2.1: Impacts of IWS on a water utility (Source: Klingel, 2012; Kumpel & Nelson, 2016; Florian & Pandit, 2018)

Negative Impacts	Positive Impacts
Increased frequencies of maintenance required on the equipment	Reduced pressure reduces leakages in deteriorated equipment especially on weak joints
Contributes towards meter damages	Overall, scarcity may sometimes be managed
Pipes become exposed to vacuum conditions between supplies	Intervals between supply duration allow for maintenance works
Increased water hammer episodes	
Increased leakages and pipe bursts	
Increased risk of water contamination from infiltration	
Requires increased doses of residual chlorine	
Increased NRW	
Wastage of water	
Water for firefighting is not available between supplies	
Poor service delivery	
Loss of revenue	
Equipment is either over-or underutilised	
Increased rates of corrosion build-up	
Increased rates of wear and tear on infrastructure	
Inequitable supply	
Illegal connections	
Consumers lose confidence in the water utility	
Unplanned connections	
Requires more human capital leading to increased labour costs	

Despite these known consequences, policies on IWS hardly ever take cognisance of the state of supply infrastructure, even though ultimately the entire water supply system may be affected (Galaitsi *et al.*, 2016). Lastly, Charalambous and Liemberger (2016) describe IWS as a vicious cycle as illustrated in **Figure 2.1**, that can only be resolved if any one of the four contributing factors could be permanently resolved.

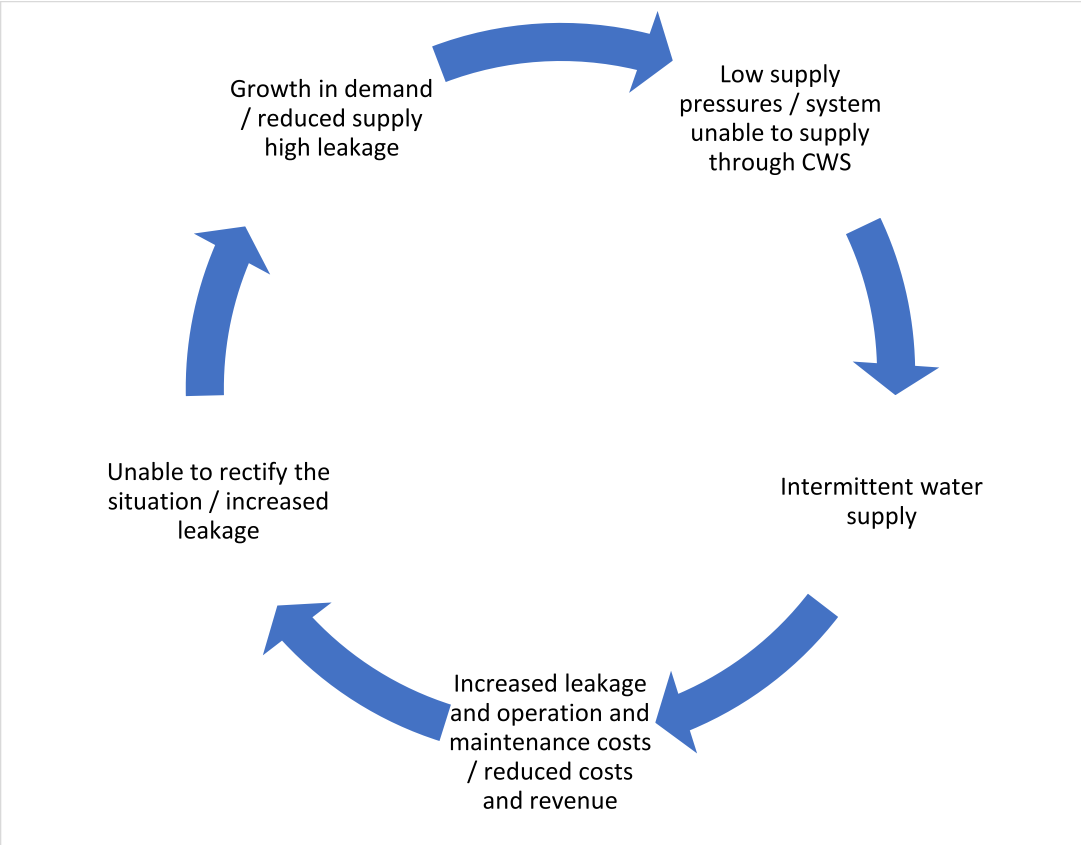

Figure 2.1: The vicious cycle of IWS (Adapted from Charalambous & Liemberger, 2016)

2.3. Types of IWS

In different regions of the world, the practise of IWS varies between piped systems in which water is only supplied for a few hours in a day to those that only supply for a few hours in a week. Likewise, there can be variations in the duration of supply within the confines of one city, among utilities and between seasons (Kumpel & Nelson, 2016). The discrepancy on how water is accessed in an intermittent system, which makes supply vary from being predictable to unpredictable, has severe impacts on the consumers (Galaitsi *et al.*, 2016) and on the water utilities. In most cases, the provision of water is not on a day-to-day basis but can be once in a week or in exceptional situations, once every fortnight (Kumpel & Nelson, 2016).

In this regard, the types of IWS are placed in three categories, all of which are based on the frequency of the supply. In the first category, the type of IWS is scheduled or regular; this type of supply is described as one in which the periods when water supply is cut off via a predetermined timetable. The timetable can have timeframes that can be days apart or in extreme cases more extended periods. Nevertheless, the frequency of the supply is foreseeable and can be anticipated, and the pressure is relatively consistent in every supply (Galaitsi *et al*., 2016).

The second type is considered as irregular, unscheduled or unreliable. In the irregular or unpredictable category of IWS, the supply of water is accompanied by challenges that include inequitable access to the commodity amongst consumers (Kumpel *et al*., 2017). In this type of intermittency, water is supplied in undefined timeframes, some of which may be a couple of days apart. Although consumers are not able to exactly ascertain when water will be supplied, they are able to anticipate receiving some volume of water during the allocated time (Galaitsi *et al*., 2016). Undefined supply times are normally accompanied by the risk of consumers receiving inadequate quantities of water. The situation is often exacerbated by long stretches of time between supply periods and restricted storage capacity on the part of the consumers. As a result of the inconsistency and unpredictable nature of supply, consumers are forced to make decisions on how to adapt to the situation, which may be emotionally, physically and socially demanding (Galaitsi *et al*., 2016).

The seasonal category is slightly different from the earlier two categories of IWS. This is because IWS can either take the form of scheduled or unscheduled supply depending on the seasonal availability of water resources. The volume of water available during different seasons of the year can affect intermittency (Lee & Schwab, 2005). Long, dry seasons tend to impact on the quantity of raw water available. This form of temporal water scarcity can cause a water utility to implement IWS in attempt to equitably distribute the available water resources to its consumers.

In a critical analysis of IWS consequences and pathways, Abu-Madi and Trifunovic (2013) defined three distinct categories which explained how a water utility could practise intermittency. These included intermittent supply with continuous delivery (ISCD), continuous supply with intermittent delivery (CSID) and intermittent supply with intermittent delivery (ISID). In the ISCD category, the water utility has both adequate storage and pumping capacity. However, the abstraction of raw water from the source is restricted, while supply to consumers remains uninterrupted. Therefore, the intermittency aspect is only implemented in the context of the durations the water utility can pump water from the source to the reservoirs. For the CSID category, the water utility abstracts raw water continuously from the source but supply to the consumers is intermittent. Lastly, under the ISID category, both the abstraction of water from the source and its supply to the consumers are intermittent. According to these researchers, ISID intermittency is implemented when water resources are insufficient, and the water supply system has inadequate capacity. In view of the different types and categories there is of IWS, Soltanjalili, Haddad, Mariño and Asce (2013) point out that its implementation needs to be properly planned for and subsequently carefully managed.

2.4. Causes of IWS

For many water utilities, a combination of factors could have led to the implementation of IWS, including, extended periods of drought, escalating demand, urbanisation and absence of awareness and planning (Charalambous & Liemberger, 2016). Although the water utility can still potentially supply water continuously, the challenges arising from the loss of integrity of the water supply infrastructure negatively affects the supply capacity (Klingel, 2012). In most cases, operating a system intermittently is not a planned course of action but a result of external limitations like technical inadequacies (Klingel, 2012). The consideration of IWS in this regard, is restricted to systems that by design are intended to operate continuously. This has great significance when considering technical inadequacies that lead to intermittent functionality or the outcome for intermittent distribution of water (Klingel, 2012).

IWS was and is not included as a component in the initial design of most water systems, but is a combined reflection of infrastructure that is deteriorating and a demand that has exceeded design limitations. IWS has inevitably caused serious challenges in the proper functionality and management of a WDN (Charalambous & Liemberger, 2016). In addition to water scarcity and the reality that most water treatment plants in developing countries were by design intended to supply much smaller populations than what these do now, many of these supply systems have become incapable of providing water through CWS (Lee & Schwab, 2005).

Systems that are operated intermittently are not only complex, but they are affected by several aspects besides scheduling, that relate to intermittency both externally and internally. Internal aspects comprise bad administration, inadequate skilled labour, and poor operation and management of the system. External aspects include deficiencies in power supply and unplanned extensions to the systems. In addition, these also include changing demographical and economical aspects, alterations in hydrological management and an absence of consumers' awareness (Ingeduld, Pradhan, Svitak & Terrai, 2008). The complex interactions between these aspects sustain the intermittency and have significant effects on the functional operation of the system. Managing such effects requires a fundamental understanding and taking the required actions to resolve the underlying causes (Simukonda *et al.*, 2018). Five major causes of IWS are discussed in further detail below.

2.4.1. Increased demand and urbanisation

With the global population on the increase and urbanisation taking a global trend, the demand for water in urban areas is escalating (Sharma & Vairavamoorthy, 2009). Increasing population and urbanisation are rapidly creating an increased demand for potable water (Khatri & Vairavamoorthy, 2007). Often, the available resources are inadequate and therefore, fail to meet that demand. In addition, it is stated that these two factors would lead to excessive water scarcity, to an extent that cities would be forced to find alternative water sources. These by then may be located much deeper in the case of groundwater, or further away in the case of surface water. Over time, outsized populations will have a negative impact on the ability of the natural ecosystems to provide consistent water resources (Khatri & Vairavamoorthy, 2007). This relates to an increase in the capital, operation and maintenance expenses for the treatment, transportation and distribution of water. Therefore, it is increasingly becoming a challenge for water utilities in many countries to consistently provide potable water to the growing city populations (Sharma & Vairavamoorthy, 2009).

Estimates from data gathered in 2018 revealed that 53.5% of the global population was residing in urban areas. This percentage is expected to rise to 60 by the year 2030 and that by that time, about 33% of the population would be residing in cities with a minimum of 500 000 people (United Nations, Department of Economic and Social Affairs, Population Division, 2018).

In the past few years, many urban areas have rapidly increased in size due to rural-urban migration. The social and economic advancement of a population is highly dependent on water. It has therefore become extremely taxing for governments to meet the growing demand for water in urban areas (Vairavamoorthy, Gorantiwar & Mohan, 2007). As a result, WDNs in urban areas are negatively affected by the fast rate of population increase. This increase has affected several water utilities, especially in financially challenged nations, for which establishing supplementary water resources is not a feasible alternative (Andey & Kelkar, 2007). Because of the discrepancy that lies between investing in water supply infrastructure and increased demand for water, many water utilities in the urban areas of developing nations have resorted to IWS (Edokpayi, Rogawski, Kahler, Hill, Reynolds, Nyathi, Smith, Odiyo, Samie, Bessong & Dillingham, 2018).

Several water utilities in urban areas have resorted to IWS. This is, despite its negative impacts, because in such instances CWS cannot be sustained with the available water resources (Totsuka *et al.*, 2004). In such instances, IWS is used as a type of demand management in which supply is discontinued in selected sections of the WDN at alternate times. Populations that are affected by IWS in urban areas develop techniques to survive through periods of intermittency. These techniques range from storing extra volumes of water to procuring additional water from alternative sources. Households that have the financial capability and cannot withstand IWS turn to self-supply, while the less privileged households remain vulnerable to IWS (Kjellén, 2006).

2.4.2. Water scarcity

The design and management of WDNs are severely impacted by urban development and population growth. The present-day rise in water use and reduction in the available water resources have resulted in an imbalance between water demand and supply, which, in turn, have led to situations of water scarcity (Fontanazza *et al*., 2007). Additionally, the combination of climate change and population increase are creating a wider gap between supply and demand (Charalambous, 2012). Those responsible for making decisions regularly refer to the shortage of water resources as the motive for IWS, which prevents CWS to consumers (Andey & Kelkar, 2007). Therefore, a distinction has to be made between physical water shortage and shortage based on economic and technical reasons (Totsuka *et al*., 2004).

From a global perspective, third world cities can be classified into two groups. For the cities in the first group, availability of water resources is not an issue as far as quantity is concerned. Nevertheless, inappropriate management practises and extreme leakage in the WDN contribute to the poor performance of both the water utility and WDN (Basu & Main, 2001). In situations where economic resources are restricted and water is constantly in short supply, expanding the System may be unaffordable, which leads to a scenario called economic water scarcity. Managing supply duration may be the only viable solution under these circumstances (Solgi *et al*., 2015). In instances where economic water scarcity has led to the implementation of IWS, the issue was not water shortages or inadequate water resources (Klingel, 2012).

For example, according to Simukonda *et al*. (2018), Zambian water utilities had not been spared from economic water scarcity. In the case of Lusaka Water and Sewerage Company (LWSC), all the aspects related to economic water scarcity, were identified. These aspects included the management of the utility and water resources, state of water supply infrastructure, lack of skilled labour and national energy deficiencies.

The second group comprises cities in which the availability of adequate water resources is a major issue, to the extent that supply is regulated and rationed (Abderrahman, 2000). This type of water scarcity is known as physical water scarcity. When water resources become scarce, IWS is considered the only viable condition (McKenzie, 2016; Soltanjalili *et al*., 2013). According to Musingafi (2013), physical water scarcity does not necessarily mean the absence of water but constitute a scenario where water resources are not readily available in geographical locations where a high-water demand exists.

IWS and the apportioning of water resources are two techniques frequently used to deal with physical water scarcity, for the duration when quantities of raw water are inadequate (De Marchis, Fontanazza, Freni, Loggia, Napoli & Notaro, 2011). In situations like these, the water utility attempts to supply the constrained reserves of water as proficiently as possible. Under these circumstances, water is supplied intermittently, and the systems operated with comparatively low pressures (Abderrahman, 2000). **Figure 2.2** illustrates the global situation of water scarcity in 2014.

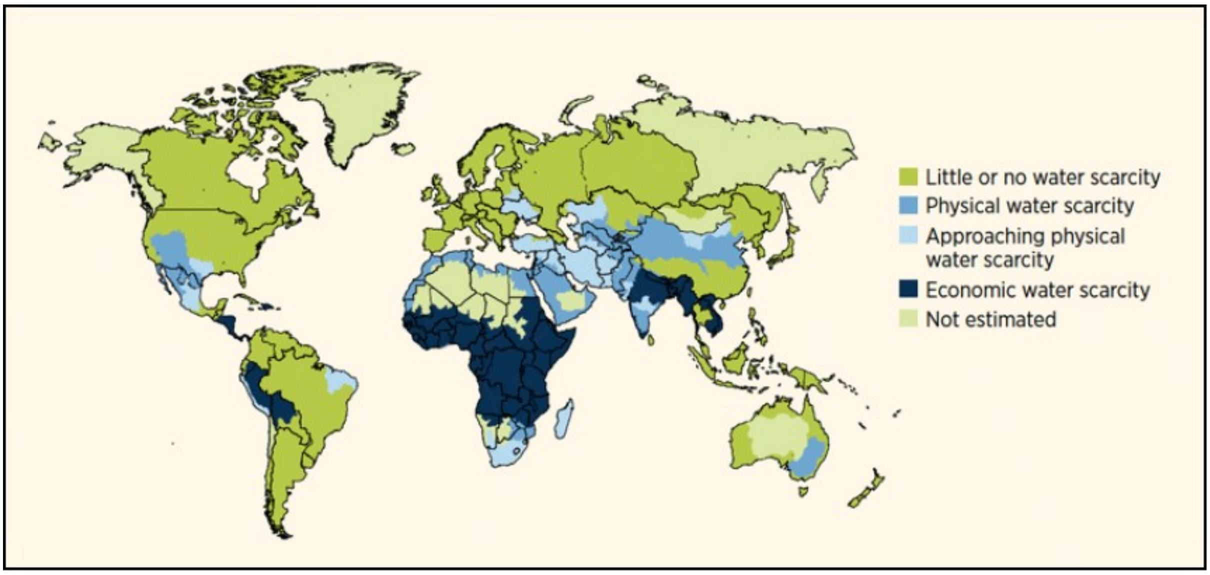

Figure 2.2: Global physical and economic water scarcity (Source: United Nations, 2014)

2.4.3. Inconsistent sources of energy

Power supply is a critical component in the operation of a water supply system. Any disruption in supply has an effect on the operations of a water utility (Simukonda *et al*., 2018) and its ability to sustain CWS. Continuing with the example of LWSC in Zambia, Simukonda *et al*. (2018) illustrated how the absence of defined timelines for power disruptions from the electricity utility (the Zambia Electricity Supply Corporation (ZESCO)) had significantly impacted on the operations of this water utility. In a study which set out to determine the causes of IWS in Lusaka, Simukonda *et al*. (2018) found that LWSC's mode of supply was heavily reliant on boreholes, which also depended on pumps to fill up the reservoirs. The study further pointed out that that situation had been a challenge for the utility since 2008, when power outages became a common phenomenon in Lusaka.

According to Nganyanyuka, Georgiadou, Lungo, Martinez and Wesselink (2013), electricity supply disruptions are common during the dry season in Tanzania. The Dar es Salaam Water and Sewerage Corporation (DAWASCO) were not only affected by power disruptions, but also by power supplied at reduced voltages. During such phases, the utility was not able to operate the pumps to fill up the reservoirs. Not only could the pumps not be operated on low voltage, but also did it increase the likelihood of the pumps being damaged.

2.4.4. Aged and deteriorated infrastructure

Inadequate finances and poorly managed water supply systems contribute to deteriorating supply systems, which subsequently puts the quality of water supplied and its consistency at risk (Khatri & Vairavamoorthy, 2007). In many developing countries, underground water supply infrastructure has generally not been properly maintained (Khatri & Vairavamoorthy, 2007). In many instances this infrastructure is more than 100 years old, which renders it more susceptible to operational deficiencies (Khatri & Vairavamoorthy, 2007).

The continued decline in integrity of water supply systems diminishes the capacity to serve both present and future generations with the required level of water services. Several cities are now confronted with costly challenges related to refurbishment and replacement of infrastructure (Khatri & Vairavamoorthy, 2007). The longer the challenges remain unresolved, the more susceptible to failure and degradation the infrastructure becomes, which further risks the integrity of environments, human health, assets and the economic wellbeing of a nation (Khatri & Vairavamoorthy, 2007). In addition, IWS becomes inevitable in situations where expansions or repair works have to be done on a water supply system that has failed (Solgi *et al*., 2015).

2.4.5. Unplanned system extensions

Extending WDNs becomes imperative when the number of consumers increases in urban areas. This often results in unplanned extensions to the existing system, in order to accommodate and service the new connections. For example, in Lusaka (Zambia), most new residential areas are only connected to the water supply system after they are already fully developed, and construction works have been completed (Simukonda *et al.*, 2018). In such cases, extending the existing WDN becomes more feasible than installing a new one (Simukonda *et al*., 2018). Besides the fact that most water supply systems in developing countries are operating under IWS, which brings challenges of its own, such extensions stress the supply system further as some equipment is inherently suspected to operate beyond the intended design capacity and specifications. Such unplanned extensions on a WDN impacts the duration and quantity of supply to residential areas, compared to before extensions were made (Simukonda *et al*., 2018).

2.5. Role of the water utilities in IWS

According to Charalambous (2012), a water utility is an institution that oversees water supply for a specified jurisdiction. He adds that it can be a section of the government, a private company, a water board or corporation operating independently, but at some point, interacts with government on policies and its performance. He further elaborates that the water utility is responsible for projects that involve water supply and sanitation, the operation and maintenance of a water supply system as well as the associated financial obligations. In the same vein, Florian and Pandit (2018) indicate that a water utility has the responsibility to ensure that it supplies water that meets the acceptable standards in quality and quantity.

Situations may arise in which the water utility resorts to supplying water intermittently because of inadequate capacity or resources. In this regard, water utilities attempt to control certain aspects of operating a WDN during IWS. However, three main aspects contribute greatly towards sustaining IWS. These include continuity of supply (also referred to as hours of supply), non-revenue water, and operation and maintenance of the water supply system.

2.5.1. Continuity of supply

According to the Water Operators' Partnerships (2010), one key indicator used to measure the performance of water utilities is continuity of supply. Continuity of supply is claimed to be of utmost importance, because several other indicators such as the cost of production, NRW, pipe bursts, service delivery and water quality depend on it. It is argued that water utility managers attribute reduced hours of supply to inadequate capacity of water supply infrastructure and limited financial resources. In addition, global experience has proved that focus on asset management and service delivery, instead of inadequate resources, can contribute towards attaining continuity of supply.

2.5.2. Reducing non-revenue water

The volume of water that is produced but subsequently lost from the supply system does not contribute to the volume which is supplied to the consumer, and is referred to as non-revenue water (Andey & Kelkar, 2007). In other words, this is the difference between the volume of water recorded at the bulk supply meter and the sum total of that recorded at the meters of consumers (Andey & Kelkar, 2007). In order to effectively manage water resources, a water utility must account for the water it abstracts (Charalambous, 2012). Lee and Schwab (2005), indicated that water losses came from illegal connections, leaking valves and pipes, and from unmetered connections. Often, the successful management of a water utility is measured by how effectively it reduces its NRW (Sharma & Vairavamoorthy, 2009).

In order to improve the supply of potable water, policymakers must realise that controlling NRW needs to take precedence in the vision of the utility (Charalambous, 2012). Managing NRW should be a continuous process that requires effective and sustainable measures (Charalambous, 2012). It is generally accepted that if the hours of supply are to be increased based on an assumption that the water utilities have a sufficient supply capacity and reservoirs, NRW would also increase. Although this scenario may generate a slight increase in the volumes produced and subsequently sold to consumers, more financial resources would be required to reduce NRW (Water Operators' Partnerships, 2010).

Kumpel and Nelson (2016) found that water systems that were operated intermittently were generally associated with excessive leaks. These could potentially have an impact on the supply pressure and act as entry points for contaminants. In addition, it was noted that the limited data available on water loss in distribution systems indicated that WDNs that were operated between 30 and 50 percent of intermittency, had significant water losses. Water utilities need to acknowledge that controlling NRW is critical to the effective operation of WDNs and thus should be optimistic about it (Charalambous, 2012). When a water utility prioritises leakage control, the results are normally exhibited by declining quantities of water losses over time as well as in the WDN's enhanced operational efficiency (Charalambous, 2012).

2.5.3. Proper implementation of operation and maintenance programmes

A WDN that is not properly maintained can affect the water quality to the extent that it becomes a significant health risk to the consumers (Lee & Schwab, 2005). IWS systems are normally associated with high flow rates and low pressures, which implies that their operation requires additional monitoring to achieve supply that is equitable. In addition, regular maintenance of the system becomes a necessity due to corrosion, pressure fluctuations and pumps, which in IWS operate more intensively (Florian & Pandit, 2018). Under IWS, pumps run for between 20 and 24 hours, which is in contrast to those in CWS, which are only operated to stabilise consumption (McIntosh, 2003) . Operation costs in IWS systems increase because pipes require frequent fixing and changing to manage leaks and prevent bursts (McIntosh, 2003).

2.6. Impacts of IWS on a water utility

Even though IWS is inevitable in certain situations, the benefits of its implementation if any, are minimal and do not substantiate IWS as the most practical method of operating WDNs in the long term (Charalambous & Liemberger, 2016). One notable benefit usually associated with IWS is that the intervals between supplies allow for maintenance and repair work to be done (Florian & Pandit, 2018). Another benefit, which according to Florian and Pandit (2018) was probably debatable, was that IWS could be used to preserve water resources in periods of scarcity. However, Charalambous and Liemberger (2016) disregarded this benefit in an earlier publication. In Charalambous and Liemberger's study, it is argued that although IWS could be used to preserve water resources, significant volumes of the preserved water subsequently escaped through leaks in the system which became pronounced in this mode of operation.

For the most part, IWS yields undesirable effects on water quality, water supply infrastructure, and adds a financial burden on the water utility (Charalambous & Liemberger, 2016). Generally, a system that is operated intermittently gives rise to unplanned maintenance, which also creates a financial burden for the water utility because it further reduces revenue from water sales (Charalambous & Liemberger, 2016).

Challenges associated with IWS can be classified into two groups. The first group comprises challenges related to the intermittent operation of a system designed for CWS. The second focuses on the costs associated with the intermittent operation of a WDN (Soltanjalili *et al.*, 2013). The following section includes some of the challenges associated with IWS.

2.6.1. Water loss and NRW

The International Water Association (IWA) water balance table provides a visual tool to fully understand water losses and non-revenue water. It is indicated in **Table 2.2**.

Table 2.3: IWA water balance table

System Input Volume	Authorised Consumption	Billed Authorised Consumption	Billed Metered Consumption	Revenue water
			Billed Unmetered Consumption	
		Unbilled Authorised Consumption	Unbilled Metered Consumption	Non-Revenue Water
			Unbilled Unmetered Consumption	
	Water Losses	Apparent Losses	Authorised Consumption	
			Meterring Inaccuracies and Data Handling Errors	
		Real Losses	Leakage on Transmission and/or Distribution Mains	
			Leakage and Overflow at Utility's Storage Tanks	
			Leakage on Service Connections up to Point of Customer Metering	

The NRW in many developing countries particularly those in Africa and Asia was between 20 and 70 percent (Sharma & Vairavamoorthy, 2009). The wide range was attributed to leakages from the WDN and mismanagement of water meters. It was stated that it would be easier for water utilities in third world countries to expand their coverage areas by reducing NRW to a minimum (Sharma & Vairavamoorthy, 2009).

Even though attempts can be made to control the quantity of water lost from a WDN, by supplying reduced volumes or altering the operation mode of the system, water loss remains significant in the implementation of IWS (Klingel, 2012). It eventually becomes impossible to supply enough water in IWS when water is lost from the system at significant rates. The system in such cases is run intermittently in an attempt to reduce the volume of water lost through leakages, even though IWS subsequently increases the leakage rate (Klingel, 2012).

