Water and Wastewater Management in Local Government:

Skills Needs and Development

Final Report Part I

To

The Local Government Sector Education and Training (LGSETA)

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1 Executive summary

Context

Water and wastewater management in South Africa is almost reaching a crisis level and for this reason there is an increasing need for collaboration among different stakeholders. In 2014, the Local Government Sector Education & Training (LGSETA) and the Vaal University of Technology (VUT) formed a partnership by signing a memorandum of agreement. The aim of the partnership is to address the problem of skills development and water management by local government in South Africa. The first step in this journey was to initiate a project that, among other issues, can provide an engagement platform for academic institutions and local government to seek solutions to water and wastewater management problems. It is for this reason that the VUT and LGSETA jointly organized a round table discussion (RTD) at the Emperors Palace Convention Centre on the 25th February 2015. The aim of the RTS was to get the buy in from the municipalities and there after field work was conducted to assess the efficiency of water and wastewater management by the local government. The project is worked on through a collaboration of VUT with University of the Witwatersrand and Tshwane University of Technology (TUT). The aim of this project was to integrate the ideas presented by various stakeholders with the project objectives in order to focus on the identified priority issues. This work analysed the situation as presently is, emerging challenges and matching new technologies to the challenges. The approach was to identify technologies that are relevant to region specific problems and link these with skill development needs. This project focused primarily on Gauteng, Free State, Mpumalanga, North West and Limpopo. However, secondary data was obtained from other provinces for comparison purposes. The report on the project is divided into two parts where Part I deals with water and Part II deals with water, wastewater and the link between the two and energy.

Round table discussion

The round table discussion was attended by about 100 delegates including international experts in water management. The discussion was opened by the Vice-Chancellor of the Vaal University of Technology, Professor Irene Moutlana, who gave a succinct global perspective of the partnership and defined our role as South Africans in global efforts to address the problem of water provision to all. The role of LGSETA was eloquently explained by the Administrator of the LGSETA, Mr. Ngaba Nqandela. He explained that SETAs are supposed to become for their sectors, thought leaders and they are supposed to be repertoires of knowledge, information and wisdom on skills matters for their sectors. The Mayor of Ekhuruleni, Cnll Mondi Gungumbele observed: “This partnership that has been struck by the VUT and the local government SETA is a very important step as we seek an academic and scientific answer to the challenges we face around the issue, waster in South Africa". The CEO of the Water Research Commission, Mr. D Naidoo, emphasized the importance of deriving the benefit of the interrelation between water and energy.

It was recommended during the RTD that there is need to:

(a) Coordinate advisory functions and apply differentiated regulations for local governments;
(b) Inculcate in the public a sense of deep reverence for water as is the case in Middle East;
(c) Generate ideas that can be converted into content, which result in development of relevant curriculum to equip people with skills relevant to the South African situation;
(d) Develop more skills in science and engineering;
(e) Collect and exchange data identify, priorities, pollution sources and hotspots;
(f) Generate region specific data and extrapolate, to other regions, only where applicable and
(g) Implement low-cost but efficient technologies and management strategies such as intelligent pressure regulation.

The next task of this team therefore, was to collect primary data and evaluated the feasibility of the recommended strategies and the related skills that will be required. The focus was on piped water and other sources of water.

Water management and availability

Municipal managed water: The management of wastewater treatment and water distribution and metering were found to be affected by largely by operational problems. There was inconsistent data the flow rate, chemical dosage and lack of effective water quality monitoring. To produce safe drinking water, appropriate operational practices and appropriate water treatment technologies must be implemented in all small water treatment plants. In some cases the technicians working at the plant had long experience with limited technical knowledge. One of the major constraints in managing water demand is the absence of well-structured education and training programmes suitably targeted to stakeholders in the water management chain. Thus the report highlighted on the information on skills shortage in water sector in South Africa, key focus areas for skills development and water training and skills development.