IWS poses a challenge towards implementing a leakage control plan in most third world cities. This is because of the limited duration and low pressures that accompany this type of supply (Sharma &

Vairavamoorthy, 2009). Leakage detection techniques cannot be applied on a supply system which is not consistently filled with water at the required operating pressure, hence, require the system to be operated in continuous mode (Klingel, 2012). A water supply system that is operated intermittently for an extended period of time can eventually completely break down due to the increased rate of leakages (McKenzie, 2016). Although leakage control is a cheaper option for conserving water resources, it is often disregarded as a potential solution (Charalambous & Liemberger, 2016).

The data in most publications on NRW in developing countries do not give a clear distinction as to which water loss factors dominate (Vairavamoorthy *et al*., 2007). It therefore becomes challenging to implement suitable water loss techniques that address the root cause. This lack of information therefore prevents the implementation of techniques that can improve the functionality of the system and, subsequently, service delivery.

2.6.2. Compromised integrity of the WDN

Pressure surges and variations experienced in IWS systems affect the integrity of water supply infrastructure (Chowdhury, Ahmed & Gaffar, 2002). The compromised integrity leads to an increased frequency of pipe bursts, malfunctioning of system components and escalating quantities of water loss (Bradley, Weeraratne & Mediwake, 2002).

In Lemesos, Cyprus where IWS had been implemented, a significant increase in the number of pipe bursts was observed (Charalambous (2012). The study found that IWS systems recorded an increase of 200 percent for mains bursts and 100 percent for bursts in the service connections. The results further revealed that IWS led to issues regarding the quality of water distributed, and reduced customer satisfaction. IWS has been determined to increase leaking in a water system by nine percent. This justifies the need to avoid the implementation of IWS, specifically for systems designed for CWS (Charalambous, 2012). A 300 percent increase in breakdowns affecting the distribution mains was recorded when a comparison was made between CWS and IWS. The frequency of the breakdown average increased from one in every 7.14 kilometres to one in every 2.38 kilometres in CWS and IWS respectively (Charalambous, 2012).

2.6.3. Wastage of water

Ironically, IWS systems often need more water to operate due to increased levels of wastage (Florian & Pandit, 2018). In between supplies in IWS, consumers tend to store water for use, however, when supply is restored, the water that remains unused is discarded to create storage space for fresh water (Florian & Pandit, 2018). This practise constitutes severe wastage of water and adds to capacity costs for a water utility, because it must supply water that is not used (Florian & Pandit, 2018). However, the quantities of water discarded would be reduced if the consumers were assured of reliable supply, despite supply being intermittent (Sharma & Vairavamoorthy, 2009).

As noted by Charalambous and Liemberger (2016), in cases where IWS was irregular, consumers tend to leave their taps open in order to know when the supply is restored. Consumers used this form of notification in order to draw adequate quantities for storage during the supply duration. In addition, vandalism of water supply infrastructure was observed. This involved removing of control valves from the WDN where these were assumed to restrict the flow and volumes supplied.

2.6.4. Deterioration of infrastructure

Water supply equipment and infrastructure deteriorate at a faster rate under IWS, because of how it impacts the structural integrity of a WDN (Charalambous & Liemberger, 2016). Compared to a CWS, an IWS system requires high capital expenditure to sustain the system and make it robust because valves are subjected to accelerated degradation, while water meters become inaccurate. (Florian & Pandit, 2018). Subjecting the pipes to air and water (when supply is off and on respectively) interchangeably in IWS enhances corrosion, which consequently leads to higher operational and maintenance expenses (Florian & Pandit, 2018). Furthermore, pressure fluctuations experienced in IWS contribute towards the breakdown of a water supply system (Lee & Schwab, 2005). Corrosion in a water pipeline increases the rate of biofilm formation. Once fully formed, the biofilm counteracts by intensifying the rate of corrosion on pipes surfaces (Egorov, Naumova, Tereschenko, Kislitsin & Ford, 2003). Therefore, this enhances the rate of deterioration on the water supply equipment. Using deteriorated infrastructure threatens the quality of water supplied and the reliability of such a supply. Relying on such infrastructure, in turn, can increase water supply costs (Lee & Schwab, 2005).

2.6.5. Variations in supply pressure and back-siphonage and infiltration

A WDN has the primary objective of providing water to all its consumers, at sufficient pressure, quantity and quality (Fontanazza *et al*., 2007). Although critical water supply elements include suitable water quality and adequate volumes, the level of efficiency can be reduced by inconsistencies in the supply pressure (Klingel, 2012). Because systems that are operated under IWS are not designed to operate in such a mode, significant challenges, including pressure inadequacies, arise with this type of supply (Vairavamoorthy, Gorantiwar & Pathirana, 2008). A WDN that is operated outside of its design specifications, particularly with regard to supply pressure, impacts the network and its consumers (Soltanjalili, *et al.*, 2013).

During the intermittent mode of supply, pipes only remain pressurised for restricted durations and not continuously, as required by the design specifications (Klingel, 2012), Several impacts have been linked to the intermittent filling and emptying of pipes, which subsequently reduce water quality

(Klingel, 2012). During IWS, some sections of the pipe become depleted of water once the supply duration is completed. This phenomenon is attributed to the fact that some of the water is lost from the system through leaks or pump abstraction. Often, the pumps used during the supply period can give rise to negative pressure in the piping network and pressure surges. The more leaks a pipeline has, the more susceptible the system becomes to pressure loss (Lee & Schwab, 2005).

The differences in pressure between the inside of the pipeline and the surrounding environment during the unpressurised periods can cause water to flow towards the reduced pressure. This condition leads to back-siphonage, which refers to the movement of unwanted water from external environments into the potable water pipeline (Herrick, 1997). Back-siphonage creates a vacuum condition which can pull in contaminants into the pipeline via leakage points or joints (Kelkar, Talkhande, Joshi & Andey, 2001). The risk of contamination increases in towns where sanitation is poorly managed (Vairavamoorthy *et al.*, 2008). In CWS, the water lost through leakages is usually clean water that could combine with contaminated water surrounding the WDN. However, this seldom happens because a CWS system is always pressurised. However, due to pressure fluctuations in an IWS system, the likelihood of water becoming contaminated by surrounding groundwater through leaks is increased (McKenzie, 2016). Similarly, WDNs that remain empty and unpressurised for extended durations are more susceptible to water contamination through leaks into the pipes (Vairavamoorthy *et al*., 2008).

McKenzie (2016) described the influence of system pressure variations during IWS. While pressure variations contribute greatly to inequitable supply during IWS, these also contribute towards the contamination of water within the WDN. Three illustrations were used to explain how water contamination happens in an IWS WDN in relation to pressure variations and back-siphonage. **Figure 2.3a** depicts the supply in a CWS system where the pipes remain pressurised throughout and the pressure in the pipe system is much higher than that of the environment surrounding the pipes. When supply is discontinued and the system is depressurised as shown in **Figure 2.3b**, the pressure of the surrounding environment becomes higher than that within the system. In between supplies during IWS, if the system has weak joints, cracks and leakage points, contaminants in the surrounding groundwater seep into the system through back-siphonage. When supply is eventually restored, the contaminants mix with the water in the system, therefore, compromising its quality. The newly contaminated water is subsequently distributed to consumers, as illustrated in, **Figure 2.3c**.

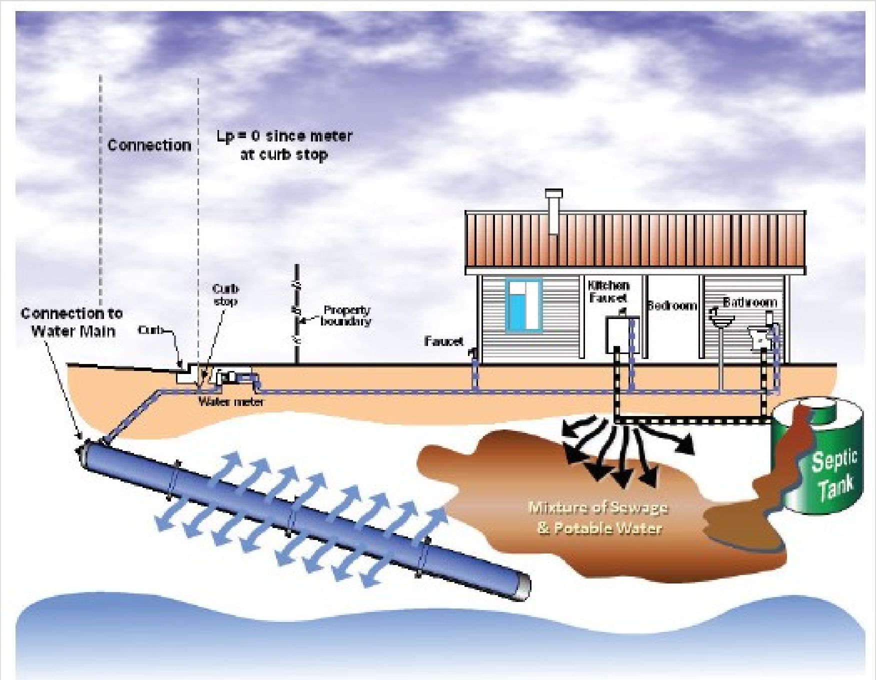

Figure 2.3a: Water supply to a consumer when the system is pressurised (Adapted from McKenzie, 2016)

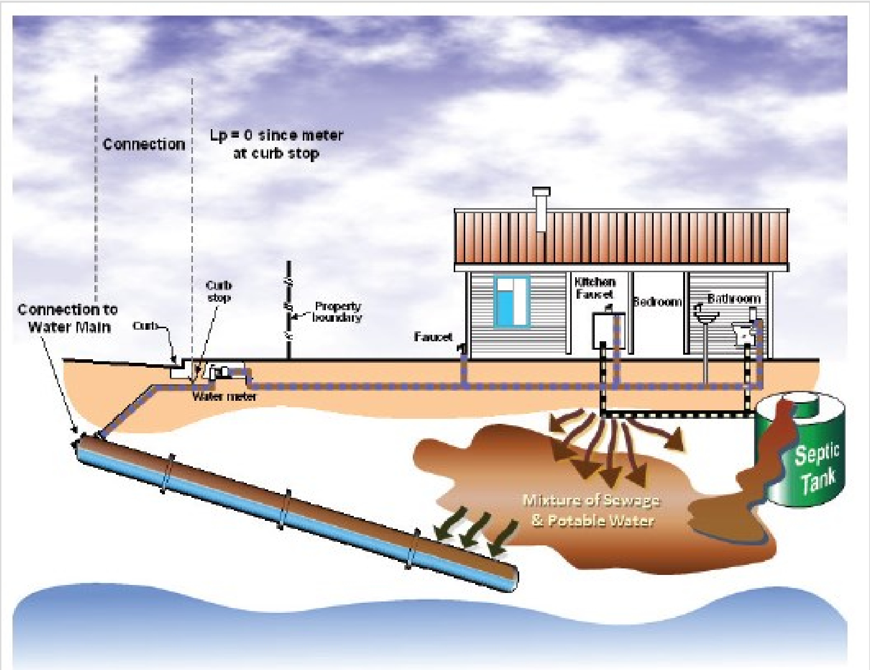

Figure 2.3b: Water supply contamination when the system is depressurised (Adapted from McKenzie, 2016)

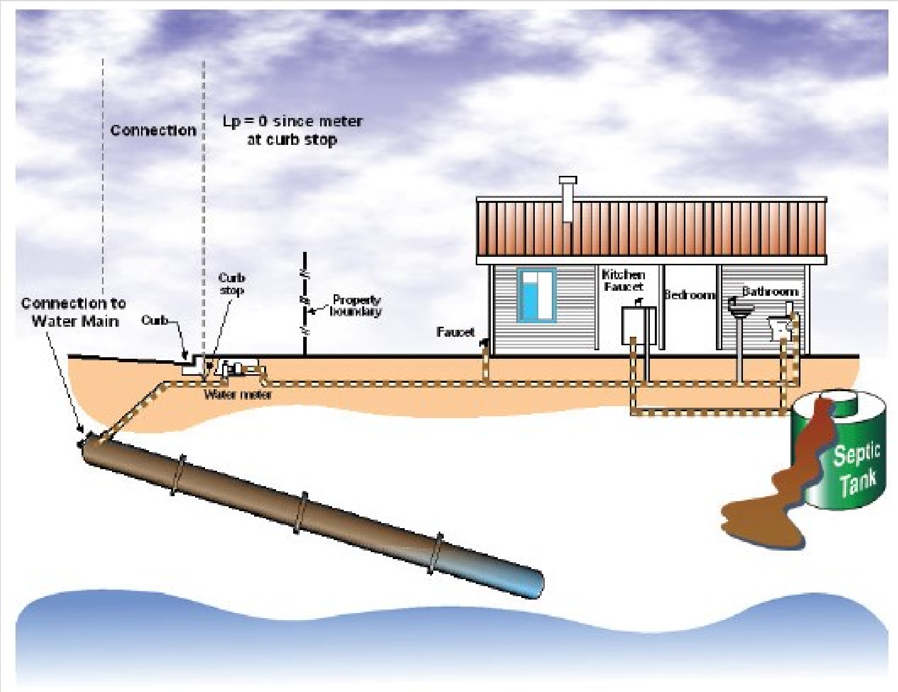

Figure 2.3c: Water supply to a consumer when the system is re-pressurized (Adapted from McKenzie, 2016)

Most water utilities, when faced with water shortages, resort to pressure reduction in the WDN or decreasing the quantity of water supplied to consumers (del Carmen, 1998). In order to overcome the effects of pressure variations that accompany IWS on a water supply system, pressure management is essential. It can be enforced in such a way that the pressure used to supply potable water is kept higher than that used to supply non-potable water (Lee & Schwab, 2005).

Compromised water quality has led to epidemics of diarrhoeal diseases which have become a huge challenge in the developing world (Gadgil, 1998). However, it is uncertain whether a combination of challenges faced by developing countries or the frequent breakdowns in the WDNs is the main contributors to poor water quality in these regions (Lee & Schwab, 2005). A communal WDN in a third world nation is regarded as an improved source of water, however, this does not guarantee that the water supplied through it will be of good quality (Lee & Schwab, 2005). Intermittency in water supply can impact on human health because it increases the risk of water contamination.

The likelihood of water contamination through pipe connections and damaged sections of the network when the system is not pressurised increases in IWS, creating a health risk for consumers (Goyal & Patel, 2015). The damaged pipes and weak connections become entry points for microbial contamination from the surrounding environments (Charalambous & Liemberger, 2016). This entrance is further enhanced by reduced pressures and vacuum conditions created in the WDN under IWS (Charalambous & Liemberger, 2016). Although the acceptable standard of protecting water from being contaminated by external factors, is to continuously maintain positive pressure in the WDN, systems operated intermittently often have zero pressure, or even vacuum conditions between supply cycles (Kumpel & Nelson, 2016).

The absence of consistent hydraulic conditions in the pipeline during IWS negatively impacts on maintaining the required levels of chlorine in the WDN. This results in the use of additional quantities of chlorine that brings about its own risks such as the formation of Trihalomethanes (THMs), which are a derivate of the predominant use of chlorine in water treatment. Epidemiological research has linked THMs to severe health impacts and as such, standards have been set for THMs in drinking water. Moreover, consumers could not handle the excess level of chlorine in their drinking water because of the unpleasant taste (Charalambous & Liemberger, 2016).

According to Lee and Schwab (2005), poorly disinfected water that flows through deteriorated infrastructure can enhance microbial growth within the WDN. It is argued that the existence of any of these conditions at the same time, within the pipe network, can have severe impacts on the quantity and quality of water supplied to the consumer. It is highlighted that IWS enhances stagnation and microbial growth within the pipe network between supply cycles. In agreement to the work of Lee and Schwab (2005), Andey and Kelkar (2007) maintain that recurring episodes of stagnation in an IWS WDN encourage the growth of microbes, which may compromise the quality of water. It was further found that pressure surges and high flow rates, which are common under IWS, cause a specific type of microbe known as biofilms, to detach from the pipe walls and discharge contaminants into the water. Contaminants discharged by biofilms cannot easily be detected during normal water quality monitoring. Consuming water of compromised quality, resulting from microbial contamination, can lead to diarrhoeal illnesses and enteropathy, which have severe impacts on children younger than five years (Edokpayi *et al.*, 2018).

Andey and Kelkar (2007) conducted a study in which several parameters between a CWS and an IWS WDN were compared. Despite the limitation of the sample size used in this study, the results revealed that more samples from the IWS WDN tested positive for faecal indicator bacteria than those from the CWS WDN. A similar experiment was conducted a few years later by Kumpel and Nelson (2013), in which the quality of water from a CWS and an IWS WDN was compared. The quality of water used from the CWS and IWS reservoirs of both systems were the same. However, the water from the IWS WDN revealed frequent detection of indicator bacteria compared to that from the CWS WDN, therefore proving that water was more prone to contamination during IWS than in CWS. Kumpel and Nelson (2013) concluded that contamination of the water in an IWS WDN took place between the reservoir and the consumers' taps, with increased levels of contamination taking place during the rainy season. It was also concluded that the contamination of a WDN was mainly caused by intrusions from the areas surrounding the pipe infrastructure.

One benefit of converting from IWS to CWS is the enhancement of the water quality (Kumpel & Nelson, 2013). Water supplied through the CWS system has a reduced likelihood of contamination and indicator bacteria concentrations at the consumers' tap compared to that supplied through IWS (Kumpel & Nelson, 2013). Nevertheless, water in a CWS WDN is also vulnerable to contamination due to factors such as high turbidity, reduced quantities of residual chlorine and occasional disruptions in supply (Kumpel & Nelson, 2013). Despite having CWS, some consumers do not receive the full benefits of having good water quality. This is because these consumers still use water stored in their homes which is more prone to contamination. The prolonged storage of water in a tank or container, which is common with consumers serviced by IWS, enhances microbial growth leading to water contamination (Coelho, James, Sunna, Abu Jaish & Chatiia, 2003). Therefore, the longer the water is stored, the higher the risk of contamination. Needless to say, whether the stored water was collected from an IWS or a CWS system, the contamination levels in that water become higher compared to that directly drawn from the tap (Kumpel & Nelson, 2013).

2.6.6. Inequitable distribution

Inequitable distribution often results due to pressure fluctuations when a system designed for CWS is operated intermittently (Fontanazza *et al*., 2007). When a WDN that is operated intermittently is filled with water, the system experiences peak flows that are above the normal standard which increases pressure losses within the network (Gottipati & Nanduri, 2014). The increased pressure loss in the system results in inequitable distribution, such that consumers connected closer to supply points receive more water than those further away (Gottipati & Nanduri, 2014). As a result, the volume of water consumers receive during supply highly depends on the existing supply pressures within the system at that time and point of supply (Andey & Kelkar, 2009).

The quantity of water a consumer can collect during IWS depends on the existing pressures at the point of collection. This is because of the pressure fluctuations within a WDN which makes the quantity of water collected vary between consumers located in high and low-pressure zones (Vairavamoorthy *et al*., 2008). Under IWS, consumers only replenish their water reserves when supply is restored (Fontanazza *et al*., 2007). As a result, several consumers use water from the system all at once, further impacting pressure reduction and inequitable distribution within the IWS network.

IWS alters the functionality of the supply system and results in competing demand amongst consumers due to inequitable supply within the network (De Marchis *et al*., 2011). According to Galaitsi *et al*. (2016), inequitable supply within a WDN depicts the capacity constraint of a water supply system. Galaitsi also states that inequitable access to water can be described as the result of combined underlying conditions.

Galaitsi *et al*. (2016) suggest that recent publications refer to three main impacts that arise from inequitable access to water. Firstly, consumers affected by inequitable supply that can afford, resort to self-supply through the installation of private water systems. Secondly, consumers become aggravated and, thirdly, they lose confidence in the water utility. Improving equity of supply and consumers' access to water is possible by employing one of two techniques. One technique includes increasing the number of connections so as to reduce the number of consumers using one connection, while the other is to extend the supply duration or increase the frequency of supply (Kumpel *et al*., 2017).

2.6.7. Increased usage of chlorine

Residual chlorine is included in the water for maintaining the quality during distribution by restricting contamination. Its inclusion is very pertinent in developing nations where the risk of contamination is higher due to sanitation systems which are compromised in some areas (Lee & Schwab, 2005). Under IWS water supply areas are divided into zones. The different zones are supplied with water at alternate times which results in sections of the WDN having stagnant water between the supply periods, in which the chlorine degenerates (Goyal & Patel, 2015). The addition of increased concentrations of chlorine reduces its degeneration between supply cycles, and ensures that minimum quantities reach the distant zones even though maintaining constant pressure in IWS can be challenging (Goyal & Patel, 2015; Egorov *et al*., 2003). Additionally, residual chlorine under IWS is essential in water to prevent it from becoming affected by contaminants that could have entered the WDN between supply cycles (Florian & Pandit, 2018).

The concentration of residual chlorine required by water in the WDN depends on how susceptible it is to contamination while being distributed (Goyal & Patel, 2015). The oxidising nature of chlorine allows it to react with a broad spectrum of elements within the water during the distribution process, potentially creating compounds that are harmful to the consumer, known as disinfection by-products (DBPs) (Goyal & Patel, 2015). It is for this reason that water utilities must ensure that the levels of residual chlorine are maintained within standardised limits to protect consumers from harmful chlorine containing compounds (Goyal & Patel, 2015).

It is important that the water gets disinfected both at the treatment stage and during its distribution, using residual chlorine. However, water that is at constant risk of recontamination requires increased doses of residual chlorine during supply (Florian & Pandit, 2018). Impending health risks that can be linked to IWS, besides typhoid and cholera, may occur where the water in the WDN retains insufficient quantities of residual chlorine (McKenzie, 2016). Increased doses of residual chlorine in a WDN during supply raises the cost of production because more resources are spent on procuring additional chlorine.

2.6.8. Meter damage

When water supply resumes in IWS, the hydraulic pressure within the pipeline is initially high (Fontanazza *et al*., 2007) resulting in a high refilling spike. According to McKenzie (2016), the problem with the refilling spike is the air that needs to give way in order for the water to fill up in the pipe. McKenzie explains that if the pipeline has air-valves that are not operational, the trapped air becomes problematic to the reticulation or the water supply equipment on the consumer's end, such as water meters and valves.

The initial quantity of water required to fill the pipes after a phase of no pressure triggers the surge in the flow. Water meters frequently exposed to peak flows that surpass the upper capacity limit of the meter, and occur abruptly, are more prone to damage (McKenzie, 2016). In addition, this type of flow increases the likelihood of meters registering incorrect readings (McIntosh, 2003). Furthermore, the ingress of dirt also damages water meters.

Charalambous and Liemberger (2016) point out that IWS has a high likelihood of causing erroneous meter readings due to the vacuum conditions created in the pipes during repeated emptying and filling between supply cycles. It is stated that during filling, the air is expelled from the pipes at extremely high velocities, leading to increased wear and tear on the mechanism that is responsible for meter registration. It is also emphasized that the repeated wet and dry conditions that the WDNs are exposed to during IWS, enhance the rate at which water meters deteriorate. Malfunctioning meters do not only pose challenges for the water utility with regard to billing, but also for the consumers, who tend to doubt the accuracy of their water bills (Charalambous & Liemberger, 2016). This leads to a loss of revenue for the water utility and spending of additional resources to repair or replace faulty water meters.

2.6.9. Illegal connections

The challenges experienced by consumers as a result of IWS, including inequitable supply and reduced hours of supply, motivates the construction of illegal connections to the WDN. However, some consumers resort to alternative self-supply mechanisms such as private pumps or storage tanks (Klingel, 2012). Even though IWS systems provide temporary solutions during water scarcity, human intervention can cause damage to the system, leading to the continuation of intermittency even when water resources may be adequate (Galaitsi *et al*., 2016).

2.6.10. More human resources required

Developing nations are often faced with challenges regarding skilled labour with adequate technical expertise to manage water supply systems in a way that would enhance water services delivery so as to meet growing demand (Cohen, 2006). Compared to CWS, IWS needs more human intervention to operate and manage the water supply system. Under IWS conditions, valves require frequent opening and closing for the various zones on the WDN to be supplied with water at the specified time intervals and durations (Florian & Pandit, 2018). Furthermore, the system requires constant monitoring and management to attain equitable supply due to high demand rates and low pressures that accompany IWS (Florian & Pandit, 2018).

2.6.11. Poor service delivery

IWS impacts the conduct of consumers because of the poor service delivery they experience, which may additionally compound water supply challenges (Lee & Schwab, 2005). Consumers under IWS become reluctant to pay for water due to poor service delivery (Charalambous & Liemberger, 2016). According to Florian and Pandit (2018), water tariffs are often low under IWS systems due to poor service delivery and reduced quantities of water sold therefore impacting on a water utilities' revenue. The concomitant reduced revenue makes it challenging for water utilities to invest in infrastructure in order to improve service delivery or meet the required operation and maintenance costs. Resources are further impacted on by leakages, illegal connections and unmetered water demand, which contribute significantly to NRW leading to further loss of income (Florian & Pandit, 2018).

2.7. Impacts of IWS on the consumer

According to a study conducted by Majuru, Jagals and Hunter (2012), a dependable water service is defined by using three characteristics. These include access to water, its availability and potability. It is emphasised that a reliable water service is one that supplies water with good quality and does not pose a health hazard to consumers. Water needs to be easily obtainable using the appropriate technology such as a tap, and the supply has to be constantly available. Additionally, it is suggested that the water supply needs to be in quantities that are adequate for daily domestic consumption according to the global standards for domestic water use. In contrast, the wellbeing, livelihood, and health of consumers can be significantly negatively impacted upon under IWS (Kumpel & Nelson, 2016).

The high demand for water during a supply cycle leads to reduced pressure (Kumpel & Nelson, 2016). While consumers that receive water through CWS only collect the quantities of water they require when the need arises, those under IWS draw and store water during a supply cycle, to meet their needs between supply intervals (Kumpel & Nelson, 2016). Consumers located in the low supply pressure areas of the WDN tend to be impacted socially and economically due to the reduced quantities of water they receive (de Marchis *et al.*, 2010). Consequently, the customers acquire survival techniques that enable them to manage despite insufficient supply volumes or durations. These techniques include in-house storage and treatment of water, pumping, or finding alternative sources of water (Vairavamoorthy *et al.*, 2008; Kumpel & Nelson, 2016).

As noted by Kumpel and Nelson (2016), during IWS, consumers that have individual connections on their premises are at an advantage because water is accessible to them throughout the duration of supply. However, it was observed that this is most often not the case when several consumers share a centrally located connection. This, in turn, reduces the supply pressure for consumers located close to that point of connection (Kumpel *et al*., 2017). **Table 2.1** presents a summary of the impacts IWS has on the consumer. These consumers' access is further restricted because of the time spent carrying water from the source to their home. Some consumers connect pumps to the WDN in an attempt to increase the rate of flow to their connection.

IWS also affected good hygiene practices (particularly sanitation and personal hygiene practices) of activities and processes that are dependent on the quantity of water (Edokpayi *et al.*, 2018). This subsequently increases the risk of waterborne and water related diseases. Therefore, a reliable water service should deliver portable water such that it can be easily accessed and obtained via the appropriate equipment, which include taps, standpipes or water kiosks. Additionally, the source of the portable water should be constantly available and in quantities that meet the daily household demand in terms of domestic use and personal hygiene (Majuru *et al*., 2012).

Table 2.3: Impacts of IWS on the consumer (Source: Kumpel & Nelson, 2013; Florian & Pandit, 2018)

Negative Impacts	Positive Impacts
It is an inconvenience as they may need to find alternative sources of water	Reduces on the water spent per capita
Loss of income as household member(s) spend productive time fetching water	Cost saving due to low water bill
Unequal quantities of water received by households within the same community	
Must store water to use between supply frequencies	
Increased risk of waterborne and water-related diseases	
Generally affects low-income residential areas	
Unreliable supply times	
Affects good hygiene	
Incur extra cost of treating water at household level	

2.8. Possible interventions for IWS

For a water utility to avoid the impacts of IWS on both the management of the system and its integrity, it needs to consider implementing short-term and long-term interventions. These interventions can be used to preserve the integrity of the water supply system and reduce operating costs. Short-term interventions include pressure management, leakage control as well as water demand management. Pressure management is a better alternative to IWS (Klingel, 2012). It involves lowering the operating pressure of the WDN to levels that are closer to or even in some instances lower than the required standards in order to maintain a system that remains constantly pressurised (Klingel, 2012).

Leakage control reduces the quantities of water lost from the system. It may require investment in leakage detection systems and a robust programme to repair leaking pipes and connections. Water demand management can be implemented alongside pressure management where the consumer demand is lowered through several initiatives.

Long-term interventions often require a significant complement of resources. These could include improving existing infrastructure and reverting to CWS. However, according to McKenzie (2016), reverting to CWS after running the system intermittently for an extended period demands substantial effort and financial resources. This is attributed to the extensive damage a WDN becomes subjected to when operated under IWS. Charalambous and Liemberger (2016) point out that when operating under IWS, water utilities experience management challenges that necessitate them to undergo a complete transformation. Reverting to CWS amidst such challenges is complicated, because governments do not readily accept policy and institutional changes.

2.9. Summary

Sustainable water supply systems will only be in place when the water sector in developing countries receive the necessary support politically and financially (Lee & Schwab, 2005). The studies presented provide evidence that IWS results in several negative impacts on a WDN.

In view of all that has been mentioned so far, Charalambous and Liemberger (2016) propose three conclusions that can be drawn from the reliable information compiled from WDNs across the globe. Firstly, a water utility can easily implement IWS, however, the damage done to the WDN is extensive such that changing back to CWS becomes extremely challenging. Secondly, the amount of water loss in an IWS WDN is escalated because more pipe bursts take place on both the transmission mains and service connections. Thirdly, IWS increases the likelihood of water contamination which could be harmful to human health. Therefore, from these conclusions, it is emphasised that IWS is seldom a viable option, even in situations of water scarcity.

Chapter 3
Methodology

3.1. Introduction

This research aimed to respond to the research questions stated in Chapter One of this report. These questions seek responses on the prevalence of IWS in Southern Africa, and the factors that caused many water utilities in this region to service their customers through this practise from 2008 to 2017. In the context of this research and by definition, IWS is limited to consumers connected to a WDN, which is managed by a water utility.

For one to conduct a study that involves the operation of a WDN over a specified timeframe, it is imperative to refer to operational data that relates to the period of focus. A water utility normally maintains data about the management and operation of a WDN, and where available, this data could be accessed, where data was not available through the water utilities, information was abstracted from global platforms in various reports and databases. In this research, primary data, which is the data obtained directly from the water utilities, were gathered using a questionnaire, and secondary data was obtained from specially selected reports and online databases. This research sought to extract from both primary and secondary sources, data about specific parameters in water distribution including continuity of supply, supply coverage and water production. The primary and secondary data was then analysed in Microsoft Excel in order to generate results. The results were subsequently analysed to respond to the research questions. Unfortunately, the response to the questionnaires was extremely disappointing and only 0.8% was returned. Therefore, only secondary data was used.

This chapter discusses the methodology that was employed in this research. It contains six sub-sections which include selection of participants, sample size, research tool, data collection, and data analysis, and a summary.

3.2. Selection of participants

The research took into consideration all the countries in Southern Africa, as defined by the United Nations Water Atlas of 2010. This included 11 countries namely Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland (Eswatini), Tanzania, Zambia, and Zimbabwe. All the water utilities that had actively operated in each of these countries from 2008 to 2017 were considered for inclusion in the target sample. The inclusion of a water utility in the sample was regardless of whether it had only been in operation for a few years of the research period, or for the entire timeframe.

A study done by Kumpel and Nelson (2016), aimed to illustrate the global prevalence of IWS. The study focused on the prevalence of IWS in relation to continental sub-regions in the developing world. According to this study, one of the sub-regions that was most affected by this practise was Sub-Saharan Africa. This research, therefore, aims to build on the study by Kumpel and Nelson but focuses on Southern Africa as a sub-region of Sub-Sahara Africa. The need to include all the water utilities in the sample was identified, because more data would typically yield results that are more representative of the prevalence of IWS in Southern Africa.

Data on how many water utilities were active in nine of the 11 countries was obtained from the IBNET database; it however did not contain data for Angola and South Africa. In the countries Lesotho, Mozambique, Tanzania, and Zambia, which all have water regulating authorities, data was validated from the websites of, and reports by these regulators.

The contact details for the water utilities in South Africa, which are municipalities, were obtained from the South Africa Local Government Association (SALGA) website. This data was validated by comparison to the contact details provided on the websites of the Municipalities of South Africa, and provincial and local government directory of the South African government contact directory. An intensive online search for water utilities in Angola led to the identification of only one water utility, even though its service coverage was limited to only one specific region within the country.

The contact details for most water utilities included a link to the utility's website (where available), and the email address of the Managing Director or Municipal Manager, their Assistant or the Communications Manager or Human Resources Manager. There were, however, water utilities that did not have email addresses for the listed contact employees on the websites. For such cases, the general email address was used. In exceptional cases where the email address for the water utility could not be found, the water utility was excluded from the sample size.

3.3. Sample size

The selected sample was diverse and distributed in such a way that it encompassed water utilities that served both rural and urban areas. This led to a more generalised sample with varying social economic status of the customers. In the case of South Africa, not all 213 municipalities have the responsibility of water supply and distribution. In most cases, those that do not have the responsibility of water supply are local municipalities whereas those that do have, service larger areas of jurisdiction as district or metropolitan municipalities. In South Africa, 158 municipalities were actively involved in water supply and distribution during the period considered in this research. The final sample for this research comprised 252 water utilities across Southern Africa, distributed as presented in **Table 4.1**.

Table 3.1: Number of water utilities included from each country in Southern Africa

Country	Number of Utilities included in the sample size
Angola	1
Botswana	1
eSwatini	1
Lesotho	1
Malawi	5
Mozambique	15
Namibia	1
South Africa	158
Tanzania	26
Zambia	13
Zimbabwe	30
TOTAL	**252**

For the countries that indicate one water utility, one national water utility has the overall responsibility for water supply and distribution across the country. This responsibility could be delegated to several branches strategically located across the country, but ultimately performances and statistics are reported as one water utility. In contrast, for the countries that have more than one water utility, each water utility is responsible for a specific geographical area, which could be a province, district, city, or town.

3.4. Research tool

The research tool that was used to gather primary data was a questionnaire. The questionnaire was designed by the researcher and reviewed by the research team until the final draft was approved. In order to gather data from Angola and Mozambique, which are Portuguese speaking nations, the English questionnaire was translated into Portuguese. This translation was performed using Google Translate and improved by two Portuguese speaking students.

This research tool had the advantage of ease of transmittal via email, to water utilities that would be difficult and expensive to physically access. Despite restricting the amount of information contained in the questionnaire, it was perceived to be a structured mechanism to produce uniformity in the responses. In addition to uniformity, this tool provided the respondent with flexibility of time, in order to retrieve data that may not be readily available. Although McDonald (2016) argued that data management remained a challenge even for the well-financed water utilities, allocating a reasonable amount of time for the completion of the questionnaire potentially allowed for a substantial volume of first-hand data to be collected.

The six-page questionnaire was made up of three sections, which comprised a total of 21 questions that were either multiple-choice, statistical or descriptive in nature. The first section consisted of six questions, relating to general information about the respondent and the water utility. The second section contained 13 questions, four of which were multiple-choice, while the rest requested statistical data (to be given as annual averages or totals). The last two questions, contained in the third section, required a descriptive type of response. The questionnaires used for this research, both in English and Portuguese, are contained in **Appendix A** of this dissertation.

3.5. Data collection

The data collection process was undertaken in two stages, one for primary data and the second for the secondary data. Although both stages took place simultaneously, the first stage commenced soon after ethical clearance approval by Stellenbosch University Ethical Committee. The data collection process for the first stage lasted three months and that for the second stage extended to six months. In addition to ethical approval, permission to research each of the 252 water utilities had to be granted via a formal letter from each water utility. It was only after a signed and stamped permission letter was received from a water utility, that a consent letter and subsequently questionnaire could be sent to collect the primary data. Secondary data was gathered from various databases and reports.

The water utilities were invited to participate in the research via an email to the contact persons identified during the ‘selection of participants’ stage. The contact persons held any of the following positions: Managing Director or Human Resource, Municipal or Communications Manager. In instances where the email address of their assistant was available, the email was copied to the assistant as well. The communication to the contact person requested him/her to assist in the research by responding to the content of the email or forward the email to a colleague who may be in a better position to assist. The colleague, in the context of this research was the Operations, Utilities, or Engineering Manager, and this suggestion was contained in the email. It was, however, important that the respective manager has overall responsibility for the operations of the WDN, or at least be involved in the management of technical data in the water utility. In some instances, the manager delegated the responsibility of completing the questionnaire to other employees, involved in management. The subsections below elaborate on the collection of primary and secondary data.

1. Primary data

The data required for this research included different aspects of the WDNs that were managed by one water utility. Because of this, only one questionnaire was sent to every water utility. A tracking list was developed in Microsoft Excel that included all 252 water utilities. The tracking list was used to monitor the different stages of the data collection process regarding the emails exchanged between the researcher and the water utility. Furthermore, it was used to monitor whether the completed “application letter”, “consent letter”, and “questionnaire” were received from each water utility.

The email account that was used to communicate to the water utilities had its settings configured in such a way as to return a ‘delivery report’. This delivery report indicated to the researcher whether an email had been successfully delivered. Also, it was set up to send back a ‘read report’, through which the researcher could know whether recipients read the email sent to them. However, the sending back of the ‘read report’ was completely dependent on whether the recipient wanted the report to be sent back or not, by clicking the ‘Yes’ or ‘No’ options when prompted to do so by the email.

The first set of emails that were sent out to the water utilities included a cover letter titled ‘Application for institutional permission’. This letter introduced the researcher, summarised what the research entailed, and what was required of the water utility. Another attachment to this email was a template for the permission letter, which the water utility was supposed to use to grant the researcher permission. 35% of these emails returned delivery failure reports, with the bulk of this percentage being from South Africa. Most of the email addresses obtained from the SALGA website were either no longer in use, or the recipients had since left the water utility. However, some of the water utilities responded by giving alternative email addresses to which the email could be sent. A further search of updated and active email addresses for the pre-determined contact positions in the water utility led to the two websites mentioned in Section 4.2. These websites contained contact details of key personnel within the municipalities in South Africa, which had been updated in June 2018 and therefore, were more current for use in the research.

The second set of emails were follow-up emails and new emails to the updated email addresses. Some of the email addresses for the water utilities were still not active, despite being provided on the various websites. This conclusion was made after the delivery reports that were received a few days after the emails were sent out indicated ‘delivery failed’. The last set of emails were a follow up on the previous emails.

For the water utilities that responded, back and forth emails were exchanged between the utility and the researcher, until either a decline to participate in the research or permission granted to conduct the research was received. In some instances, the water utility promised to get back to the researcher after they had concluded their internal procedures, but no further response was received during the three months of data collection. For two of the water utilities, the communication continued until the questionnaires were received. Several water utilities required a project proposal on a template that was provided, before they could grant permission to conduct the research. Unfortunately, 90% of the water utilities that requested these project proposals did not respond after receiving the completed proposals. After three months and more than 800 emails, a total of 12 permission letters, nine declines, two consent letters, and two completed questionnaires were received, which equates to an overall response percentage of 0.8%, from a sample size of 252 water utilities.

2. **Secondary data**

Secondary data included statistical data from several databases, as well as published water performance and assessment reports from various institutions. In addition, data from previous surveys that had been done by the national statistic offices of the countries such as South Africa and Tanzania, which was available on an open-access online platform, were used. This data was combined to give meaningful data that could be analysed, in order to respond to the research questions. The list of sources that were used to compile the secondary data in this research is presented in **Table 4.2**.

Table 3.2: Sources of secondary statistical data

No.	Source	Type of source	Period of data available	Data obtained
1	IBNet Benchmarking assessments	Annual reports	2010 and 2014	Various countries data
2	National Water Supply and Sanitation Council (NWASCO)	Annual reports	2009 - 2017(excluding 2012)	Zambia data
3	Energy and Water Utilities Regulatory Authority (ERUWA)	Annual reports	2012 - 2017	Tanzania data
4	Water and Sewerage Company(WASCO)	Annual reports	2008 - 2015	Lesotho data
5	eSwatini Water Services Corporation(SWSC)	Annual reports	2010, 2012 - 2017	eSwatini data
6	Water Utilities Corporation (WUC)	Annual reports	2012 - 2016	Botswana data
7	NamWater Annual report	Annual reports	2017	Namibia data
8	Lesotho Electricity and Water Authority (LEWA)	Annual reports	2013 - 2017	Lesotho data
9	Knoema - WHO/UNICEF data	Database	2010 - 2015	Various countries data
10	International Benchmarking Network (IBNET)	Database	2008 - 2017	Various countries data
11	Joint Monitoring Programme (JMP)	Database	2008 - 2015	Various countries data
12	World bank databank - World Development Indicators	Database	2009 - 2017	Various countries data
13	STATS SA	Database	2008 - 2017	South Africa data
14	DWS Access to Infrastructure Data	Database	2008 - 2017	South Africa data
15	Tanzania National Bureau of Statistics	Database	2010 - 2013	Tanzania Data
16	UN-Water and African water utilities assessment reports	Reports	2008 - 2017	Various countries data
17	Individual municipality websites	Water data	2011 - 2017	South Africa data

3.6. Data analysis

Because of the poor response rate to the questionnaires, primary data was only incorporated when analysing data pertaining to one aspect of the third research question, which relates to the municipalities in South Africa practising CWS or IWS. The secondary data gathered from the various sources presented in **Table 4.2** was analysed using Microsoft Excel. Statistical analyses were performed for various combinations of the data, for which tables were compiled and graphs plotted. The values in the tables were further analysed and used in the ArcMap package of ArcGIS, to present the data demographically and geographically in the maps of Southern Africa and South Africa. The maps present a more visual illustration for specific parameters of IWS for the individual countries. The maps also allowed for a more graphical comparison between countries to be made with regard to the level of IWS. The results from these analyses were used to provide an informed response to the research questions stated in Chapter One.

3.7. Summary

This chapter discussed the methods used for this research in order to arrive at the responses to the research questions. It further discussed how the sample was determined, and how the research tool was used. Lastly, it discussed how the primary data and secondary data were collected and analysed to arrive at the results. The results from these analyses are presented and discussed in the Results and Discussion chapter.

Chapter 4

Results and discussion

4.1. Introduction

The aim of this research is to investigate the prevalence of IWS in Southern Africa by using statistical data. An investigation of several factors often associated with IWS will be performed, by analysing statistical trends over a 10-year period. These factors include the population in Southern Africa with piped water connections, the connection ratio, hours of supply and NRW. Furthermore, the aim is to identify the leading causes of IWS among water utilities for the countries in this region. The research also intends to demonstrate the extent to which the population of a country in Southern Africa is affected by IWS. This objective was addressed using the case study of South Africa.

In view of this, the purpose of this research was achieved by performing a series of statistical analyses, using the secondary data gathered from the sources listed in **Table 3.2** in the previous chapter. The statistical analyses were performed using various functions in Microsoft Excel, while the maps were developed using ArcMap, an ArcGIS application. The data collection process was described in Chapter Three.

It is, however, emphasised that the IWS reported by the results in this chapter is a combination of both temporary and permanent IWS. This is because the sources of data may not have known or considered the difference between temporary and permanent IWS, but rather reported it only as IWS. Additionally, the sources did not define IWS in terms of temporary or permanent IWS. Furthermore, where possible in the presentation of the results in this chapter, the reasons for IWS were evaluated to distinguish between temporary and permanent IWS.

In the context of the results presented in this chapter, temporary IWS is the interruption in water supply where consumers are given prior notification of the interruption and water supply is restored to CWS within a defined timeframe. Water utilities often implement temporary IWS for defined timeframes in order to carry out repair or maintenance works on the water supply system, and in some instances, rehabilitation or upgrade works. Permanent IWS on the other hand, is where the water utility consistently supplies water to the consumers by rationing. This is usually because the state of the water supply system or water resources fail to sustain CWS. Consequently, IWS becomes the normal mode of water supply for the water utility and is continued for an undefined timeframe, which can last for several months or years.

This chapter contains six sections, each of which presents the results relating to one of the three research questions. This introductory section provides a brief overview of the research and what was required to respond to the research questions. The second section presents an overview of the number of connections and the connection ratio in Southern Africa. The third section reports the results of the analyses done in addressing the first objective on the continuity of supply. Section four includes the results of the second objective for which an analysis was done involving NRW as a potential impact of IWS. The fifth section addresses the third objective, which was to identify the causes of IWS among water utilities in Southern Africa. Section six presents the analyses for the last objective, objective number four, which was to demonstrate the extent to which the population of a country in Southern Africa is affected by IWS. The reader is referred to **Appendix D** for the sources of data that was used to develop some of the figures presented in this chapter.

Research question one: Was there an improvement in the water supply duration to consumers affected by IWS in Southern Africa between 2008 and 2017?

Before attempting to answer research question one, it was important to determine the population in Southern Africa that had access to piped water connections during the 10 years under investigation. Additionally, it was important to determine the connection ratio, in order to provide a better understanding of the population numbers that were serviced by water utilities and could potentially be affected by IWS in this region.

4.2. Population with piped connections and connection ratio

Figure 4.1 presents the estimated population in Southern Africa that received water through piped water connections in relation to the total population of the region. The estimated population for each of the 11 countries were added to arrive at the total population for Southern Africa, which is highlighted by the blue trend line in this figure. The population with access to piped water connections is illustrated as totals for the region, and also divided into rural and urban areas. Some of the data was unfortunately only available for the years 2008 to 2015.

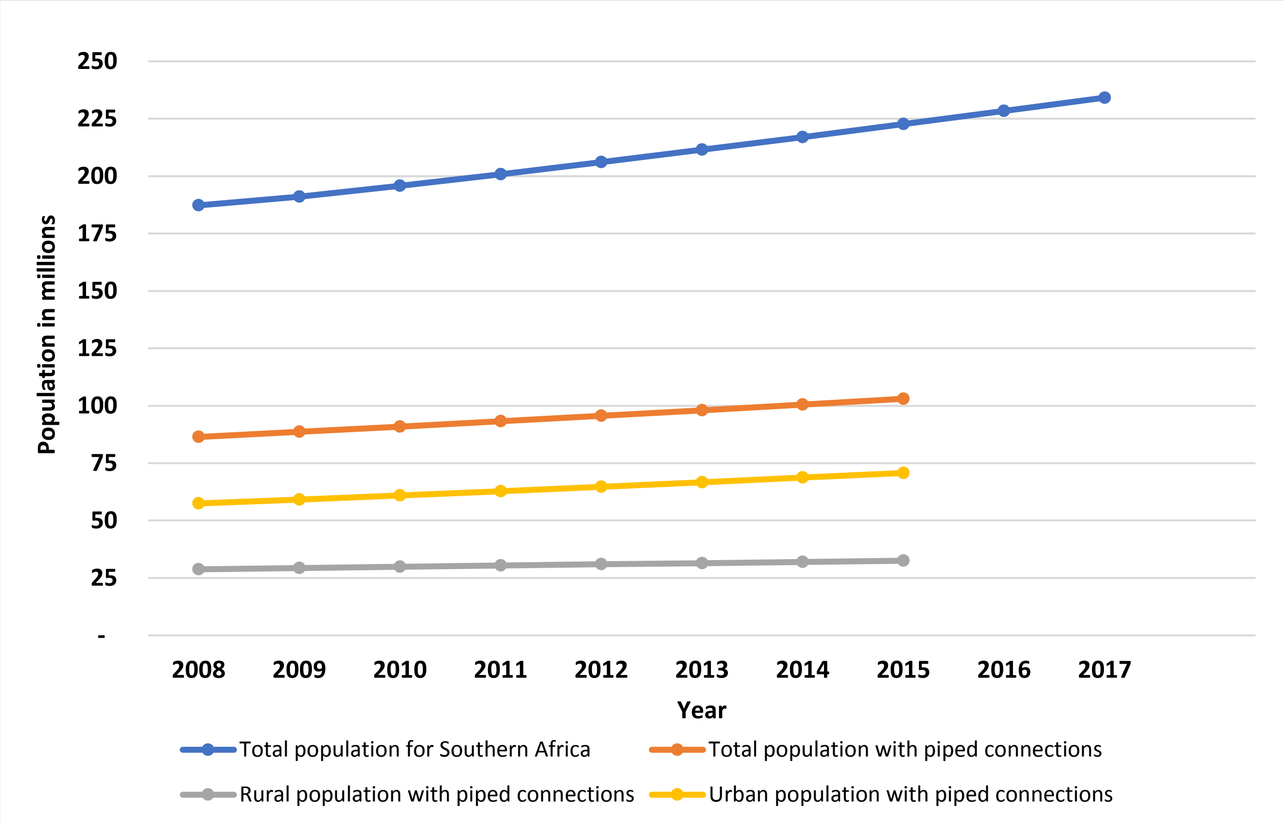

Figure 4.1: Southern African population served with piped water connections (Source: "JMP", n.d.; "Water - World and regional statistics, national data, maps, rankings", n.d.)

From **Figure 4.1,** there was an increase in the population accessing water through piped water connections in both rural and urban areas between 2008 and 2015. The rural population serviced increased by 12.8% from 28.8 million in 2008 to 32.5 million in 2015. On the other hand, the urban areas experienced a larger increase of 23%, with the serviced population increasing from 57.5 million to 70.7 million from 2008 to 2015. The total population in Southern Africa serviced with piped water connections (combining both rural and urban) increased by 19.2% from 86.4 million to 103 million during the same period. Despite the increase in the population with access to water through piped water connections, this may not imply a consistent supply of water for many residents in this region, due to the possibility of IWS being implemented.

The connection ratio presented in **Figure 4.2,** is an illustration of the average number of people in a country that use one piped connection to access water. This ratio is calculated using **Equation 4.1**. A trend line was established between the connection ratios for each country, in order to illustrate its performance in this regard. The data was however incomplete, and as a result, connection ratios are only presented for the countries and years where data is available. However, it must be noted that these connection ratios were calculated based on the total population of a country and the total number of piped water connections.

$$Connection\ ratio\ =\ \frac{Total\ population\ in\ location}{Total\ number\ of\ connections\ in\ a\ location}$$

Equation 4.1

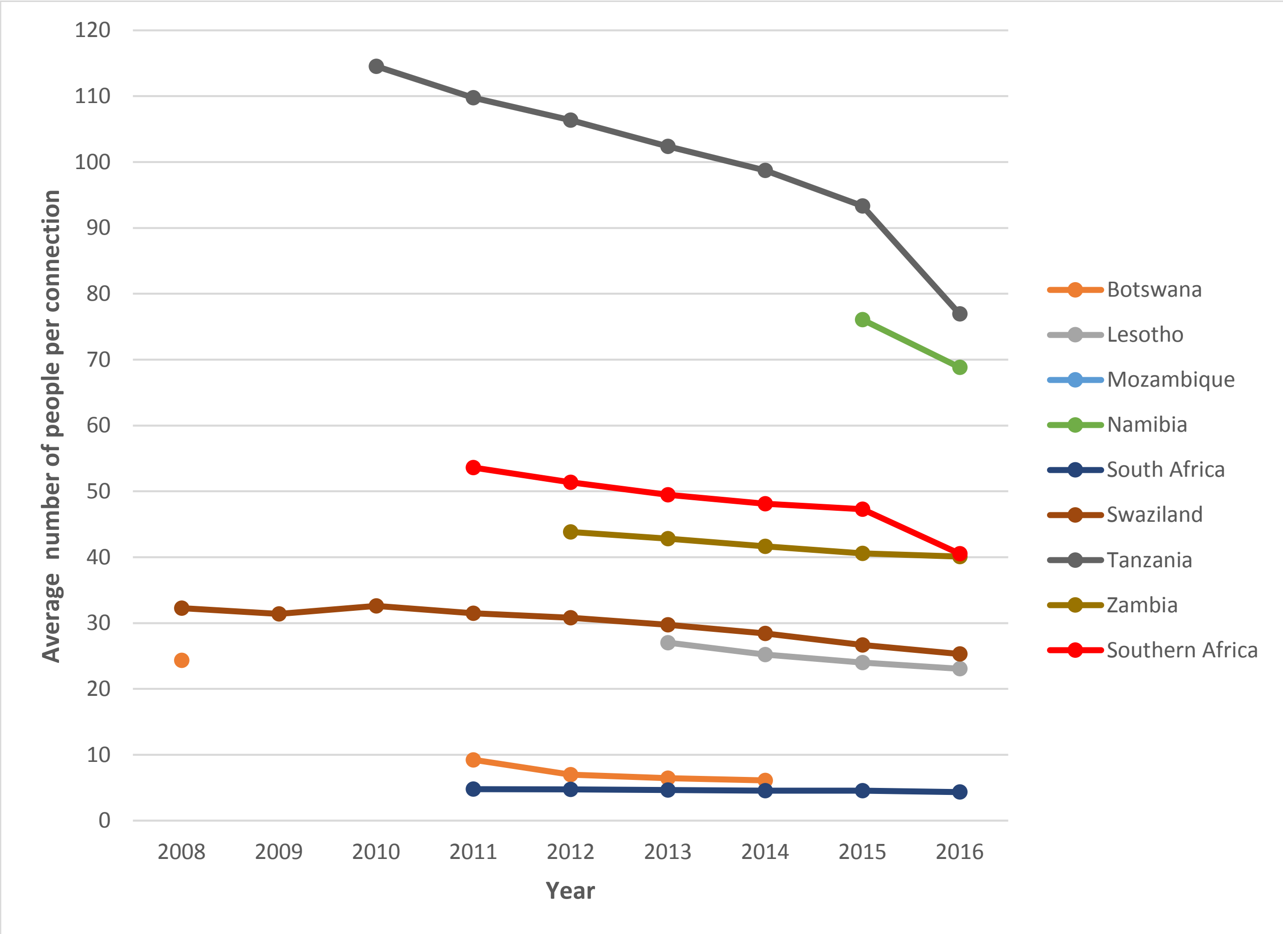

Figure 4.2: Connection ratios in Southern Africa

Based on the results presented in **Figure 4.2**, all the countries presented a reduction in the connection ratio, with Botswana and Tanzania demonstrating significant reductions. The connection ratio for Botswana reduced from 24.3 people per connection in 2008 to 6.1 people per connection in 2014, a reduction of 74.9%. On the other hand, Tanzania's connection ratio reduced by 33% from 114.6 people per connection in 2010 to 76.9 people per connection in 2016. South Africa had the lowest average number of people using one piped water connection, as reflected by the connection ratio of 4.8 in 2011 that reduced to 4.3 in 2016. Considering the year 2016, Namibia and Tanzania had the highest connection ratios of 68.8 and 76.9, respectively. In essence, this means that in 2016, an average of 69 people in Namibia used one piped water connection, while in Tanzania this average was as high as 77. The connection ratio for Southern Africa was calculated from 2011 to 2016 because prior to this period, only Tanzania and Swaziland (Eswatini) had data some data. In addition, the weighted average connection ratio for the region would have been dominated by Tanzania, which had both a higher population and connection ratio. Consequently, the weighted average connection ratio that would have resulted from 2008 to 2010 would not have given a true reflection for Southern Africa. However, from 2011, a complete dataset was available, resulting in a realistic trend.

Despite the missing information, the connection ratios presented in **Figure 4.2** provide significant information. The connection ratios reflect the disparity between the countries in Southern Africa regarding the average number of people that use one piped water connection. Additionally, the connection ratios do not consider the population distribution within a nation. However, the researcher is of the view that these connection ratios are more applicable in urban areas where a larger population has access to piped water connections as demonstrated in **Figure 4.1**. According to Kumpel and Nelson (2013), it can be challenging to manage the impacts of water quality resulting from IWS in an area that has a high number of people using one connection. Furthermore, Kumpel and Nelson (2016) pointed out that with an increase in the number of people using one piped water connection, each person has reduced access to water during intermittent supply.

4.3. Continuity of supply

The continuity of supply in terms of the average hours of supply is illustrated in **Figure 4.3**. The data is presented based on the weighted annual average hours of supply for each country, as was obtained from the different sources of data. To determine the weighted annual average supply hours for Southern Africa, calculations were done using the weighted average formula presented in **Equation 4.2**. The values input into this equation for each year was based on the countries for which the average hours of supply were available.

$$Weighted\ hours\ of\ supply\ = \frac{((H_1 \times\ T_1) + (H_2 \times\ T_2) + (H_3 \times\ T_3) + \cdots +\ (H_{11} \times\ T_{11}))}{(T_1 + T_2 + T_3 + \cdots + T_{11})}\ hours$$

Equation 4.2

Where;

H = the weighted average hours of supply for the individual country in a specified year

T = the total population in a country for a specified year

1, 2, 3 …11 = country one, country two, country three…country 11

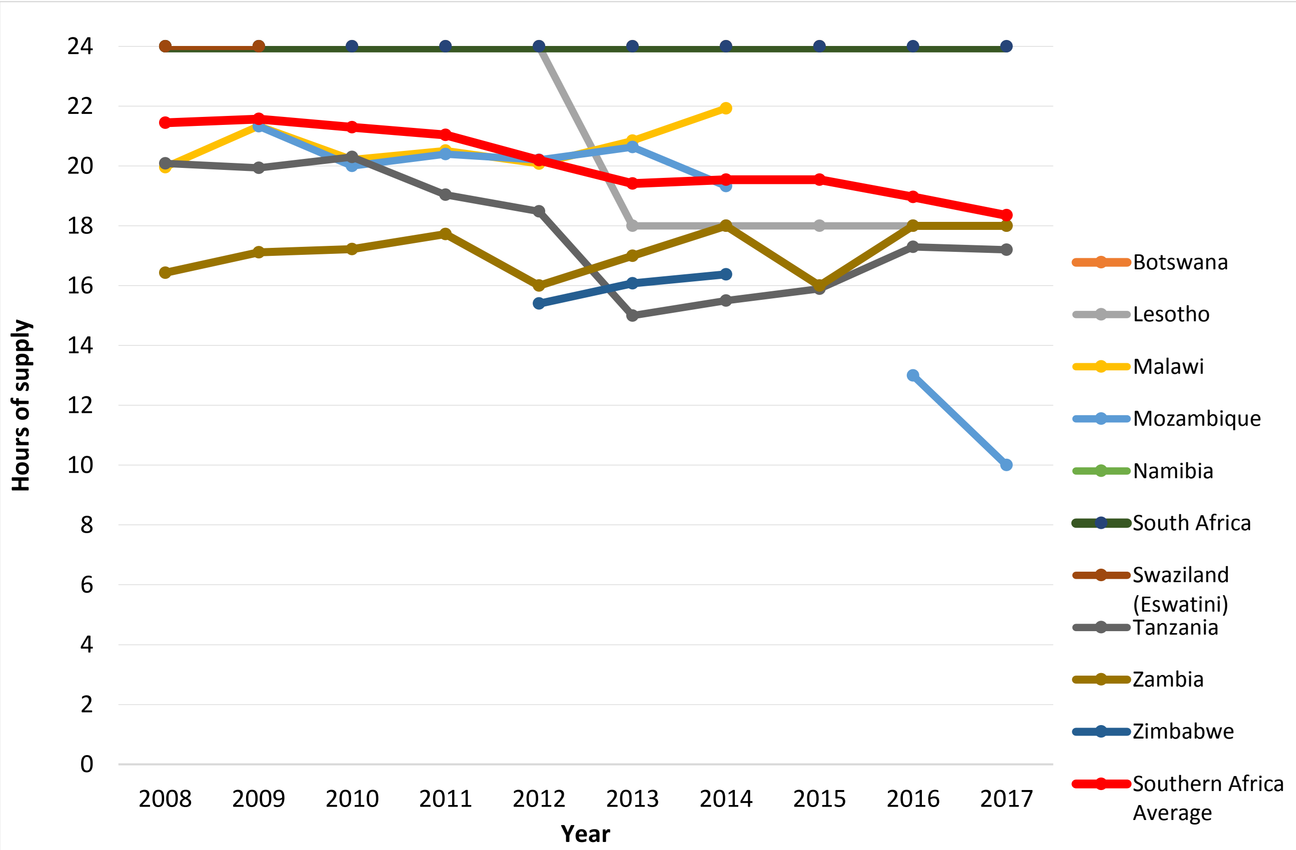

Figure 4.3: Continuity of supply in Southern African countries

In **Figure 4.3**, the trend line for Southern Africa reveals a decline in the regional weighted average hours of supply from 21.49 hours in 2008 to 18.35 hours in 2017. Although this outcome supports the predictions made by earlier researchers that the hours of supply under IWS would reduce over time (Kumpel & Nelson, 2016; Kaminsky & Kumpel, 2018), it is difficult to agree with or disprove these predictions based on this result, due to the incomplete dataset. South Africa, Namibia, Swaziland (Eswatini) and Botswana all returned average hours of supply of 24. However, the prediction held true for countries such as Lesotho, Mozambique and Tanzania, as these presented a decrease in hours of supply. For example, Lesotho moved from an average of 24 hours in 2008 to 18 hours in 2012, which remained constant through to 2017. Following a similar trend, Mozambique had an average of 21.3 hours in 2009, which eventually reduced to 10 hours in 2017. The average hours of supply in Tanzania, started at 20.1 hours in 2008, reduced to 16.1 hours in 2012, increased to 17.3 hours in 2016 and reduced slightly to 17.2 hours in 2017. The marginal fluctuations are immaterial in the context of the accuracy of the data.

Interestingly, Malawi and Zimbabwe presented an increase in the hours of supply for the period for which data was available. Given the limited data available for these countries, and the unavailability of data in more recent years, it is impossible to predict whether these marginal improvements were sustainable or even accurate. Despite an increase in hours of supply between 2008 and 2017 for Zambia, the range varied between 16 and 18 hours over the entire 10-year period. Reference can be made to **Appendix C** for details of the average hours of supply.

Figures 4.4a, 4.4b and **4.4c** present a mapped illustration of the weighted annual average hours of supply for 2008, 2012 and 2017, respectively. The maps included in these figures present the variation in the hours of supply per country in each of the three years, in order to illustrate the variation in the hours of supply over the five-year intervals. The maps in **Figure 4.4** complement the map in **Figure 1.2** in Chapter One as well as the trend lines illustrated in **Figure 4.3.** The maps in **Figures 4.4a, 4.4b and 4.4c** illustrate a decline in the hours of supply for Lesotho, Mozambique and Tanzania in the five-year intervals represented by these three years. South Africa, however, maintained a supply of 24 hours in each of the three years, while Zambia remained in the range of 15 to 18 hours. No data was available for Angola throughout.

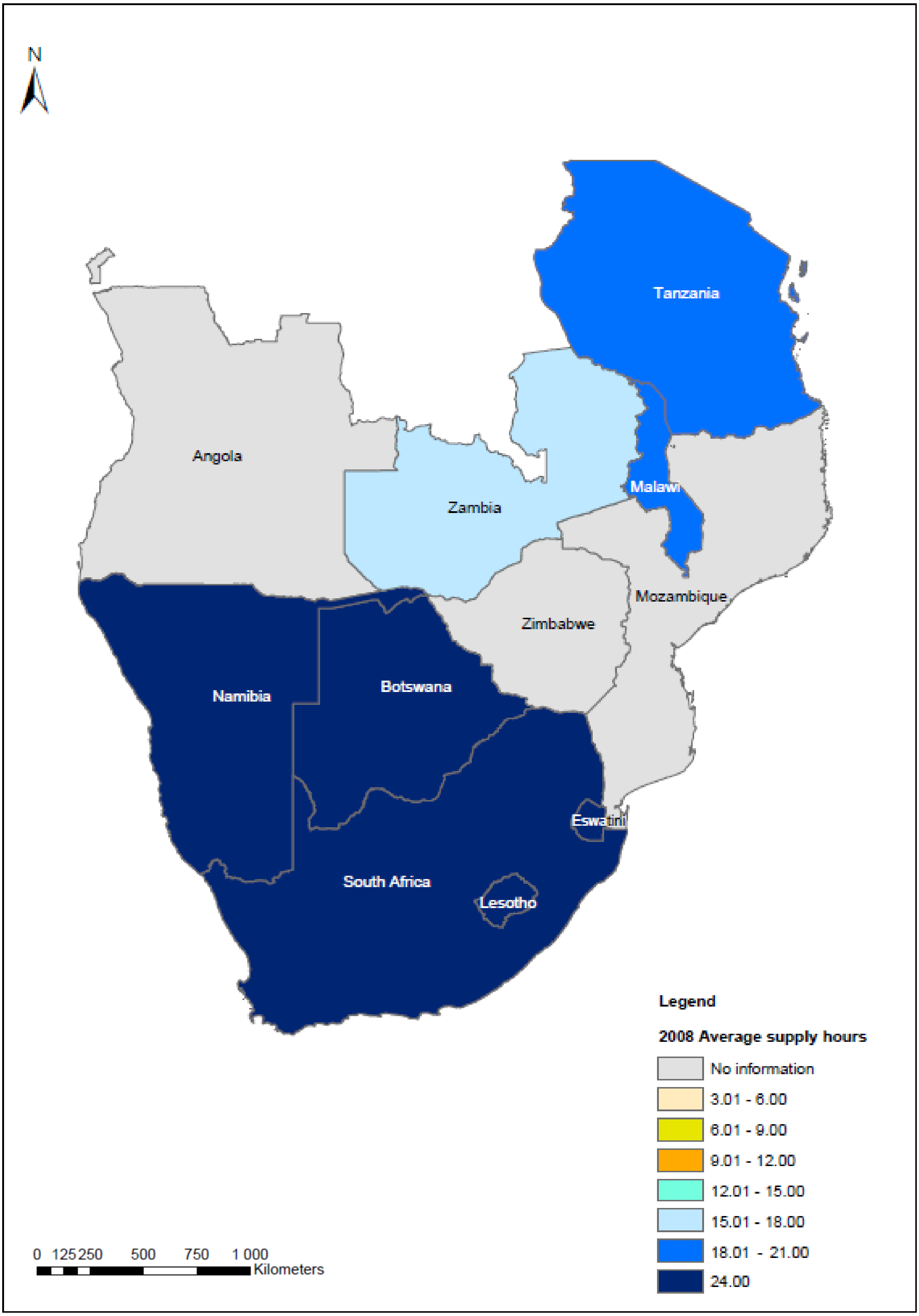

Figure 4.4a: Southern Africa hours of supply for 2008

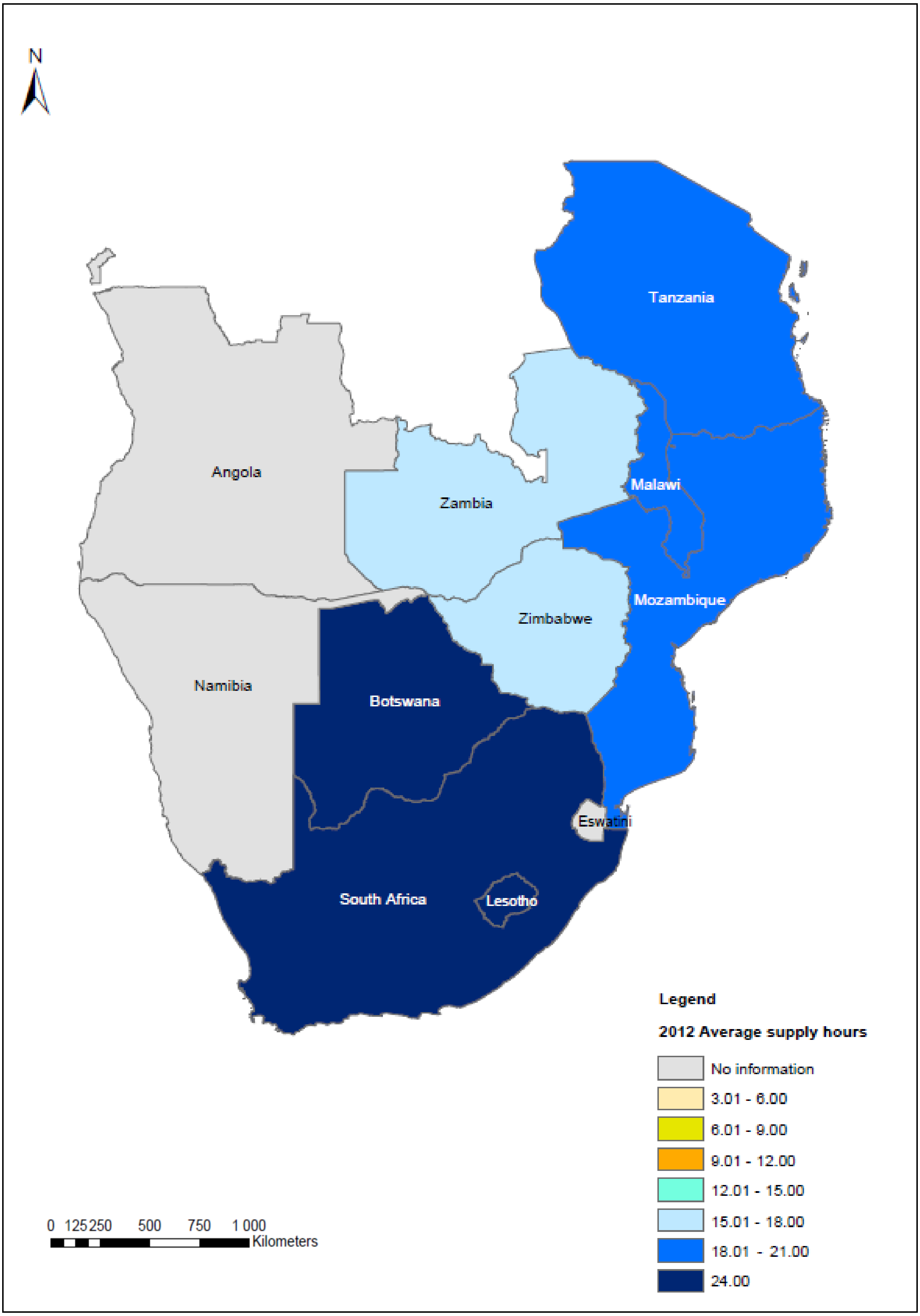

Figure 4.4b: Southern Africa hours of supply for 2012

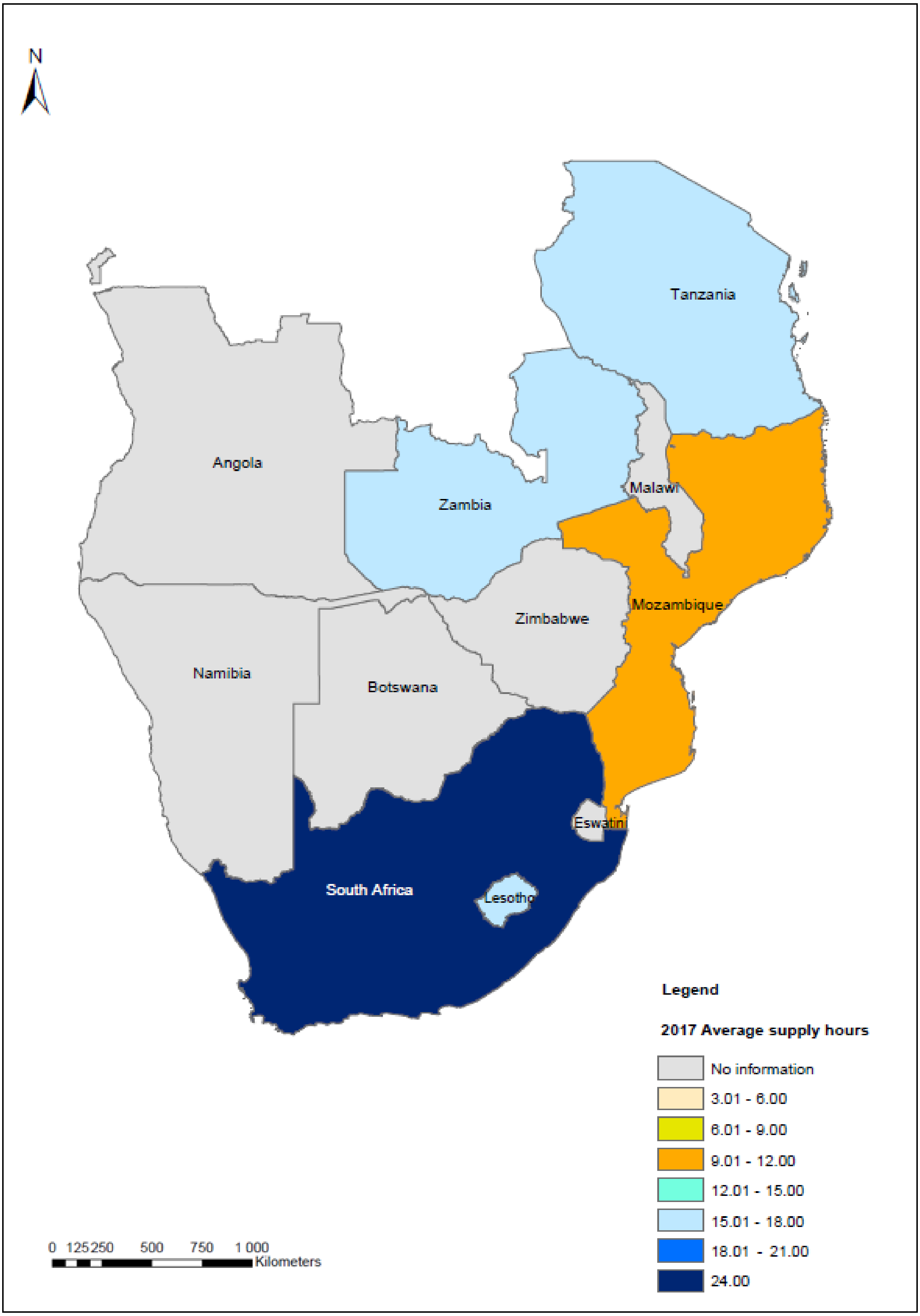

Figure 4.4c: Southern Africa hours of supply for 2017

Research question two: What are the leading causes of IWS among water utilities in Southern Africa?

Before answering the second research question, it may be relevant to consider the trends associated with non-revenue water (NRW). NRW is one of the main factors upon which the performance of a water utility is measured, and is often associated with IWS. Where NRW does not necessarily lead to the implementation of IWS, NRW almost inevitably increases once IWS is implemented. In this regard, the second research question is answered in Section 4.5, in which it is noted that there are five leading causes of IWS in Southern Africa.

4.4. NRW in Southern Africa

NRW performance and trends for the countries in Southern Africa between 2008 and 2017 are illustrated in **Figure 4.5**. The NRW in this research is presented as a percentage, which is the reflection of the water lost during the water supply process, from the point of abstraction to final distribution to the consumers. The NRW percentages in this figure indicate the annual weighted percentages for each country as obtained from the various data sources. The Southern African average was calculated using **Equation 4.2**.

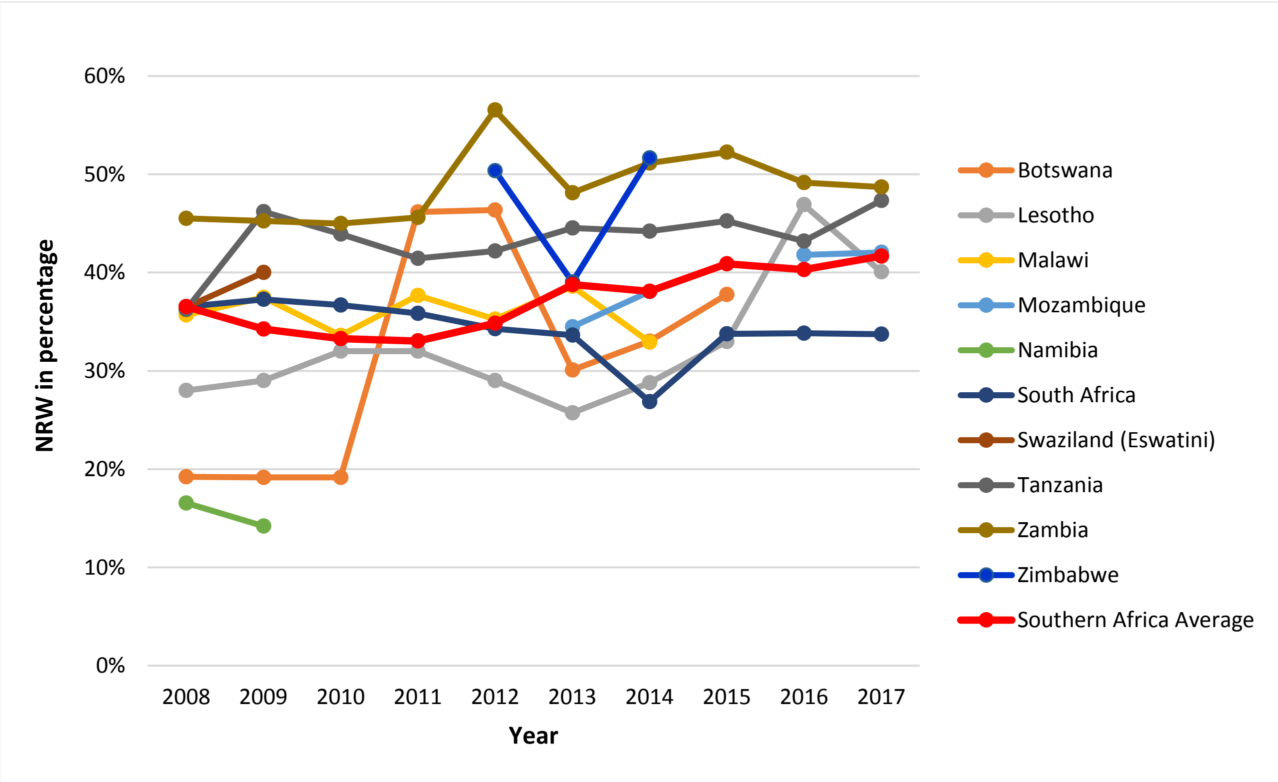

Figure 4.5: NRW in Southern African countries

The trends established in **Figure 4.5** demonstrate an increase in NRW for most of the countries in Southern Africa during the study period. For instance, the regional average for Southern Africa increased from 36.5% in 2008 to 41.7% in 2017. Zambia and Tanzania presented NRW percentages above 40% for the entire period, with Zambia reaching an all-time high for the region of 56.5% in 2012. Botswana and Lesotho also experienced significant increases in NRW during this period. Botswana's NRW increased from 19.20% in 2008 to 37.76% in 2015, which is extremely significant. For Lesotho, the NRW percentage increased from 28% in 2008 to 41.68% in 2017. From 2014, South Africa presented the lowest figures (apart from 2015), with the 2017 NRW reported at 33.7%.

According to Sharma and Vairavamoorthy (2009), NRW is indicative of a water utility's ability to manage leaks and gather revenue. While it is not directly related to IWS, high levels of NRW can cause a water utility to implement IWS in attempt to manage leaks or manage the available water resources. Interestingly, the countries that returned NRW percentages above 40%, namely Lesotho, Mozambique, Tanzania and Zambia, all reported less than 20 hours of water supply per day (see **Figure 4.3**). By implication, one can assume that high levels of NRW impact on the available water resources and a water utility's ability to supply the demand. In turn, this impact may lead to the implementation of IWS.

4.5. Causes of IWS in Southern Africa

Figure 4.6a illustrates the summary of challenges faced by water utilities in Southern Africa. The summary was compiled by combining the main challenges faced by each country in this region. Challenges that were similar in nature were placed in the same category. For example, 'dams drying up' and 'water shortages' were all placed in the 'inadequate water resources' category. The frequency of each challenge was determined for the period between 2008 and 2017. The reader is referred to **Appendix B** for a summary of all challenges experienced. These challenges have been linked to the causes and impacts of IWS, as discussed in Chapter Two. Therefore, in the context of this research, these challenges can be referred to as causes of IWS.

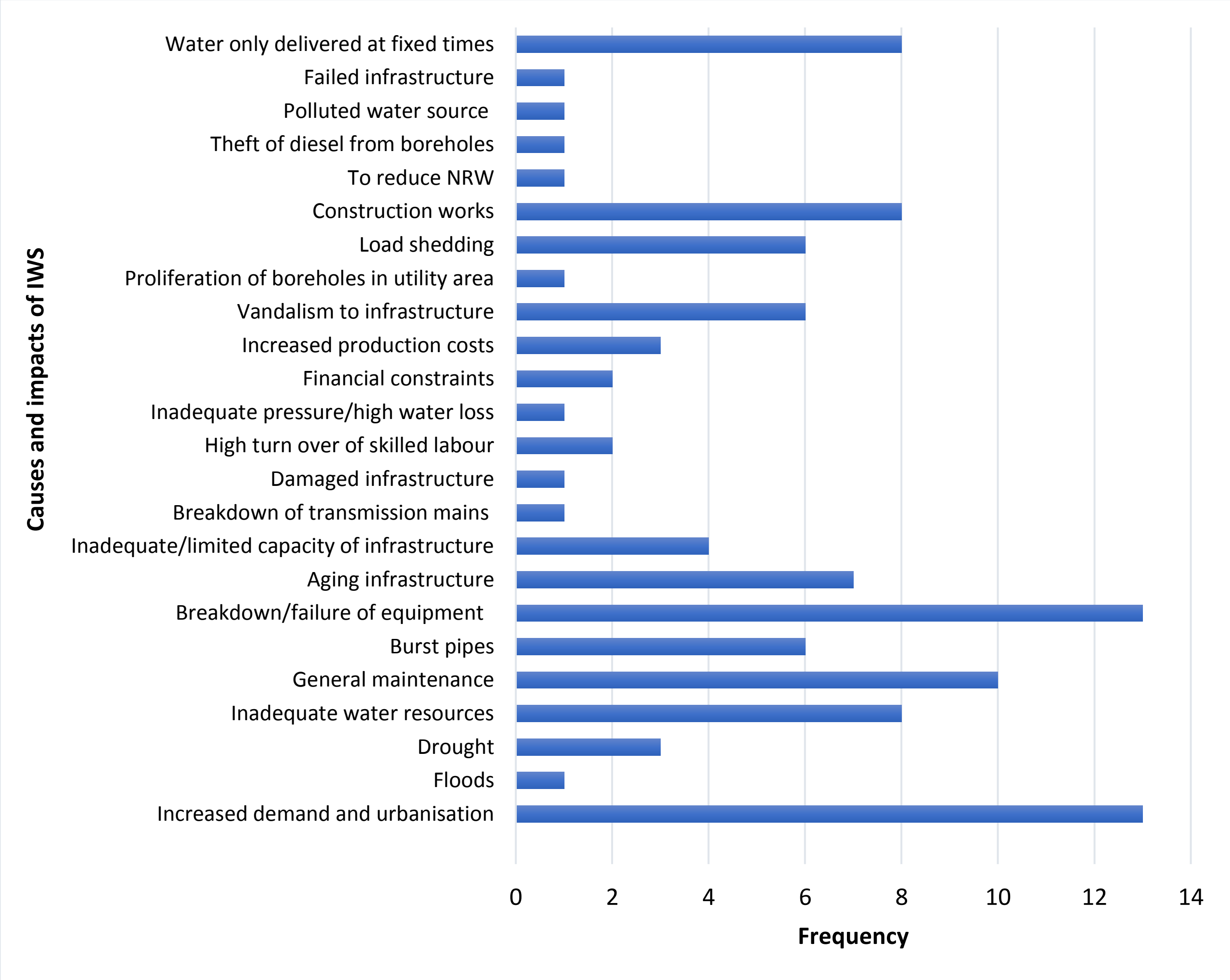

Figure 4.6a: Challenges faced by water utilities in relation to IWS

A total of 24 challenges faced by water utilities across Southern Africa were identified and categorised. Of these challenges, six stood out in terms of the frequency of occurrence and by comparison to the causes of IWS described in Chapter Two. According to **Figure 4.6a**, the six dominant aspects that can be considered as causes of IWS in Southern Africa are;

i. Increased demand and urbanisation
ii. Faulty equipment and pipe bursts
iii. Inadequate water resources
iv. Ageing infrastructure
v. General maintenance
vi. Construction works.

However, faulty equipment and pipe bursts, general maintenance and construction works may not necessarily be categorised as causes of IWS, even though they could lead to temporary supply interruptions. This is because, under normal circumstances, faulty equipment and pipe bursts, general maintenance and construction works are planned for and cause temporary supply interruptions, as opposed to IWS as a permanent management strategy. In addition, consumers likely to be affected by IWS resulting from such works are given prior notification to plan for their water requirements during the interruption in water supply. Although the category denoted as 'water only supplied at fixed times' shows a significant frequency in **Figure 4.6a**, it is neither a cause nor an impact of IWS. It is rather, by definition IWS itself. Other aspects in this figure that have significant frequencies include pipe bursts, load shedding and vandalism to infrastructure. These too contribute towards the implementation and sustaining of IWS in Southern Africa.

The results illustrated in **Figure 4.6a**, however, are not necessarily applicable to the entire region. This is because information on the challenges that affected some countries during certain years was not available. The analysis also excluded Angola, Malawi and Zimbabwe due to unavailability of data. Four results relating to the causes did, however, support earlier research by Klingel (2012), in which the technical inefficiencies associated with IWS were highlighted. These include breakdown/failure of equipment, failed infrastructure, inadequate pressure/high water loss and burst pipes. Furthermore, the results also support the study conducted by Sharma and Vairavamoorthy (2009) on urban water demand management, in which several challenges faced by water utilities in developing countries were identified.

The causes of IWS in **Figure 4.6a** were further classified in order to determine the critical factors that contributed to permanent IWS amongst water utilities in Southern Africa. The reclassification illustrated in **Figure 4.6b**, was done in such a way that the 24 causes of IWS in **Figure 4.6a** were combined into ten categories based on the similarity of their root cause or consequence. For example, 'inadequate water resources' and 'drought', which both relate to physical water scarcity were placed under the 'inadequate water resources' category. Similarly, 'increased production costs' and 'financial constraints', which both relate to the water utilities' need for financial resources were placed under the 'financial constraints' category. However, the category 'water only delivered at fixed times', was excluded in the reclassification as this is by definition IWS.

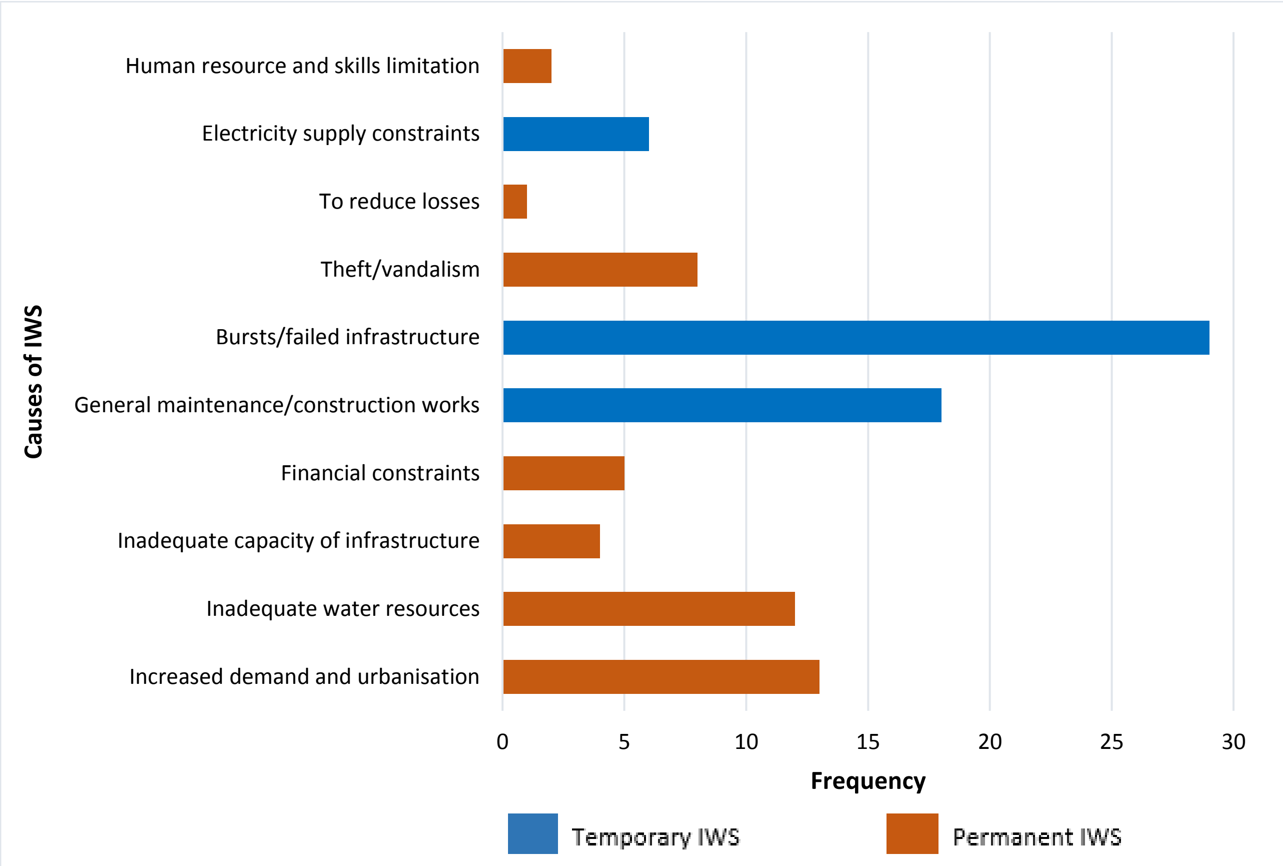

Figure 4.6b: Reclassified causes of IWS among water utilities in Southern Africa

The reclassified categories illustrated in **Figure 4.6b** reveal a different aspect of the dominant causes of IWS in Southern Africa, based on the frequencies of the ten categories in this figure. It is apparent that the causes allude to both temporary and permanent IWS. The majority of the reasons point towards temporary IWS and include bursts, failed infrastructure, general maintenance/construction works and electricity supply constraints.

Figure 4.6b also demonstrates the causes of permanent IWS in Southern Africa. These include increased demand and urbanisation, inadequate water resources, theft/vandalism, financial constraints and inadequate capacity of supply infrastructure. Several countries in Southern Africa have experienced drought in the recent few years, which has resulted in inadequate water resources. Water utilities may be further challenged as electricity is a key component in the water production process, which is required to run the pumps. Without electricity to run the pumps, water supply becomes limited to the periods when electricity is available and subsequently, impacting on the number of hours the water utility can supply water to the consumers. With an increase in demand and urbanisation, electricity supply interruption may have further impact on the water supply cycle. Reduced hours of supply, in turn may lead to an increase in illegal connections and vandalism of water supply infrastructure.

This, therefore, points out that the causes and impacts of IWS are often interrelated. In addition, one cause of IWS could yield consequences that subsequently become causes of IWS, and thus the vicious cycle of IWS as explained by Charalambous and Liemberger (2016), is sustained. There are five leading causes of IWS amongst water utilities in Southern Africa. These include bursts/failed infrastructure, increased demand and urbanisation, inadequate water resources, theft/vandalism to water supply infrastructure, and electricity supply constraints.

Research question three: To what extent is the population in a Southern African country affected by IWS?

Research question three is answered in Section 4.6 using the case study of South Africa. The results indicate that up to 25% of the population in a Southern African country can be affected by IWS. In order to adequately respond to this research question, four factors were taken into consideration during the data analysis process. These factors include the population, connection ratio, causes of IWS and the population affected by IWS.

4.6. Population affected by IWS - a case study of South Africa

This section presents an overview of IWS in South Africa. A summary of the estimated population affected by IWS for each of the 10 years is provided, alongside the total population of the country for the corresponding year. Subsequently, the connection ratio for each province is presented, followed by a summary of the leading causes of IWS according to municipalities in South Africa. This is followed by a figure presenting the municipalities affected by IWS. The last three figures provide an overview of South African demographics in relation to IWS. The majority of the data used in these analyses was obtained from Stats SA, unless stated otherwise in the caption.

4.6.1. Total population versus population affected by IWS

The comparison between the total population of South Africa and the population in South Africa affected by IWS, is illustrated in **Figure 4.7**. The population affected by IWS represents the total for the nine provinces.

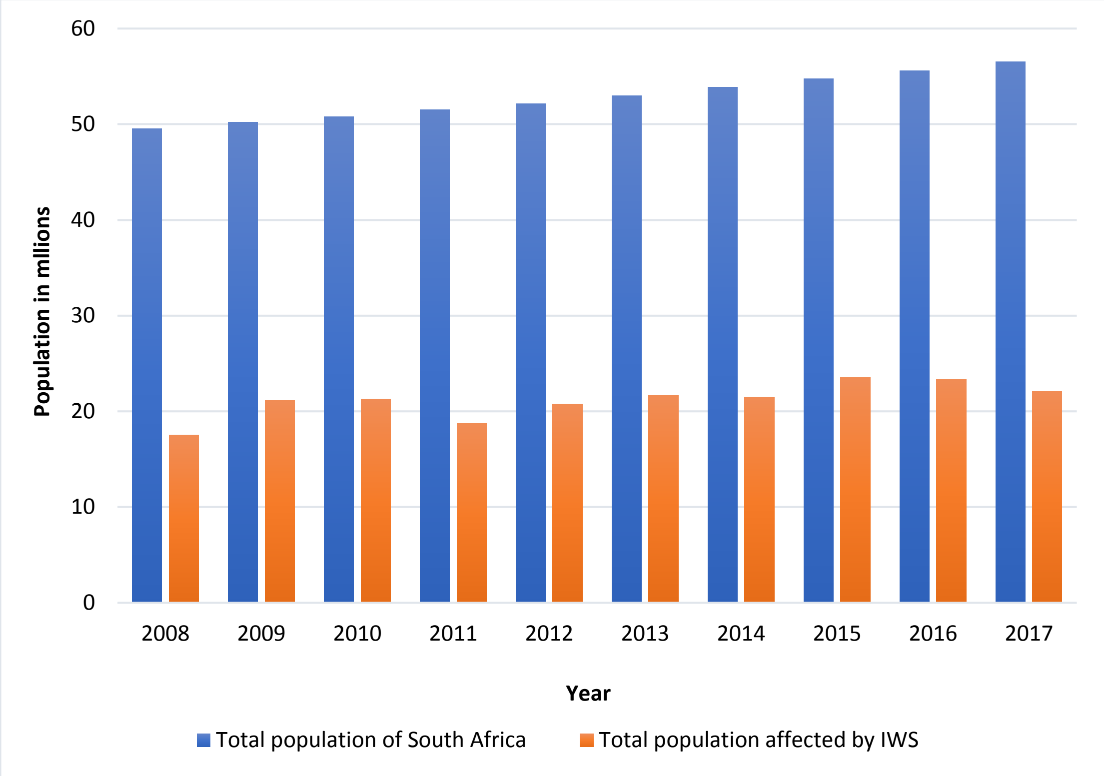

Figure 4.7: South African population versus population affected by IWS

Figure 4.7 is an illustration of the relationship between the total population of South Africa and the population that was affected by IWS in South Africa from 2008 to 2017. The population of South Africa increased by only 12% between 2008 and 2017, while there was a more significant increase of 26% in the population affected by IWS during the same period. These two percentages imply that the population affected by IWS in South Africa increased at more than double the rate of the population increase. From another perspective, the population affected by IWS in each of the years represented accounted for more than 25% of the total population of South Africa. For example, in 2008, the estimated population affected by IWS was 17.5 million, which accounts for 35.3 % of the total population. Similarly, in 2017, an estimated 22 million people were affected by IWS, which represented 39.3% of the population. Furthermore, the population affected by IWS was highest in 2015, when 43% of the South African population was affected by some form of IWS.

4.6.2. Connection ratio

The connection ratios illustrated in **Figure 4.8** represent the ratio between the number of connections and the population. For South Africa, this ratio is illustrated for each province based on the number of connections and population for that province. **Equation 4.1** is used to calculate the different connection ratios. The data used in this analysis was only available from 2012 to 2017.

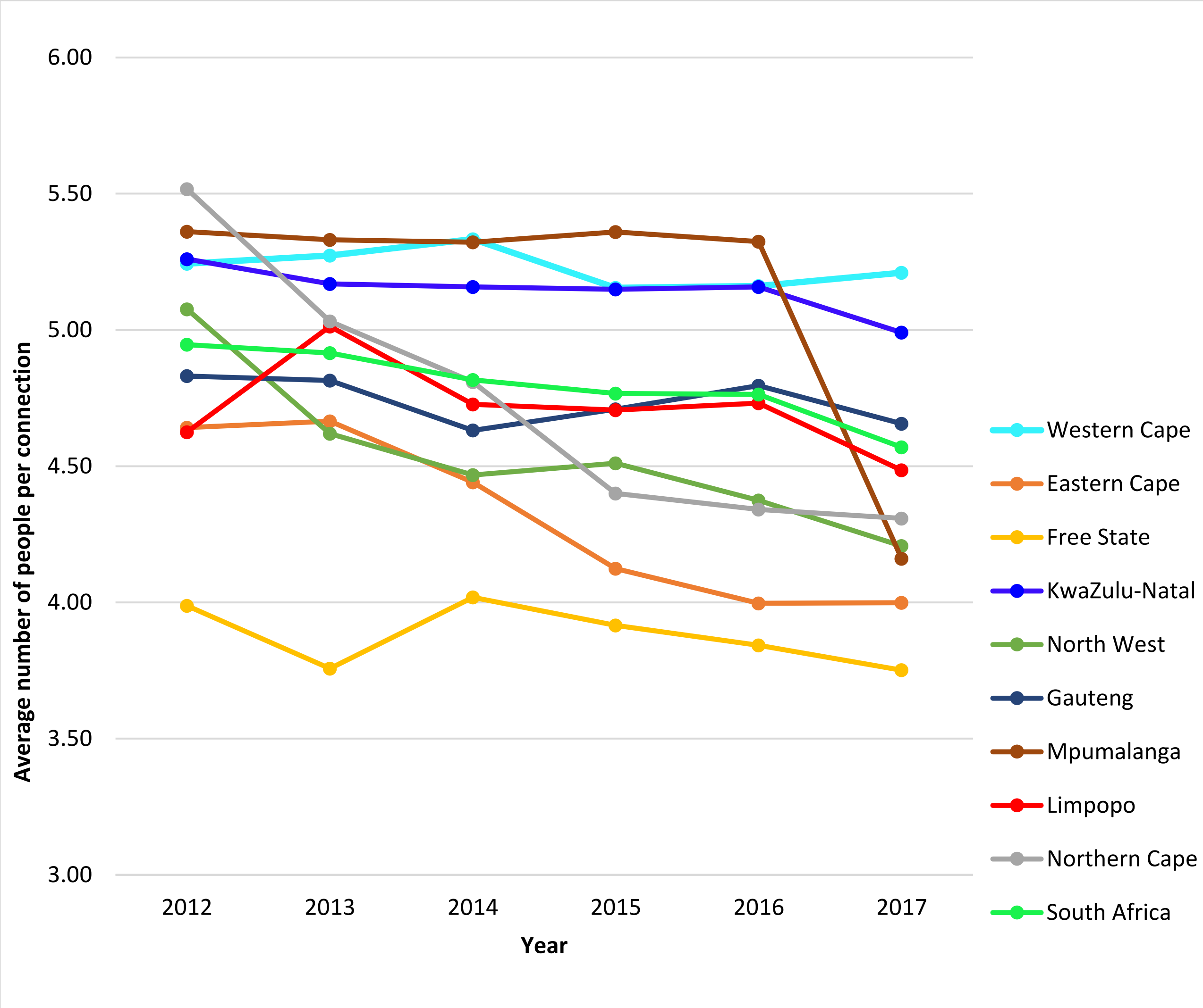

Figure 4.8: Connection ratios for South African provinces

Figure 4.8 demonstrates the average number of people using one piped water connection relation to the total population of South Africa. According to this figure, many people in South Africa have access to piped water connections. This statement is based on the low connection ratios for all the nine provinces, which range between 3.7 and 5.5 for the six years represented. In addition, the trend lines established indicate a steady decline in the connection ratio in most provinces, implying that more people in South Africa gained access to piped water connections as the years passed. Notable improvements were reported by the Northern Cape and Mpumalanga Provinces, for which the connection ratios indicate a significant reduction. The connection ratio for the Northern Cape Province reduced from 5.5 in 2012 to 4.3 in 2017, while that of Mpumalanga reduced from 5.3 to 4.1 over the same period. Despite this reduction in Mpumalanga, the province had the highest connection ratio for four of the six years presented. On the other hand, the Free State Province returned the lowest connection ratio, which reduced from 4 people per connection in 2012 to 3.7 in 2017. South Africa returned a weighted average connection ratio that reduced from 4.9 in 2012 to 4.6 in 2017. This, therefore, presents clear evidence that more people in South Africa gained access to piped water connections from 2012 to 2017. Refer to **Appendix C** for details of the connection ratios for South Africa.

4.6.3. Causes of IWS in South Africa

Table 4.1 presents a summary for the causes of IWS among South African municipalities. The data used in this analysis is based on the results of various household surveys carried out by Stats SA. In this table, the summary of these causes is presented with an indication of which cause was prevalent in a specific year.

Table 4.1: Causes of IWS in South Africa

CAUSE	YEAR									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Increased demand	✓	✓	✓	✓	✓	✓				✓
General maintenance	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Burst pipes	✓	✓	✓	✓	✓	✓				
Faulty equipment	✓	✓	✓	✓	✓	✓			✓	
Inadequate pressure/high water loss										✓
Vandalism to infrastructure	✓			✓	✓	✓				✓
Construction works		✓		✓	✓	✓	✓			✓
Water only delivered at fixed times			✓	✓	✓	✓	✓	✓	✓	✓

From **Table 4.1**, there are eight dominant causes of IWS that were reported through the household surveys. Although the category of ‘water delivered at fixed times’ was classified as a reason for inconsistencies in water supply, it is not a cause of IWS because it is essentially by definition IWS. As can be noted in **Table 4.1**, general maintenance was the most dominant cause of intermittency because it appeared every year. It can thus be assumed that many municipalities in South Africa practise CWS, and only resort to IWS for purposes of conducting maintenance work on the water supply system. However, with ‘increased demand’ and ’water only delivered at fixed times’ respectively appearing in seven and eight of the 10 years, it is safe to assume that some of the municipalities practise IWS as the normal mode of operation.

Similar to **Figure 4.6a** and **4.6b, Figure 4.9** presents the causes of IWS, but only those applicable to South Africa. In this figure, the causes of IWS are illustrated based on its frequency of occurrence over the 10-year period under investigation, as well as an indication as to whether these relate to temporary or permanent IWS.

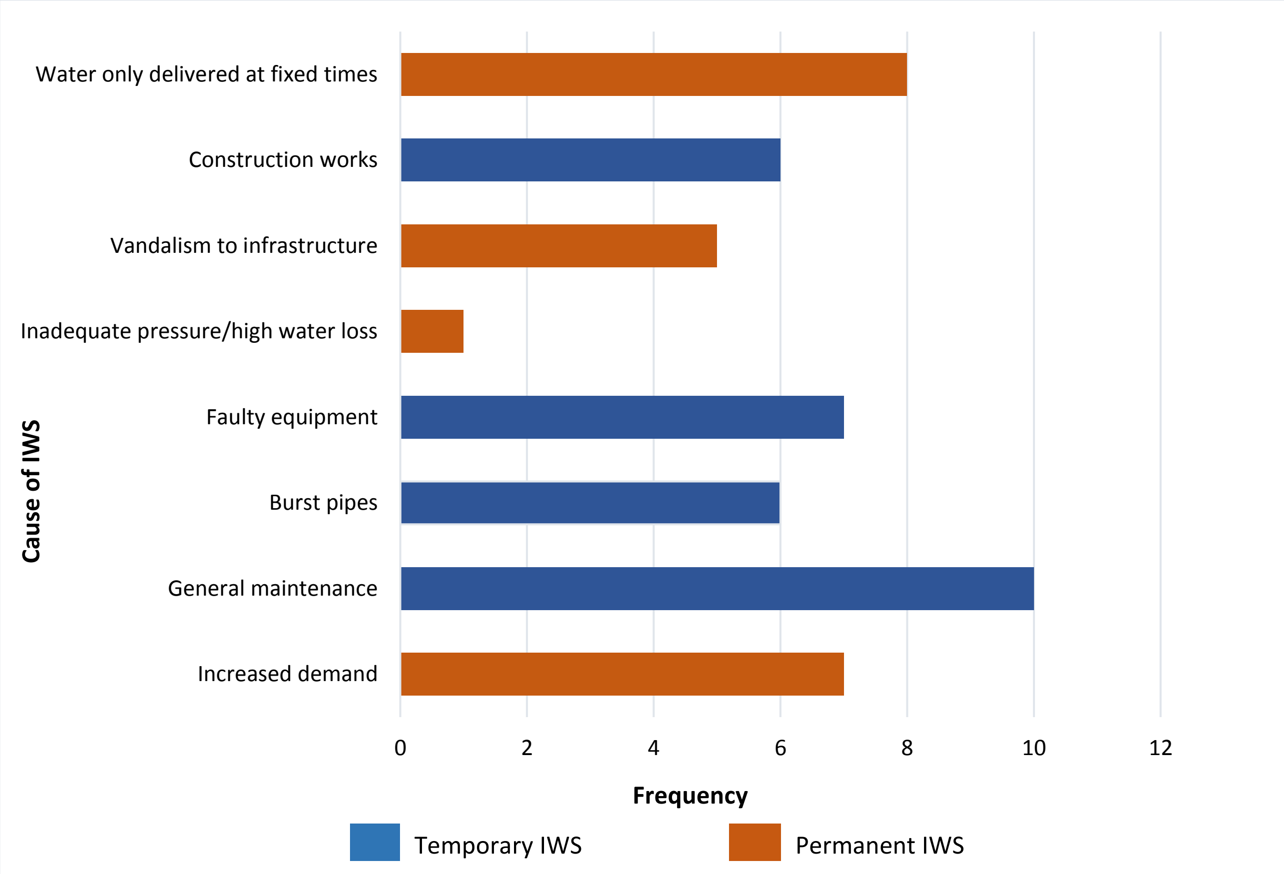

Figure 4.9: Causes of IWS in South Africa

A critical review of **Figure 4.9** would reveal the following outcomes. The reasons of IWS listed point to both permanent IWS implemented as a water supply strategy, and temporary intermittency that could result from say a burst pipe.

The reasons 'water delivered only at fixed times', 'vandalism to infrastructure', 'inadequate pressure/high water loss' and 'increased demand' would typically refer to IWS as a water supply strategy. The combined frequency of these reasons is 21. It has to be noted that vandalism could lead to temporary or permanent IWS. However, when vandalism involves illegal water connections, it has been observed that it often leads to permanent IWS. It is therefore added to permanent IWS calculations.

The reasons 'construction works', 'faulty equipment', 'burst pipes', and 'general maintenance' would typically refer to a temporary supply failure or temporary intermittency. The combined frequency of these reasons is 29.

One could therefore argue that 42% of the cases reported are IWS as a strategy while 58% of the cases probably represent temporary intermittency. While 42% may not sound significant to some, it is extremely significant. It suggests that in at least 42% of the causes reported, the water supply authority is faced with such extreme challenges, that it probably decided to implement IWS as a formal water supply strategy.

4.6.4. Municipalities affected by IWS

The municipalities affected by IWS in 2017 are illustrated in **Figure 4.10**, which provides the geographical location of these municipalities on a map of South Africa. The compilation of this figure is based on the information obtained from various South African news articles, online platforms and the IBNET. The map was compiled on the assumption that even if only one town within the municipality was affected, the entire municipal area was indicated as affected by IWS. The municipalities coloured in grey are those for which no specific information could be found, those in blue are those where CWS could be confirmed. Those municipal areas coloured in pink represent those where temporary intermittency was observed, while those in red probably indicate municipal areas where IWS is implemented as a formal water supply strategy.

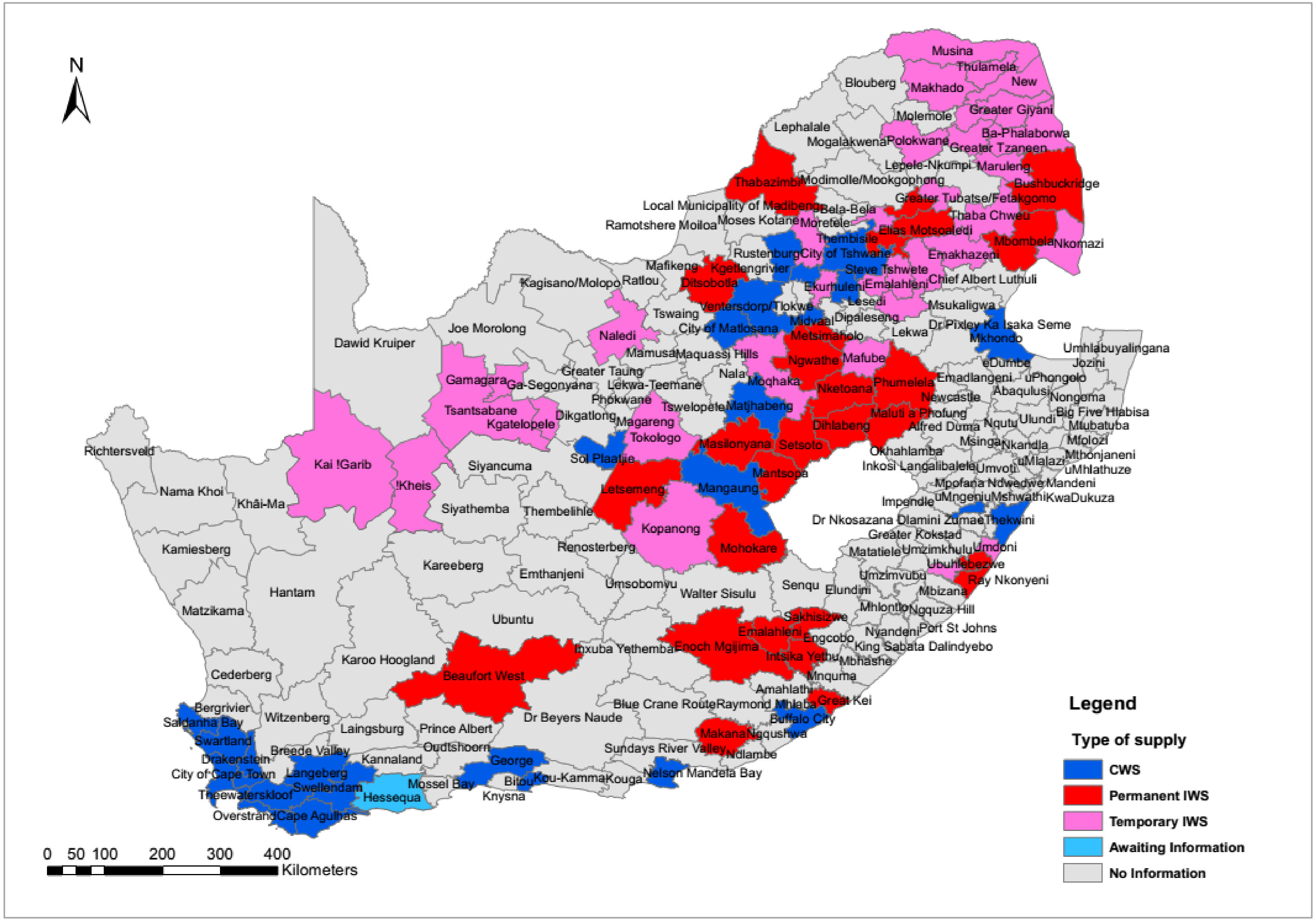

Figure 4.10: Municipalities affected by IWS

South Africa makes for interesting research into IWS. This is because according to data obtained from the IBNET as presented earlier in **Figure 4.3**, South Africa practises CWS. This is further supported by **Figure 1.2** in Chapter One, which illustrated the hours of supply for several countries worldwide, on which South Africa was indicated as having 24 hours of water supply. On the contrary, the results presented in **Figure 4.10**, using information obtained from various online social platforms and open access websites, as well as news articles, reveal that almost a quarter of municipalities in South Africa are affected by IWS. According to **Figure 4.10,** 54 of the 213 municipalities represented on this map experience some form of noteworthy IWS, albeit temporary or permanent intermittency as a strategy. Most of the affected municipalities according to this figure, are in the Free State, Limpopo and Mpumalanga Provinces and to a lesser extent, the Northern Cape Province.

A significant number of municipalities can be noted to practise CWS, of which most are large cities or metropolitan areas such as the City of Cape Town, Ekurhuleni (East Rand), Nelson Mandela bay Municipality (Port Elizabeth), Buffalo City Municipality (East London), eThekwini Municipality (Durban) and Mangaung Municipality (Bloemfontein). Some smaller municipalities (based on their populations) such as Saldanha Bay, Metsimaholo, Stellenbosch, Potchefstroom (also known as Venterdorp/Tlokwe municipality), Langeberg, Theewaterskloof, Cape Agulhas, Drakenstein, Swartland, and Sol Plaatjie also practise CWS. From the research, the practise of CWS by many of these municipalities can be largely attributed to their financial capabilities and investments made in the water sector. It would be very interesting to investigate those municipalities for which no information could be found at the time of this research project. Therefore, enhancing **Figure 4.10** could be the focus of future research in this regard.

While the municipalities coloured in pink are a concern, these are essentially not the focus of this study, as an analysis of the reasons of intermittency suggest temporary IWS. It has to be noted though, that it is likely that the level of temporary IWS in these municipalities are most likely unacceptably high, warranting reporting by its residents. In some instances, there appears to be no horizon on the “temporary intermittency”, because taps ran dry and remain dry for periods varying between one and five months. Therefore, in these instances, the pink could even suggest a complete collapse of the service.

The municipalities coloured in red is where formal IWS is most likely implemented. The number of red municipalities is significant in the overall context of South Africa, and most certainly proves that the data initially reported in this research is not accurate (IBNET). South Africa, as a country, therefore cannot claim 24 hours of supply as being the norm.

4.6.5. Population affected by some form of intermittency

The estimated population that was affected by some form of intermittency in South Africa between 2008 and 2017 is illustrated in **Figure 4.11a**. The information is presented by province. Trend lines were added to demonstrate how the affected population varied during the 10-year period under consideration.

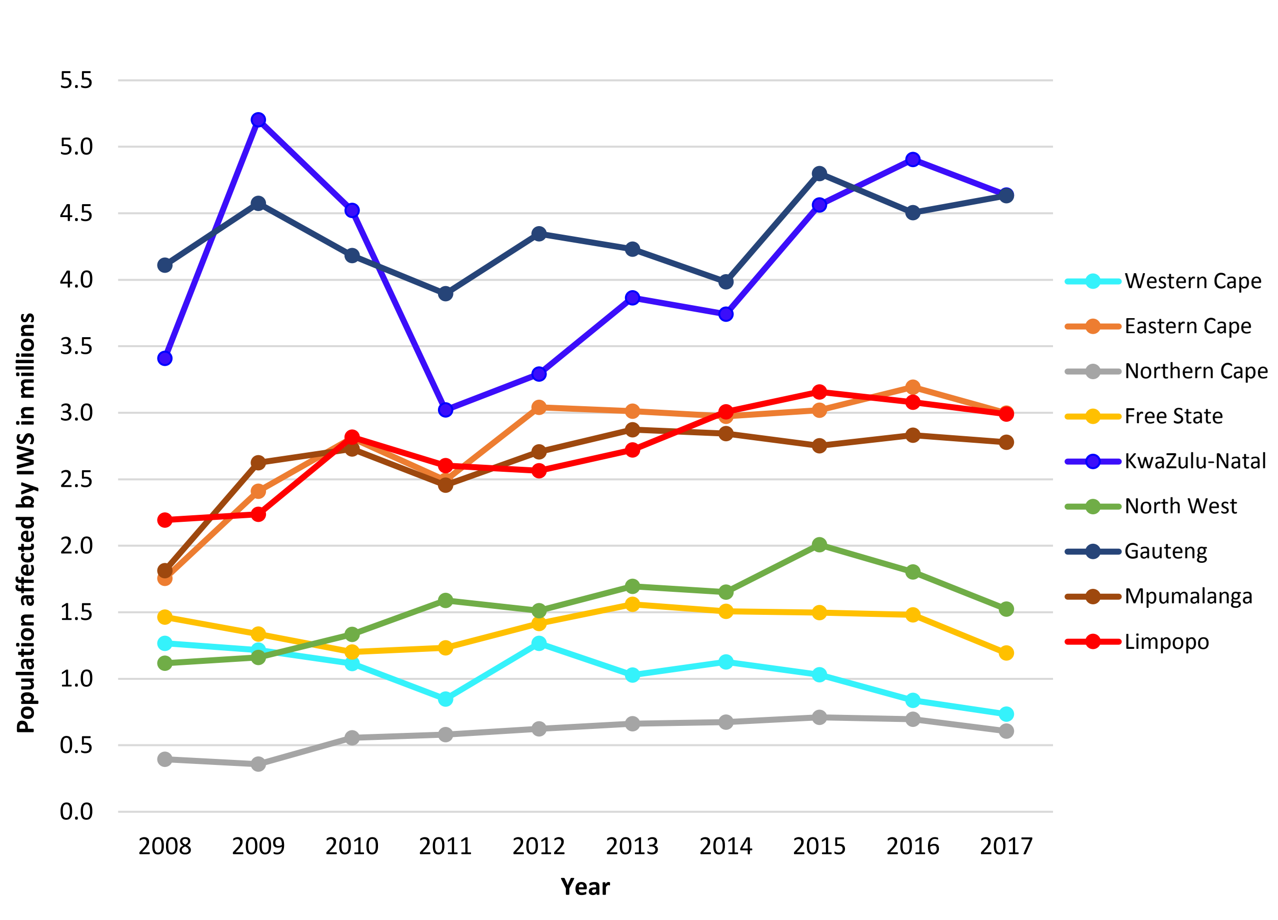

Figure 4.11a: Provincial variations in the population affected by intermittency of supply

The trend lines in **Figure 4.11a** indicate that the provinces with the largest population numbers affected by intermittency in South Africa are Kwazulu-Natal and Gauteng. The variance in the trend lines for KwaZulu-Natal and Gauteng can most likely be attributed to reporting inaccuracies. In order to reduce the impact of these perceived reporting inaccuracies, **Figure 4.11b** was generated from the same data by plotting the three-year moving averages.

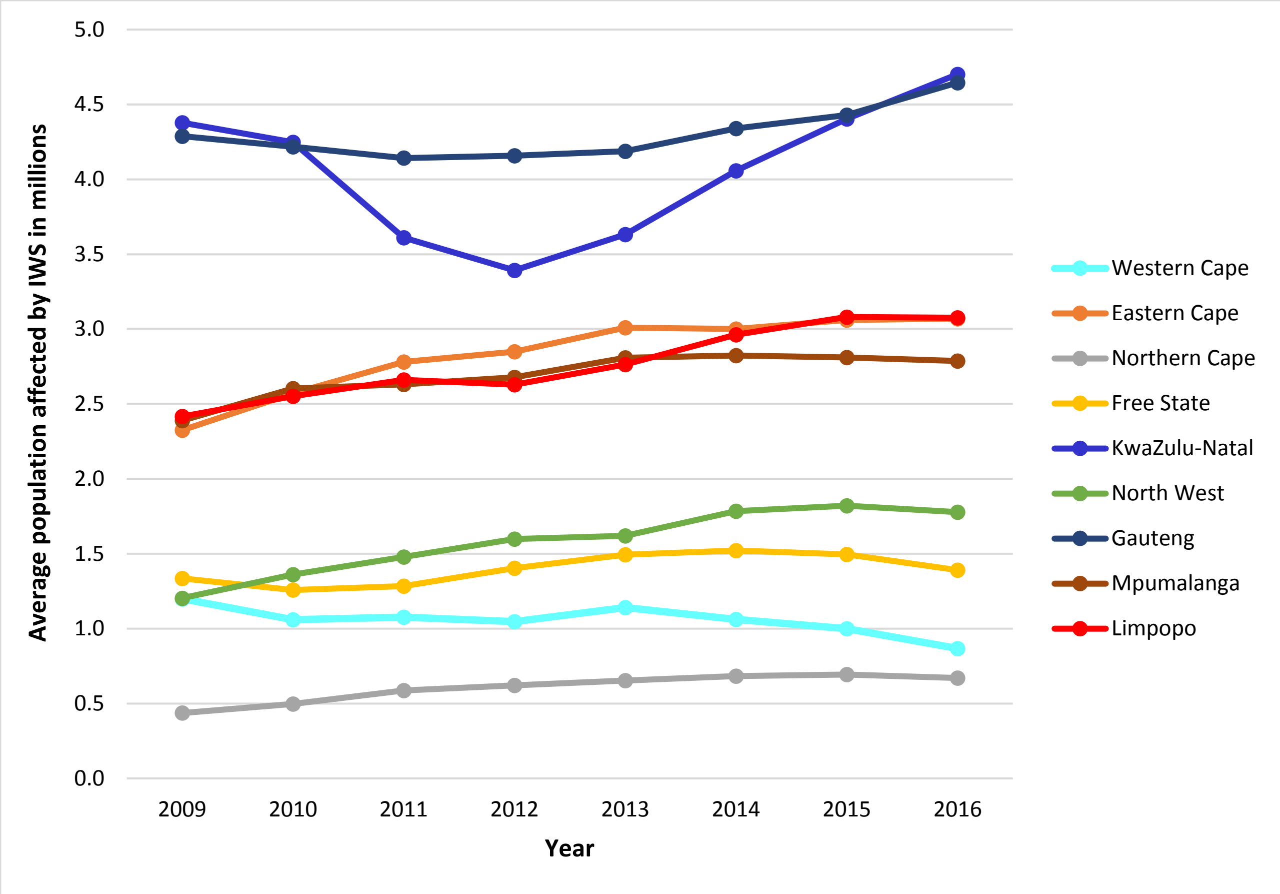

Figure 4.11b: Three-year moving averages of population affected by intermittency in South Africa

Based on **Figure 11b,** the population affected by intermittency in KwaZulu-Natal increased significantly from 2012 to 2016 from 3.4 million to 4.7 million. Another notable province was Gauteng, for which the population affected by intermittency remained above four million for the entire 10-year period. The Eastern Cape and Limpopo Provinces each returned an increase of 28% in the population affected by IWS between 2009 and 2016, while for Mpumalanga Province, the increase was 25%. Although the Northern Cape Province stands out as having the lowest population affected by intermittency, amounting to less than a million, there was an increase of 52% between 2009 and 2016. In the North West Province, the increase was 33%. Significant improvements were seemingly made in the Western Cape, where the population affected by intermittency declined by 38% between 2009 and 2016.

The percentage of the total population affected by intermittency in 2017 by province, is illustrated in **Figure 4.12**.

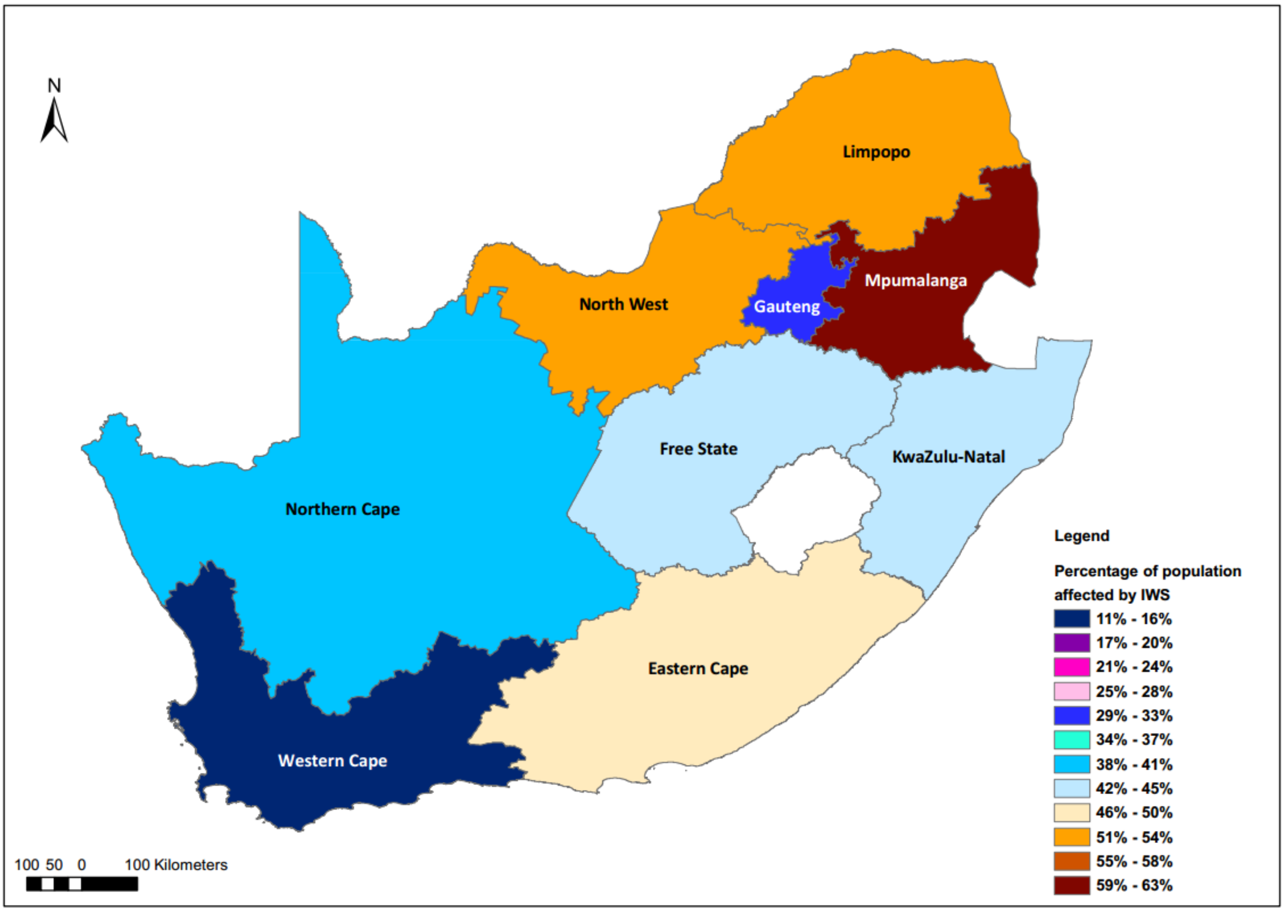

Figure 4.12: Percentage of population experiencing intermittency in 2017

The 2017 percentages of the population affected by intermittency, by province, indicates that Mpumalanga had the highest percentage while the Western Cape had the lowest. In addition, according to this figure, in 2017, only 11.3% of the Western Cape population was affected by intermittency, whereas, in Mpumalanga and Limpopo, the percentages were as high as 62.5% and 51.8% respectively. Refer to **Appendix C** for population affected by intermittency in South Africa.

Figure 4.13 illustrates the population number, by province that was affected by intermittency in 2017.

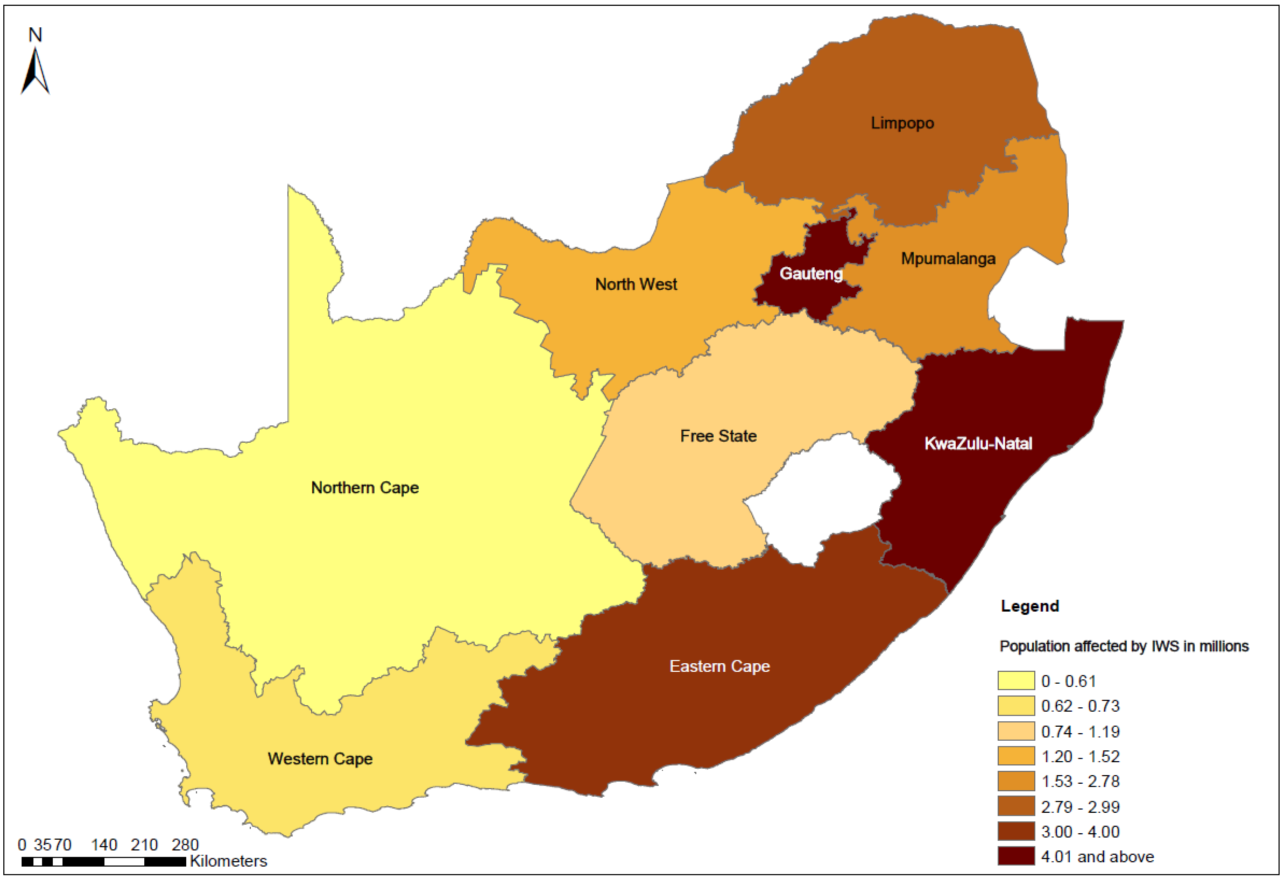

Figure 4.13: Population numbers affected by intermittency per province in 2017

Given the uneven distribution of the population in South Africa by province, it was decided to also plot the population numbers affected by intermittency by province. In **Figure 4.13,** an analysis based on the actual population affected by intermittency revealed that KwaZulu-Natal had the highest population affected of approximately 4.6 million people. Gauteng returned a similar number of 4.6 million people affected by intermittency, followed by the Eastern Cape with 3.0 million. In contrast to the high percentage of the province's population affected by intermittency indicated for Mpumalanga in **Figure 4.12**, a population of only 2.8 million was affected. Overall, these results suggest that representing the population affected by intermittency in terms of the actual population rather than the percentage of the affected population in a location provides a better understanding of the magnitude of IWS. It has to be reiterated that the data on which this research is based, did not distinguish between temporary and permanent intermittency.

Chapter 5
Conclusions and recommendations

5.1. Conclusions

This research set out to investigate the prevalence and trends of IWS in 11 Southern African countries, using historical statistical data covering a period of 10 years (2008 to 2017). The countries that were included are Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland (Eswatini), Tanzania, Zambia and Zimbabwe. Several conclusions can be drawn from this research pertaining to water supply practises in Southern Africa.

The results of this research indicate that there has been an increase in the population with piped water connections in Southern Africa, thus suggesting improved water supply networks on a high level. Similarly, the decrease in the regional connection ratio also points to a high level of improvement in the population with access to piped water connections. The regional average connection ratio presented a significant reduction of 27.8% between 2011 and 2016, reducing from 53.6 to 40.5 people per connection, respectively. The connection ratio for South Africa is by far the best for the entire region, and on average improved from 4.7 to 4.3 between 2012 and 2017.

The daily hours of supply decreased for all countries within the region, apart from South Africa which reports 24 hours of supply (based on analysis of that specific data set obtained from IBNET). The weighted average hours of supply for the region decreased from 21.5 in 2008 to 18.4 in 2017. Similarly, between the years 2008 and 2017, the hours of supply generally presented a decline for some of the countries, a trend which was especially relevant in Tanzania, Mozambique and Lesotho. Both the maps and figures confirm the literature sources which state that once IWS is implemented, the supply duration tends to reduce (Kumpel & Nelson, 2016; Kaminsky & Kumpel, 2018). It would appear therefore, that reverting to CWS becomes increasingly challenging and costly once IWS is implemented, as was claimed by Charalambous (2012).

A potential conclusion from the fact that connection ratios are improving, while supply durations are coming down, is that huge investments are made to address supply inequality, while necessary upgrades to the bulk water infrastructure lags behind. This could also point towards inadequate planning of bulk water infrastructure in the region.

The results also demonstrate that generally, NRW percentage for the region is increasing. The trends demonstrating this increase were particularly evident for Botswana (between 2008 and 2015 which presented an increase from 19.2% to 37.8%. The regional weighted average increased from 36.5% to 41.7%. Although it has been reported by Kaminsky and Kumpel (2018) that there exists no clear correlation between NRW and hours of supply, some of the countries that had NRW of above 40%

in 2017 demonstrated a decrease in the hours of supply during the 10-year period, notably Lesotho, Mozambique and Tanzania.

Summarised reasons provided for IWS in the region, indicated dominance of bursts/failed infrastructure, increased demand and urbanisation, as well as inadequate water resources. It has to be noted that the first is generally linked to temporary IWS, while the second and third reasons are generally linked to permanent IWS. Electricity constraints, theft/vandalism and financial constraints also feature as fairly common reasons. The first reason could again mostly allude to temporary IWS, whereas the last two can probably be linked to permanent IWS.

The extent of IWS in a Southern African country was demonstrated using the case study of South Africa. By considering a different dataset than IBNET, namely Stats SA, a different picture in terms of the hours of supply for South Africa as a whole was created. There were several cases of IWS reported, and the reasons for this reported IWS were analysed. From the analysis of the dataset from Stats SA, it was clear that there were a combination of temporary and permanent IWS reported on, which strictly speaking in terms of the definition of IWS is not correct (based on the literature review, IWS as a formal supply strategy was investigated). By analysing the reasons presented, it was, however, possible to distinguish between temporary and permanent IWS. From a high level, one could argue that the prevalence of permanent IWS can be linked to about 42% of the reported cases, whereas the prevalence of temporary IWS could be linked to about 58% of the reported cases.

It was decided to also access various online sources and news reports, in order to further clarify the discrepancies reported regarding the South African IWS situation. A map was generated showing 54 municipalities in which some form of IWS were reported. Through further analysis of the reports, it was possible to distinguish between temporary and permanent IWS. In this regard, it is important to note that permanent IWS is most likely prevalent in 29 municipal areas.

Similarly, the population affected by some form of intermittency was mapped for South Africa. It was shown that, while the impact of intermittency in the Western Cape Province is fairly low, population numbers totalling 9.2 million were affected by some form of intermittent water supply in Gauteng and KwaZulu-Natal Provinces combined. The estimated total population affected by intermittency in South Africa comes to 22 million, which represents 39.3% of the total population. The IBNET data, which indicate CWS for the whole of South Africa, is therefore clearly incorrect, and the true picture of IWS in South Africa is much more accurately presented by the map in **Figure 4.10**.

5.2. Recommendations for future research

The findings presented in this dissertation give an insight in to the prevalence and extent of IWS in Southern African countries. From the research results, it is obvious that this research could be enhanced, as such, the recommendations for future research in this aspect include the following:

- **Figure 4.10,** which presents the municipalities in South Africa, has a significant number of "no information" data points, which were coloured grey. It would be very interesting if more information could be found for these municipal areas pertaining to water supply practises.

- Based on the municipalities that were identified as practising permanent IWS in **Figure 4.10**, an in-depth study should be done to determine the service level delivery of these municipalities, even if it is conducting a detailed study incorporating one such municipality per province. The study could incorporate the views of the consumers on the levels of service delivery as well as the quality of water received during supply cycles.

- With regard to NRW, it would be interesting to estimate the actual quantities of water losses reflected by the NRW percentages in **Figure 4.5**. This would ascertain whether 'inadequate water resources' is among the main causes of IWS for this region in relation to the structural integrity of the water supply infrastructure.

- Another perspective could be to determine the percentage of a water utility's piped connections that are affected by IWS with focus on the following:
    i. Categories of residential areas the IWS connections service whether low, middle, or high-income areas.
    ii. The supply frequency from the consumers' point of view since water utilities are in most cases unwilling to share this information.
    iii. How long the areas have been serviced through IWS and if there is a difference in the hours of supply based on historical experiences of the consumer.

Lastly, this research will serve as a base for future similar studies for other countries or regions in Africa. Similar research can be used to determine the prevalent causes of IWS in these regions and subsequently aid in planning the appropriate mitigation measures towards the transition from IWS to CWS. It should be noted though, that sending out another or improved research questionnaire, or attempting similar research via questionnaires in this region, to this specific target audience, will probably not yield meaningful results.

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Appendix A

Application letter for institutional permission - English

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APPLICATION LETTER FOR INSTITUTIONAL PERMISSION

INSTITUTION NAME & ADDRESS: ………………………………………………………………..

INSTITUTION CONTACT PERSON: …………………………………………………..

INSTITUTION CONTACT NUMBER: ………………………………………………….

INSTITUTION EMAIL ADDRESS: ………………………………………………………………………

TITLE OF RESEARCH PROJECT: PREVALENCE AND TRENDS OF INTERMITTENT WATER SUPPLY IN SOUTHERN AFRICA

ETHICS APPLICATION REFERENCE NUMBER: ING-2018-7226

RESEARCHER: BUBALA MWIINGA CHIMBANGA

DEPT NAME & ADDRESS: DEPARTMENT OF CIVIL ENGINEERING, BOSMAN STREET, STELLENBOSCH 7600.

CONTACT NUMBER: +27835141698

EMAIL ADDRESS: 21587078@sun.ac.za

Dear…………….

I am a *Master of Engineering (MEng)* student at the Department of Civil Engineering at Stellenbosch University, and I would appreciate your assistance with one facet of my research project.

Please take some time to read the information presented in the following four points, which will explain the purpose of this letter as well as the purpose of my research project, and then feel free to contact me if you require any additional information. This research study has been approved by the Research Ethics Committee (REC) at Stellenbosch University and will be conducted according to accepted and applicable national and international ethical guidelines and principles.

1. **<u>A short introduction to the project:</u>**

Supplying water continuously for 24 hours to consumers within a water supply system, is the intent of water a water utility by both design and operation of water supply infrastructure. Unfortunately, most water utilities over the years have resorted to supplying water intermittently to some consumers connected to their water distribution system. This has resulted in negative impacts to both the consumer and the water utility. A significant amount of research has been done to determine and highlight the impacts intermittent water supply has had on the consumer, water quality and water supply infrastructure. However not much has been done to demonstrate whether this undesirable type of water supply is improving or worsening. This is particularly so from a quantitative and statistical point of view, for water utilities within a defined region. In addition, there *has not been much research on the predominant causes that have kept water utilities in a specified region practicing intermittent water supply. This research will attempt to offer a solution to this knowledge gap, for Southern Africa over a period of 10 years (2008 to 2017); through collecting quantitative data using a questionnaire from various water utilities and analysing it statistically.*

2. The purpose of the project:

The goals of the research are to:

i. *Determine whether there is an improvement in the number of water supply hours, to consumers under intermittent water supply in Southern Africa, between 2008 and 2017.*
ii. *Determine the causes and impacts of intermittent water supply in Southern Africa.*

Based on the goals of this research, the specific objectives of this research are to:

i. *Identify the water countries that practise intermittent water supply.*
ii. *Identify the main factors that lead water utilities to practicing intermittent water supply.*
iii. *Determine the weighted average number of water supply hours for the years starting 2008 to 2017.*
iv. *Establish a trend in the hours of water supply per day for each country during the 10-year period.*
v. *Identify the common impacts that have resulted from intermittent water supply.*
vi. *Estimate the number of consumers affected by intermittent water supply in the region.*

3. Your assistance would be appreciated in the following regard:

I am requesting permission from your institution to send questionnaires to the member of staff in your institution who has overall responsibility for the operation of the water supply system covering both water production and distribution. This employee could be the Engineering or Operations Manager or may go by a different job title in your institution. The questionnaire will request for statistical water production and distribution data for your institution that may be in your institutions' archives and not be readily available on a public domain. This data will greatly contribute towards making the findings of this research more representative for the region. These responses that will be given in the questionnaire will be combined with those from other similar institutions in within the country. It will be analysed statistically to give representative average values for water production and distribution, for the country as a whole.

4. Confidentiality:

The information and responses to this survey will be solely used for academic purposes. The information and data collected during this research will remain confidential. Only researcher and the researchers' Supervisor will have access to the data. The name of the water utility and identifying details will never be revealed in any publication of the results of this research.

If you have any further questions or concerns about the research, please feel free to contact me via email (21587078@sun.ac.za) or telephonically (+27835141698). Alternatively, feel free to contact my supervisor, Mr. Carlo Loubser, via email (carloloubser@sun.ac.za) or telephonically (+27218089724).

Thank you in advance for your assistance in this regard.

Kind regards,

Bubala Mwiinga Chimbanga
Principal Investigator

Application letter for institutional permission - Portuguese

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CARTA DE INSCRIÇÃO PARA PERMISSÃO INSTITUCIONAL

NOME E ENDEREÇO INSTITUCIONAL: ....

PESSOA DE CONTATO DA INSTITUIÇÃO: ....

NÚMERO DE CONTATO DA INSTITUIÇÃO: ....

ENDEREÇO DE EMAIL DA INSTITUIÇÃO: ....

TÍTULO DO PROJETO DE PESQUISA: PREVALÊNCIA E TENDÊNCIAS DO ABASTECIMENTO DE ÁGUA INTERMITENTE NA ÁFRICA AUSTRAL

NÚMERO DE REFERÊNCIA DA APLICAÇÃO DE ÉTICA: ING-201 8 - 7226

INVESTIGADOR: BUBALA MWIINGA CHIMBANGA

NOME E ENDEREÇO DO DEPTO: DEPARTAMENTO DE ENGENHARIA CIVIL, BOSMAN STREET, STELLENBOSCH 7600.

NÚMERO DE CONTATO: +27835141698

ENDEREÇO DE E-MAIL: 21587078@sun.ac.za

Prezado …………….

Por favor, note que eu sou um Mestrado em Engenharia (Meng) estudante no Departamento de Engenharia Civil da Universidade de Stellenbosch, e eu gostaria de sua ajuda com uma faceta do meu projeto de pesquisa.

Por favor, dedique algum tempo para ler as informações apresentadas nos quatro pontos seguintes, que explicarão o propósito desta carta, assim como o propósito do meu projeto de pesquisa, e então sinta-se à vontade para entrar em contato comigo caso necessite de alguma informação adicional. Esta pesquisa foi aprovada pelo Comitê de Ética em Pesquisa (CEP) da Universidade de Stellenbosch e será conduzida de acordo com as diretrizes e princípios éticos nacionais e internacionais aceitos e aplicáveis.

1. **Uma breve introdução ao projeto:**

Fornecer água continuamente por 24 horas aos consumidores dentro de um sistema de abastecimento de água é a intenção da água e da utilidade da água tanto pelo projeto quanto pela operação da infraestrutura de abastecimento de água. Infelizmente, a maioria das empresas de água ao longo dos anos tem recorrido a fornecer água intermitentemente a alguns consumidores conectados ao seu sistema de distribuição de água. Issoresultou em impactos negativos tanto para o consumidor quanto para a concessionária de água. Uma quantidade significativa de pesquisas foi feita para determinar e destacar os impactos que o fornecimento intermitente de água teve sobre a infraestrutura de consumo, qualidade da água e abastecimento de água. No entanto, pouco foi feito para demonstrar se este tipo indesejável de abastecimento de água está melhorando ou piorando. Isto é particularmente verdade, do ponto de vista quantitativo e estatístico, para empresas de serviços de água dentro de uma região definida. Além disso, não tem havido muita pesquisa sobre as causas predominantes que mantiveram as empresas de água em uma região específica praticando o fornecimento de água intermitente. Esta pesquisa tentará oferecer uma solução para *essa lacuna de conhecimento, para a África Austral, por um período de 10 anos (200 8 a 2017); através da recolha de dados quantitativos, utilizando um questionário de várias utilidades e analisando-as estatisticamente.*

2. O objetivo do projeto:

Os objetivos da pesquisa são:

- *i. Determinar se há uma melhoria no número de horas de abastecimento de água, para consumidores sob fornecimento intermitente de água na África Austral, entre 2008 e 2017.*
- *ii. Determinar as causas e os impactos do fornecimento intermitente de água na África Austral.*

Com base nos objetivos desta pesquisa, os objetivos específicos desta pesquisa são:

- *i. Identifique os países da água que praticam o abastecimento de água intermitente.*
- *ii. Identificar os principais factores que levam s ÚTEIS água para praticar o abastecimento de água intermitente.*
- *iii. determinar o peso ponderado número médio de horas de abastecimento de água para os anos que se iniciam em 200 8 para 2017.*
- *iv. Estabelecer uma tendência nas horas de abastecimento de água para cada país durante o período de 10 anos.*
- *v. Identifique os impactos comuns que resultaram do fornecimento intermitente de água.*
- *vi. Estimar o número de consumidores afetados pelo abastecimento intermitente de água na região.*

3. Y assistência r ou seria apreciado da seguinte relação:

Estou solicitando permissão de sua instituição para enviar questionários para o membro do pessoal em sua instituição que ha é a responsabilidade global para o funcionamento do sistema de abastecimento de água que cobre tanto a produção e distribuição de água. Esse funcionário pode ser o Gerente de Engenharia ou Operações ou pode ter um cargo diferente em sua instituição. O questionário solicitará para dados de produção e de distribuição de água estatísticos para sua instituição que podem estar em arquivos de seus instituições e não estar prontamente disponível em um domínio público. Esses dados contribuirão muito para tornar as descobertas desta pesquisa mais representativas para a região. Estas respostas que serão dadas no questionário serão combinadas com as de outras instituições similares dentro do país. Será analisado estatisticamente para fornecer valores médios representativos para a produção e distribuição de água, para o país como um todo.

4. Confidencialidade:

As informações e respostas a esta pesquisa serão usadas exclusivamente para fins acadêmicos. As informações e dados coletados durante esta pesquisa permanecerão confidenciais. Somente o pesquisador e o supervisor dos pesquisadores terão acesso aos dados. O nome da empresa de abastecimento de água e os detalhes de identificação nunca serão revelados em nenhuma publicação dos resultados desta pesquisa.

Se você tiver outras dúvidas ou preocupações sobre a pesquisa, sinta-se à vontade para entrar em contato comigo por e-mail (21587078@sun.ac.za) ou telefonicamente (+27835141698) ou (+260977641643 no WhatsApp). Alternativamente, não hesite em contactar supervisor m y, Sr. Carlo Loubser, via e-mail (carloloubser@sun.ac.za) ou telefonicamente (27218089724).

Agradecemos antecipadamente por sua ajuda a este respeito.

Atenciosamente,

Bubala Mwiinga Chimbanga.
Investigador principal

Consent letter - English

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ELECTRONIC CONSENT TO PARTICIPATE IN RESEARCH

TITLE OF RESEARCH PROJECT:	PREVALENCE AND TRENDS OF INTERMITTENT WATER SUPPLY IN SOUTHERN AFRICA
REFERENCE NUMBER:	ING-2018-7226
PRINCIPAL INVESTIGATOR:	BUBALA MWIINGA CHIMBANGA
ADDRESS:	CIVIL ENGINEERING DEPARTMENT, BOSMAN STREET, STELLENBOSCH 7600, SOUTH AFRICA.
CONTACT NUMBER:	+27835141698
E-MAIL:	21587078@sun.ac.za

Dear Prospective Participant,

Kindly note that I am a MEng student at the Department of Civil Engineering at Stellenbosch University, and I would like to invite you to participate in a research project entitled 'Prevalence and trends of intermittent water supply in Southern Africa'.

Please take some time to read the information presented here, which will explain the details of this project and contact me if you require further explanation or clarification of any aspect of the study. This study has been approved by the Research Ethics Committee (REC) at Stellenbosch University and will be conducted according to accepted and applicable national and international ethical guidelines and principles.

1. **INTRODUCTION:** Intermittent water supply is where the consumers are supplied with water for less than 24 hours in a day and sometimes once in more than 24 hours. Very few studies have been conducted on this subject in Africa, particularly from a quantitative point of view. This study aims to understand the extent of intermittent water supply practises in Southern Africa over a 10-year period (2008 to 2017), using information from 2008 to 2017. The study intends to gather statistical data on water production and distribution during this period, using a pre-designed questionnaire. 252 water utilities in 11 countries within Southern Africa will be included in the sample size. The participating countries will include; Angola, Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland (Eswatini), Tanzania, Zambia and Zimbabwe. The data collected will be analysed statistically and reported as a collective average for the region and the individual countries.
2. **PURPOSE:** The purpose of this study is to investigate the factors leading to intermittent water supply, and the impacts and trends that have resulted thereof. The study intends to establish a trend of intermittent water supply in Southern Africa and be able to determine whether this type of supply has reduced or worsened between 2008 and 2017.
3. **PROCEDURES:** If you volunteer to participate in this study, you will be required to complete a questionnaire that will take about an hour to complete. The questionnaire will be filled out anonymously and thus can be done during the time that best suits the respondent so that it does not interfere with normal tasks and duties. After reading the informed consent letter, should you decide to participate in the research, the questionnaire will be emailed to you complete. Completing the questionnaire will indicate the utility's full participation in the study.

4. **TIME:** The questionnaire will take approximately an hour to complete depending on the availability of data. However, 10 working days will be given for completing to allow for the required data to be gathered and for the participant to respond at a time that best suits them.
5. **RISKS:** There are no anticipated risks or discomforts resulting from one's participation in the study.
6. **BENEFITS:** The knowledge obtained from this study will be of great value in guiding water professionals, managers and researchers, towards a detailed understanding of the extent of intermittent water supply impacts and prevalence in Southern Africa. They will thus use the results to make informed decisions pertaining to water supply within the Southern African region.
7. **CONFIDENTIALITY:** The information and responses to this survey will be solely used for academic purposes. The information and data collected during this research will remain confidential. Only researcher and the researchers' Supervisor will have access to the data and know the responses given in the questionnaire. The name of the water utility and identifying details will never be revealed in any publication of the results of this research.
8. **CONDITION OF PARTICIPATION**

   Your involvement in the study is to give responses by completing the questionnaire. Your participation in this research project is completely voluntary, refusal to participate will involve no penalty. You are free to withdraw your consent or discontinue participation at any time without prejudice or penalty. You are also free to refuse to answer any question you may not be comfortable with.
9. **RECORDINGS:** No voice recordings will be made or used in the research.
10. **DATA STORAGE:** The information will be saved in a folder on a password protected laptop. Printed copies will be kept in a lockable drawer, in the researcher's office which has restricted entry. The name of the utility and identifying details will never be revealed in any publication containing the results of this research. The printed copies of information will be destroyed by shredding; while the softcopies will be deleted from both the desktop and the recycle bin. The information will only be destroyed after the researcher has completed the examination process for her studies in 2019.

If you have any questions or concerns about this research project, please feel free to contact the principal investigator Ms. Bubala Mwiinga Chimbanga on +27835141698 for voice calls and SMS and +260977641643 for WhatsApp calls if your water utility is outside South Africa, and email me on 21587078@sun.ac.za . You can also contact my supervisor Mr. Carlo Loubser on +27218089724 and email carloloubser@sun.ac.za .

RIGHTS OF RESEARCH PARTICPANTS: You may withdraw your consent at any time and discontinue participation without penalty. You are not waiving any legal claims, rights or remedies because of your participation in this research study. If you have questions regarding your rights as a research subject, contact Ms. Maléne Fouché (mfouche@sun.ac.za / 021 808 4622) at the Division for Research Development. You have the right to receive a copy of this Consent form.

If you are willing to participate in this research project, please select the relevant box in the Declaration of Consent below and email the form to the principal investigator via the email address given at the table at beginning of this letter.

DECLARATION BY THE PARTICIPANT

As the **participant** I hereby declare that:

- I have read the above information and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is voluntary and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- If the principal investigator feels that it is in my best interest, or if I do not follow the study plan as agreed to, then I may be asked to leave the study before it has finished.
- All issues related to privacy, and the confidentiality and use of the information I provide, have been explained to my satisfaction.

As the **participant** I hereby select the following option:

	I accept the invitation to participate in your research project, and if I decide to be interviewed it would automatically mean that I have given consent for my responses to be used confidentially and anonymously.
	I accept the invitation to participate in your research project, and if I decide to complete the questionnaire it would automatically mean that I have given consent for my responses to be used confidentially and anonymously.
	I decline the invitation to participate in your research project.

DECLARATION BY THE PRINCIPAL INVESTIGATOR

As the **principal investigator** I hereby declare that the information contained in this document has been thoroughly explained to the participant. I also declare that the participant has been encouraged (and has been given ample time) to ask any questions. In addition, I would like to select the following option:

	The conversation with the participant was conducted in a language in which the participant is fluent.
	The conversation with the participant was conducted with the assistance of a translator, and this "Consent Form" is available to the participant in a language in which the participant is fluent.

______________________________ ____________________

Signed at *(place)* **Date**

____

Signature of Principal Investigator

Consent letter - Portuguese

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STELLENBOSCH UNIVERSIDADE
CONSENTIMENTO ELETRÔNICO PARA PARTICIPAR DA PESQUISA

TÍTULO DO PROJETO DE PESQUISA:	PREVALÊNCIA E TENDÊNCIAS DO ABASTECIMENTO DE ÁGUA INTERMITENTE NA ÁFRICA AUSTRAL
NÚMERO DE REFERÊNCIA:	ING-2018-7226
INVESTIGADOR PRINCIPAL:	BUBALA MWIINGA CHIMBANGA
ENDEREÇO:	DEPARTAMENTO DE ENGENHARIA CIVIL, BOSMAN STREET, STELLENBOSCH 7600, ÁFRICA DO SUL.
NÚMERO DE CONTATO:	+27835141698
E - mail:	21587078@sun.ac.za

caro Participante em potencial,

Por favor, note que eu sou um MEng estudante no Departamento de Engenharia Civil da Universidade de Stellenbosch, e eu gostaria de convidá-lo a participar de um projeto de pesquisa intitulado ' Revalorização e tendências do fornecimento intermitente de água na África Austral '.

Por favor, reserve algum tempo para ler as informações aqui apresentadas, as quais explicarão os detalhes deste projeto e entrarão em contato se você precisar de mais explicações ou esclarecimentos sobre qualquer aspecto do estudo. Este estudo foi aprovado pelo Comitê de Ética em Pesquisa (CEP) da Universidade de Stellenbosch e será conduzido de acordo com as diretrizes e princípios éticos nacionais e internacionais aceitos e aplicáveis.

1. **INTRODUÇÃO:** O fornecimento intermitente de água é onde os consumidores são abastecidos com água por menos de 24 horas em um dia e às vezes uma vez em mais de 24 horas. hora s. Muito poucos estudos foram realizados sobre este assunto em África, particularmente de um ponto de vista quantitativo. Este estudo tem como objetivo compreender a extensão das práticas intermitentes de abastecimento de água na África Austral ao longo de um período de 10 anos (2008 a 2017), utilizando informações do período de 8 a 20 de 2017. O estudo pretende recolher dados estatísticos sobre a produção e distribuição de água durante este período, usando um questionário pré-projetado. 297 utilit água i es em 11 países da África Austral será incluído no tamanho da amostra. Os países participantes incluirão; Angola, Botsuana, Lesoto, Malawi, Moçambique, Namíbia, África do Sul, Suazilândia, Tanzânia, Zâmbia e Zimbabué. Os dados coletados serão analisados estatisticamente e reportados como uma média coletiva para a região e os países individuais.
2. **OBJETIVO:** O objetivo deste estudo é investigar os fatores que levam ao i ntermittent abastecimento de água e os impactos e tendências que resultaram dos mesmos. O estudo pretende estabelecer uma tendência de fornecimento intermitente de água na África Austral e ser capaz de determinar se este tipo de oferta diminuiu ou piorou entre 2008 e 2017.
3. **PROCEDIMENTOS:** Se você se voluntariar para participar deste estudo, será necessário preencher um questionário que levará cerca de uma hora para ser concluído. O questionário será preenchido anonimamente e, portanto, poderá ser feito durante o tempo que melhor se adequar ao entrevistado,

para que ele não interfira nas tarefas e deveres normais. Depois de ler a carta de consentimento informado, caso decida participar da pesquisa, o questionário será enviado por e-mail para você. A conclusão do questionário indicará a participação total da empresa no estudo.

4. **TIME:** O questionário levará aproximadamente uma hora para ser concluído, dependendo da disponibilidade de dados. No entanto, 10 dias úteis serão dados para preenchimento, permitindo que os dados necessários sejam coletados e que o participante responda no momento que melhor lhes convier.
5. **RISCOS:** Não existem riscos previsíveis ou desconfortos decorrentes da sua participação no estudo.
6. **BENEFÍCIOS:** O conhecimento obtido a partir deste estudo será de grande valia para orientar os profissionais, gestores e pesquisadores da água, no sentido de uma compreensão detalhada da extensão dos impactos e da prevalência do abastecimento de água intermitente na África Austral. Eles usarão os resultados para tomar decisões informadas relativas ao abastecimento de água na região da África Austral.
7. **CONFIDENCIALIDADE:** A informação e resposta s para th é pesquisa serão utilizados exclusivamente para fins acadêmicos. As informações e dados coletados durante esta pesquisa permanecerão confidenciais. Only pesquisador e Supervisor dos pesquisadores terão acesso aos dados e saber as respostas dadas no questionário. O nome da empresa de abastecimento de água e os detalhes de identificação nunca serão revelados em nenhuma publicação dos resultados desta pesquisa.
8. **CONDIÇÃO DE PARTICIPAÇÃO:** Seu envolvimento no estudo é dar respostas preenchendo o questionário. Sua participação neste projeto de pesquisa é completamente voluntária, a recusa em participar não envolverá penalidade. Você é livre para retirar seu consentimento ou interromper a participação a qualquer momento, sem prejuízo ou penalidade. Você também é livre para recusar-se a responder a qualquer pergunta com a qual você não esteja confortável.
9. **GRAVAÇÕES:** Nenhuma gravação de voz será feita ou usada na pesquisa.
10. **ARMAZENAMENTO DE DADOS:** As informações serão salvas em uma pasta em um laptop protegido por senha. As cópias impressas serão mantidas em uma gaveta com fechadura, no escritório do pesquisador, que restringiu a entrada. O nome da utilidade e os detalhes de identificação nunca serão revelados em nenhuma publicação que contenha os resultados desta pesquisa. As cópias impressas da informação serão destruídas pela destruição; enquanto as softcopies serão excluídas da área de trabalho e da lixeira. As informações só serão destruídas depois que o pesquisador concluir o processo de exame de seus estudos em 2019.

Se você tiver dúvidas ou preocupações sobre th é projeto de pesquisa, por favor não hesite em contactar o investigador principal Ms. Bubala Mwiinga Chimbanga em +27835141698 para chamadas de voz e SMS e +260977641643 para WhatsApp chamadas se o u tilidade água é fora da África do Sul, e me enviar e-mail em 21587078@sun.ac.za. Você também pode entrar em contato com meu supervisor, Sr. Carlo Loubser, pelo telefone +27218089724 e enviar um e-mail para carloloubser@sun.ac.za.

DIREITOS DOS PARTICIPANTES DE PESQUISA: Você pode retirar seu consentimento a qualquer momento e interromper a participação sem penalidade. Você não está renunciando a quaisquer reivindicações legais, direitos ou recursos devido à sua participação neste estudo de pesquisa. Se você tiver dúvidas sobre seus direitos como sujeito de pesquisa, entre em contato Ms Maléne Fouché (mfouche@sun.ac.za / 021 808 4622) na Divisão de Desenvolvimento de Pesquisa. Você tem o direito de receber uma cópia do th é formulário de consentimento.

Se você estiver disposto a participar deste projeto de pesquisa, por favor, selecione a caixa relevante na Declaração de Consentimento abaixo e envie o formulário por e-mail para o pesquisador principal, por meio do endereço de e-mail fornecido na tabela no início desta carta.

DECLARAÇÃO DO PARTICIPANTE

Como **p articipante**, declaro que:

- Li as informações acima e está escrito em um idioma com o qual sou fluente e confortável.
- Eu tive a chance de fazer perguntas e todas as minhas perguntas foram respondidas adequadamente.
  Entendo que participar deste estudo é voluntário e não fui pressionado a participar.
- Eu posso optar por deixar o estudo a qualquer momento e não será penalizado ou prejudicado de qualquer forma.
- Se o investigador principal achar que é do meu interesse, ou se eu não seguir o plano de estudo acordado, poderei ser convidado a deixar o estudo antes de terminar.
- Todas as questões relacionadas com a privacidade ea confidencialidade e uso da informação que eu forneço, foram explicados para minha satisfação.

Como o **participante** Venho por este meio selecione a seguinte opção:

	eu aceito o convite para participar de seu projeto de pesquisa, e se eu decidir ser entrevistado seria automaticamente significa que eu tenho dar n consentimento para minhas respostas para ser usado de forma confidencial e anónima.
	Aceito o convite para participar de seu projeto de pesquisa, e se eu decidir complet e a questionário seriaautomaticamente significa que eu tenho dar o seu consentimento n para as minhas respostas para ser usado de forma confidencial e anónima.
	Eu recuso o convite para participar do seu projeto de pesquisa

DECLARAÇÃO DO PRINCIPAL INVESTIGADOR

Como **investigador principal** eu Declaro que as informações contidas neste documento foi cuidadosamente explicado ao participante. Eu também declaro que o participante foi encorajado (E ha s sido dada tempo suficiente) para fazer qualquer pergunta. Além disso, gostaria de selecionar a seguinte opção:

	o A conversa com o participante foi conduzida em um idioma no qual o participante é fluente.
	A conversa com o participante foi realizado com a ajuda de um tradutor, e th é “Formulário de Consentimento” está disponível para o participante em um idioma no qual o participante é fluente.

________________________________ ____________________

Assinado em *(local)* **Encontro**

____

Assinatura do investigador principal

English questionnaire

QUESTIONNAIRE ON WATER SUPPLY PRACTISES IN SOUTHERN AFRICA

INSTRUCTIONS

This questionnaire is divided into three sections;

i. Section one is for the background information about the company and the participant. To complete this section, insert a tick (**√**) or a cross (**X**) in the appropriate box(es). Double click on the box next to the intended response, then right click and select the edit text option and type in the **X** or **√**.
ii. Section two asks for specific information on water production and supply practises for a period of 10 years - from 2008 to 2017. To complete this section, put the curser in the box under each year and type in the response.
iii. Section three is descriptive and seeks additional information based on the participants' opinion.
iv. Return the completed questionnaire by sending it to the email address provided at the end.

SECTION 1: GENERAL INFORMATION

1. What is the name of the Municipality/Water Utility Company/Water Board (**Delete what is not applicable**) ………..
2. What is the name of the country the water utility is located?..
3. What is the rank of your job position?
   - Top management ☐
   - Middle management ☐
   - Supervisory ☐
   - Other, please specify…………………………………………………………….
4. What is your highest level of education?
   - Master's degree ☐
   - Bachelor's degree ☐
   - Diploma ☐
   - Certificate ☐
   - Other, please specify……………………………………………………………
5. How many years have you worked in the water utility?
   - Less than 2 years ☐
   - Over 2 to 5 years ☐
   - Over 5 to 8 years ☐
   - If more than 8 years, please specify…………………………………………….
6. What is the source of water for distribution excluding bulk water supplied by through a contracted company?
   - Ground water abstraction ☐
   - Surface water abstraction ☐
   - Storage tanks/ reservoir ☐

SECTION 2: ANNUAL DATA FOR 2008 TO 2017

7. What was the average water production in Mega litres per day?

YEAR	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPONSE										

8. What was the estimated percentage of water losses in the distribution system?

YEAR	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPONSE										

9. What was the main contributing factor towards the total water losses in question eight above? (**Type in the letter(s) of the supposed reason(s) in the box under each year**)

   A. Leakages in the piping system

   B. Pipe bursts

   C. Vandalism of the infrastructure

   D. Illegal connections

   E. Other, please specify

   ……

   ……

YEAR	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPONSE										

10. On average, how many major pipe bursts leading to a disruption in water supply were recorded in each year?

YEAR	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
RESPONSE										

11. What was the estimated number of piped water connections serviced by the utility?

YEAR	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
RESPONSE										

12. Of the total connections in question 11, what percentage were in rural areas?

YEAR	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
RESPONSE										

13. What percentage of the total connections in question 11, were affected by intermittent water supply?

YEAR	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
RESPONSE										

14. For the areas where water was supplied intermittently; on average, how many domestic consumers (people) received water from a single connection?

YEAR	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
RESPONSE										

15. With reference to question 14, what was the estimated population in the utility's supply network affected by intermittent water supply?

YEAR	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPONSE										

16. What was the average hours of supply per day in the intermittent water supply areas?

YEAR	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPONSE										

17. Best describe the supply cycle in practise for intermittent water supply with which the consumers received water. (**Type in the letter(s) of the supposed reason(s) in the box under each year**)

A. Three times a day

B. Two times a day

C. Once a day

D. Once in two days

E. Twice a week

F. Once a week

G. Once in ………. days (Specify)

H. Other, please specify

……

……

YEAR	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPONSE										

18. What type of intermittent water supply cycle was mostly practised in each year? (**Type in the letter(s) of the supposed reason(s) in the box under each year**)

    A. Regular or predictable schedule

    B. Irregular schedule

    C. Unreliable schedule

YEAR	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPONSE										

19. What were the main reasons for supplying water intermittently? (**Type in the letter(s) of the supposed reason(s) in the box under each year**)

    A. Inadequate raw water resources

    B. Lack of production capacity

    C. High losses due to poor performance and state of the infrastructure

    D. Lack of reliable source of electricity for water pumping and treatment processes

    E. Lack of adequate reservoir storage capacity

    F. Other, please specify;

    ……

    ……

YEAR	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPONSE										

SECTION 3: ADDITIONAL INFROMATION

20. What potential consequences have been experienced in the water distribution system consumers because of supplying water intermittently? (**Please select all that apply**)

    Water quality issues ☐
    Increased maintenance and operating costs ☐
    Increased number of illegal connections ☐
    Increased degradation of infrastructure ☐
    Increased water losses ☐
    Wastage of water ☐
    Preservation of water resources ☐
    Other, please specify in the spaces given below:

    ……
    ……
    ……
    ……
    ……
    ……..

21. If there are any other water supply factors or concerns that you think may be of value to this research, please comment here:

    ……..
    ……..……..
    ………
    ………
    ………
    ………
    ………

You have reached the end of the questionnaire. Thank you for making the time to complete this Questionnaire. Your contribution towards this research is valued and appreciated.

Kindly save the completed questionnaire as a PDF document by the name of the municipality for example 'Zululand District Municipality' or Stellenbosch Local Municipality. You can then email the document as an attachment to the researcher via 21587078@sun.ac.za

Portuguese questionnaire

QUESTIONÁRIO SOBRE PRÁTICAS DE ABASTECIMENTO DE ÁGUA NA ÁFRICA AUSTRAL

I NSTRUÇÕES

Th é questionário está dividido em três seções;

i. A seção um é para as informações básicas sobre a empresa e o participante. Para completar esta seção, insira um carrapato (√) ou uma cruz (**X**) na (s) caixa (s) apropriada (s). Clique duas vezes na caixa ao lado da resposta pretendida, clique com o botão direito do mouse e selecione a opção editar texto e digite **X** ou **√**.
ii. Secção dois perguntar s para obter informações específicas sobre as práticas de produção e abastecimento de água por um período de 10 anos - 2008-2017. Para completar esta seção, coloque o cursor na caixa abaixo de cada ano e digite a resposta.
iii. A seção três é descritiva e busca informações adicionais com base na opinião dos participantes.
iv. Voltar t ele completou questionário enviando-o para o endereço fornecido no final.

SECÇÃO 1: INFORMAÇÃO GERAL

1. Qual é o nome do Município / Empresa de Abastecimento de Água / Câmara de Água (Suprimir o que não é aplicável)…….
……
2. Qual é o nome do país onde a concessionária de água está localizada?
....

3. Qual é a classificação do seu cargo?
   - Gestão de topo ☐
   - Gestão intermédia ☐
   - Supervisão ☐
   - Outro, por favor especifique ……………………………………………………………

4. Qual é o seu nível mais alto de educação?
   - Mestrado ☐
   - Diploma de bacharel ☐
   - Diploma ☐
   - Certificado ☐
   - Outro (por favor, especifique……………………………………………………………
5. Quantas y ouvido s você trabalhou no utilitário de água?
   - Menos de 2 anos ☐
   - Mais de 2 a 5 anos ☐
   - Mais de 5 a 8 anos ☐
   - Se mais de 8 anos, por favor especifique …………………………………………

6. Qual é o F onte de água para distribuição excluindo b água ulk fornecido por meio de uma empresa contratada?

   Abstração de águas subterrâneas ☐

   Abstração de água superficial ☐

   Tanques de armazenamento / reservatório ☐

SECÇÃO 2: Dados anuais de 2008 a 2017

7. Qual foi a produção média de água em Mega litros por dia?

ANO	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
RESPOSTA										

8. Qual foi a porcentagem estimada de perdas de água no sistema de distribuição?

ANO	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
RESPOSTA										

9. Qual foi o principal fator que contribuiu para as perdas totais de água na questão oito acima? (Escreva na (s) letra (s) do (s) motivo (s) suposto (s) na caixa em cada ano)

F. Vazamentos no sistema de tubulação

G. Rajadas de tubos

H. Vandalismo da infra-estrutura

I. Conexões ilegais

J. Outro (por favor, especifique

....

....

ANO	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
RESPOSTA										

10. Em média, quantos furos principais de tubos levando a uma interrupção no abastecimento de água foram registrados em cada ano?

ANO	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPOSTA										

11. Qual foi o número estimado de conexões de água encanada atendidas pela concessionária?

ANO	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPOSTA										

12. Do total de conexões na questão 11, que porcentagem havia nas áreas rurais?

ANO	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPOSTA										

13. Que percentagem da total de conexões na questão 11, foram afetados pelo abastecimento de água intermitente?

ANO	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPOSTA										

14. Para as áreas onde a água foi fornecida intermitentemente; em média, quantos consumidores domésticos (pessoas) receberam água de uma única conexão?

ANO	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPOSTA										

15. Com referência à questão 1 4, qual foi a população estimada na rede de abastecimento da concessionária afetada pelo abastecimento intermitente de água?

ANO	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPOSTA										

16. Qual foi a média de horas de fornecimento por dia nas áreas de abastecimento intermitente de água?

ANO	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPOSTA										

17. Melhor descrever na prática o ciclo de fornecimento de água intermitente com o qual os consumidores recebiam água? (**Escreva na (s) letra (s) do (s) motivo (s) suposto (s) na caixa em cada ano**)

    I. Três vezes ao dia

    J. Duas vezes por dia

    K. Uma vez por dia

    L. Uma vez em dois dias

    M. Duas vezes por semana

    N. Uma vez por semana

    O. Uma vez em ………. dias (especifique)

    P. Outro por favor, especifique ……….....

    ………

ANO	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPOSTA										

18. Que tipo de ciclo intermitente de abastecimento de água foi praticado principalmente em 2017? (**Escreva na (s) letra (s) do (s) motivo (s) suposto (s) na caixa em cada ano**)

    B. Horário regular ou previsível

    C. Cronograma irregular

    D. Agenda não confiável

ANO	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPOSTA										

19. Quais foram as principais razões para fornecer água intermitentemente? **Digite a (s) letra (s) do (s) motivo (s) suposto (s) na caixa abaixo de cada ano**)

    G. Recursos hídricos inadequados

    H. Falta de capacidade de produção

    I. Perdas elevadas devido ao baixo desempenho e estado da infraestrutura

    J. Falta de fonte confiável de eletricidade para processos de bombeamento e tratamento de água

    K. Falta de capacidade adequada de armazenamento de reservatórios

    L. Outro (por favor, especifique

    ………

    ………

ANO	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
RESPOSTA										

SECÇÃO 3: INFRAÇÃO ADICIONAL

20. Quais possíveis conseqüências tem sido experiente nos consumidores do sistema de distribuição de água devido ao fornecimento de água de forma intermitente? (**Por favor, selecione todos que se aplicam**)

    Questões W qualidade ater ☐
    Maior manutenção e custos operacionais ☐
    Maior número de conexões ilegais ☐
    Maior degradação da infraestrutura ☐
    Perdas de água aumentadas ☐
    Desperdício de água ☐
    Preservação de recursos hídricos ☐
    Outro, especifique nos espaços abaixo:
    ………
    ………
    ………
    ………
    ………
    ………..

21. Se houver quaisquer outros fatores de abastecimento de água ou preocupações que você acha que pode ser de valor para esta pesquisa, por favor, comente aqui:

…….
…….
…….
…….
…….
…….
…….

Você chegou ao final do questionário. Obrigado por reservar um tempo para preencher este Questionário. Seu towar contribuição ds desta pesquisa é valu ed e aprovação do CE iated.

Por favor, guarde o questionário preenchido como um documento em PDF com o nome do município, por exemplo, 'Município do Distrito de Zululand' ou Município Local de Stellenbosch. Você pode então enviar um e - mail documento como anexo ao pesquisador via 21587078@sun.ac.za.

Appendix B

Challenges faced by water utilities in Southern Arica

Table B1: Challenges faced by the water utility in Botswana (Sources: Water Utilities Corporation, 2015, 2016)

CHALLENGE	YEAR									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Drought									✓	
Inadequate water resources									✓	
Faulty equipment								✓	✓	
Aged infrastructure								✓		
Breakdown of equipment								✓		
Vandalism to infrastructure								✓		
Load shedding									✓	
Theft of diesel from boreholes								✓	✓	

Table B2: Challenges faced by the water utility in Swaziland (Eswatini) (Sources: SWASCO, 2013, 2014, 2015, 2016)

CHALLENGE	YEAR									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Inadequate water resources								✓		
Aged infrastructure						✓		✓		
Inadequate infrastructure (dams)						✓		✓		
Breakdown of equipment						✓				
Inadequate pressure/high water loss										
Financial constraints						✓		✓		
Increased production costs							✓		✓	
Proliferation of boreholes in utility area									✓	

Table B3: Challenges faced by the water utility in Lesotho (Sources: WASCO, 2010, 2011, 2013, 2014, 2015)

CHALLENGE	YEAR									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Urbanisation						✓	✓			
Floods				✓						
Drought						✓				
Increased demand						✓	✓	✓		
Inadequate water resources							✓			
Aged infrastructure			✓			✓		✓		
Inadequate infrastructure							✓			
Damaged infrastructure				✓						
High turnover of skilled labour							✓			
Construction works			✓							
To reduce NRW			✓							

Table B4: Challenges faced by water utilities in Mozambique (Sources: ESAWAS, 2015)

CHALLENGE	YEAR									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Limited capacity of Infrastructure						✓				

Table B5: Challenges faced by the water utility in Namibia (Sources: NamWater, 2017)

CHALLENGE	YEAR									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Drought									✓	
Inadequate water resources									✓	
High turnover of skilled labour									✓	
Increased production costs									✓	

Table B3: Challenges faced by water utilities Tanzania (Sources: EWURA, 2013, 2014, 2016)

CHALLENGE	YEAR									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Increased demand									✓	
Inadequate water resources							✓			
Aged infrastructure						✓				
Breakdown of equipment									✓	
Equipment Breakdowns						✓				
Load shedding						✓				
Construction works							✓			

Table B7: Challenges faced by water utilities in Zambia (Sources: NWASCO 2013, 2014, 2015, 2016, 2017)

CHALLENGE	YEAR									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Inadequate water resources						✓		✓		✓
Faulty equipment						✓				
Breakdown of equipment						✓				
Load shedding						✓		✓		✓
Construction works						✓				
Polluted water source (Copperbelt)						✓				
Failed infrastructure (Dam in Kalomo)						✓				

Appendix C

Table 4: Southern Africa hours of supply (Source: http://www.ib-net.org; NWASCO 2013, 2014, 2015, 2016, 2017; van den Berg & Danilenko, 2010; Danilenko, van der Berg, Macheve & Moffitt, 2014; Water, 2016).

Country	Year									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Angola										
Botswana	24	24	24	24	24	24	24	24		
Lesotho	24	24	24	24	24	18	18	18	18	18
Malawi	19,96	21,34	20,22	20,51	20,08	20,85	21,93			
Mozambique		21,33	20	20,4	20,2	20,63	19,33		13	10
Namibia	24	24								
South Africa	24	24	24	24	24	24	24	24	24	24
Swaziland (Eswatini)	24	24								

Table C2: Population affected by IWS in South Africa (Source: "SuperWEB2(tm) - Table View", 2019)

Province	Population affected by IWS									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Western Cape	1 266 996	1 217 033	1 114 278	846 738	1 266 871	1 028 155	1 127 086	1 030 225	838 585	733 891
Eastern Cape	1 754 949	2 410 141	2 809 935	2 493 169	3 040 075	3 012 603	2 973 012	3 018 426	3 193 234	2 998 315
Northern Cape	394 954	357 709	556 452	579 321	622 740	662 496	674 836	710 058	694 740	607 596
Free State	1 463 997	1 337 054	1 202 595	1 233 781	1 416 342	1 559 699	1 506 344	1 498 689	1 481 145	1 193 496
KwaZulu-Natal	3 409 790	5 202 491	4 521 154	3 020 931	3 291 481	3 865 162	3 741 813	4 562 329	4 904 909	4 636 933
North West	1 116 825	1 160 024	1 334 034	1 588 491	1 512 317	1 694 035	1 651 206	2 007 735	1 803 963	1 523 773
Gauteng	4 109 434	4 574 994	4 183 617	3 894 951	4 346 965	4 229 503	3 986 162	4 800 037	4 505 101	4 631 615
Mpumalanga	1 812 868	2 625 685	2 728 510	2 457 186	2 706 262	2 873 476	2 844 859	2 752 714	2 832 665	2 778 441
Limpopo	2 193 972	2 237 521	2 817 849	2 603 557	2 564 621	2 721 403	3 007 174	3 157 365	3 078 590	2 991 393
Total	**17 523 786**	**21 122 651**	**21 268 424**	**18 718 122**	**20 767 673**	**21 646 532**	**21 512 491**	**23 537 578**	**23 332 931**	**22 095 452**

Table 5: South Africa provincial population demographics (Source: "SuperWEB2(tm) - Table View", 2019)

Province	Provincial population distribution									
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Western Cape	5 466 023	5 573 372	5 651 393	5 775 833	5 874 318	6 016 926	6 112 340	6 242 159	6 374 411	6 510 394
Eastern Cape	6 460 410	6 490 692	6 521 475	6 552 978	6 563 333	6 620 137	6 480 615	6 485 892	6 492 418	6 499 180
Northern Cape	1 114 308	1 123 975	1 133 581	1 143 254	1 152 145	1 162 914	1 169 777	1 183 995	1 198 723	1 213 998
Free State	2 734 529	2 737 389	2 739 727	2 742 490	2 741 155	2 753 142	2 801 676	2 822 060	2 843 693	2 866 704
KwaZulu-Natal	9 918 332	10 022 666	10 086 782	10 229 656	10 308 398	1 045 6907	10 676 928	10 812 423	10 940 668	1 1074 546
North West	3 355 324	3 401 318	3 447 258	3 496 855	3 542 407	35 97 589	3 663 481	3 725 620	3 789 697	3 856 169
Gauteng	11 445 709	11 693 933	11 937 646	12 200 238	12 457 377	12 728 438	13 203 215	13 548 620	13 906 335	14 278 351
Mpumalanga	3 865 501	3 917 408	3 969 319	4 022 088	4 071 343	4 127 970	4 217 873	4 291 313	4 366 765	4 444 073
Limpopo	5 201 121	5 262 244	5 316 059	5 384 355	5 433 547	5 517 968	5 572 642	5 638 409	5 707 230	5 778 533
Total	49 561 256	50 222 996	50 803 241	51 547 747	52 144 023	52 981 991	53 898 546	54 750 491	55 619 940	56 521 948

Connection ratios

Table C4: Connection ratios for Southern Africa

Country	Year								
	2008	2009	2010	2011	2012	2013	2014	2015	2016
Botswana	24.3			9.2	7.0	6.5	6.1		
Lesotho						27.0	25.2	24.0	23.1
Namibia								76.1	68.8
South Africa				4.8	4.7	4.6	4.6	4.5	4.3
Swaziland (Eswatini)	32.3	31.4	32.6	31.5	30.8	29.7	28.4	26.6	25.3
Tanzania			114.6	109.7	106.4	102.4	98.8	93.3	76.9
Zambia					43.8	42.8	41.6	40.6	40.1
Southern Africa	**27.3**	**31.4**	**112.5**	**53.6**	**51.4**	**49.5**	**48.1**	**47.3**	**40.5**

Table C5: Connection ratios for South Africa

Province	Year					
	2012	2013	2014	2015	2016	2017
Western Cape	5.2	5.3	5.3	5.2	5.2	5.2
Eastern Cape	4.6	4.7	4.4	4.1	4.0	4.0
Northern Cape	5.5	5.0	4.8	4.4	4.3	4.3
Free State	4.0	3.8	4.0	3.9	3.8	3.8
KwaZulu-Natal	5.3	5.2	5.2	5.1	5.2	5.0
North West	5.1	4.6	4.5	4.5	4.4	4.2
Gauteng	4.8	4.8	4.6	4.7	4.8	4.7
Mpumalanga	5.4	5.3	5.3	5.4	5.3	4.2
Limpopo	4.6	5.0	4.7	4.7	4.7	4.5
South Africa	4.9	4.9	4.8	4.8	4.8	4.6

Appendix D

Sources of data used in selected figures

Figure 4.1: Southern African population served with piped water connections

https://washdata.org/data/household#!/

https://knoema.com/atlas/topics/Water

Figure 4.2: Connection ratios in Southern Africa

Swaziland annual report, 2010, 2012, 2013, 2014, 2015, 2017

ESAWAS, 2015

EWURA, 2013, 2014, 2015, 2016, 2017

LEWA, 2013, 2014, 2015, 2016, 2017

"Municipalities of South Africa"

NWASCO 2013, 2014, 2015, 2016, 2017

WUC 2013, 2014, 2015

NamWater, 2017

https://washdata.org/data/household#!/

https://knoema.com/atlas/topics/Water

Figure 4.3: Southern Africa vs continuity of supply

http://www.ib-net.org

NWASCO 2013, 2014, 2015, 2016, 2017

Danilenko, A., Van der Berg, C., Macheve, B. & Moffitt, J. 2014. *The IBNET Water Supply and Sanitation Blue Book*.

van den Berg, C. & Danilenko, A. 2010. *The IBNET Water Supply and Sanitation Performance Blue Book*.

Figure 4.5: Southern African countries Vs NRW

NWASCO, 2012, 2013, 2014, 2015, 2016, 2017

WASCO, 2009, 2010, 2011, 2012, 2015

http://www.ib-net.org

https://washdata.org/data/household#!/

Figure 4.6a: Challenges faced by water utilities in relation to IWS

SWASCO, 2014, 2015, 2016, 2017

ESAWAS, 2015;

EWURA, 2014, 2015, 2017

WASCO, 2011, 2012, 2014, 2015, 2016

NWASCO 2013, 2015, 2017;
WUC 2015, 2016
NamWater, 2017
“SuperWEB2(tm) - Table View”, 2019

Figure 4.8 Connection ratios for South African provinces
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Figure 4.10: Municipalities affected by IWS
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