Other sources of water: South African natural resources of water supply are very stretched, hence there is a need to explore on different alternative sources. One of the alternative source of water supply is rain water harvesting. Rainwater harvesting, in conjunction with other alternative methods of exploiting water sources can greatly benefit people at the rural community areas in South Africa. Rainwater harvesting depends on an often unpredictable and sometimes unreliable source, namely rain. However, the potential of this common sense exploitation of a water source should be recognised. The report present methods of rain water harvesting and their techniques as well as treatment of stored water. Another alternative source discussed in this report is groundwater. Groundwater is the main source of potable water for some urban and many rural communities in South Africa. Public perception prevails that groundwater is not a sustainable resource for bulk domestic supply and cannot be managed properly. Despite this, a growing number of municipalities utilise groundwater on a regular basis, and provide examples of successful management of this resource. The use of ground water poses another challenge that may be associated with the quality of acquirers. The study shows the quality of groundwater in different regions and asses treatment methods.

Pint of use: Access to clean portable water is the only sure way to avoid water borne diseases. In rural areas of South Africa unfortunately provision of clean water to a number of communities is still a pipe dream. Where water is not received from a centralized treatment system, a number of alternative technologies are currently being deployed to help ameliorate water quality. We have profiled some of these alternatives; point-of-use systems, for treating water contaminated with fluoride, nitrate and biological contaminants. At this stage these technologies are not regulated by local or national authorities and their use is purely by consent and agreement between the providers and the users. A case study is also profiled on the use of a community treatment system at Tshaanda in Vhembe District. The system is a result of partnership between the local authority as users and Tshwane University of Technology and KU-Leuven as the providers. Lessons being learnt on the implementation of this system aims to help in country-wide roll out of such technologies. Meanwhile we further explore screening strategies that can be used in selecting appropriate POU systems, implementation strategies of such systems and the challenges that may arise thereof during the implementation. In addition, skills development needs to manage the POU systems are discussed.

Key findings:

- Some wastewater treatment facilities are operated exclusively by civil engineers who have limited understanding of the complexity of chemical and biochemical reaction of emerging contaminants and their effects on the microbial colonies in the biological systems.
- There is a direct link between municipal budget underspending on infrastructure and a lack of technical skills and competencies.

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Acronyms

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AD	Anaerobic Digestion
AOPs	Advanced Oxidation Processes
BOD	Biochemical Oxygen Demand
CBZ	Carbamazepine
COD:	Chemical Oxygen Demand
DBSA	Development Bank Of Southern Africa
DCF	Diclofenac
DON	Dissolved Organic Nitrogen
DRWH	Domestic Rainwater Harvesting
DWA	Department of Water Affairs
DWAF	Department of Water Affairs And Forest
EDCs	Endocrine Disrupting Compounds
FBB:	Fluidized Bed Bioreactor
GIS	Geographical Information System
HRT	Hydraulic Retention Time
ISBD	In Situ Biological Denitrification
ISRM	In Situ Redox Manipulation: ISRM
LCFAs	Low Carbon Fatty Acids
LPM	Litres Per Minute MB
	Methelyne Blue
MWW:	Molasses Wastewater
NGDB	National Groundwater Database
NSAIDs	Non-Steroidal Anti-Inflammatory Drugs
NWP	North West Province
NWP-SOER	North West Province Environmental Outlook
PAC	Powdered Activated Carbon
PPCPs	Pharmaceutical and Personal Care Products
PRBs	Permeable Reactive Barriers

RWH	Rainwater Harvesting
SAWS	South African Weather Services
SEM	Scanning Electron Microscopy
LGSETA	Local Government Sector Education And Training Authority
SMX	Sulfamethoxazole
TiO_2	Titanium (IV) Oxide
TOC	Total Organic Carbon
UKZN	University of Kwazulu Natal
US	University of Stellenbosch
UV	Ultraviolet
VUT	Vaal University of Technology
WC	Water Conservation
WDM	Water Management Demand
WH	Water Harvesting
WRC	Water Research Commission
WSA	Water Service Authorities
WSLG	Water Sector Leadership Group
WSP	Water Services Providers
WWTPs	Wastewater Treatment Plants
CPU	Condensate Polishing Units
PA	Pinch Analysis
MEN	Mass Exchange Network
CMB	Central Monitoring Basin
HCSD	High Concentration Slurry Disposal
BMCR	Boiler Maximum Continuous Rating
ETP	Effluent Treatment Plant ,
GAMS	General Algebraic Modelling System
ZLED	Zero Liquid Effluent Discharge
OD	Oxygen Demand
AU	Animal Unit
CARA	Conservation of Agricultural Resource Act

POU	Point Of Use
SIPP	Silver-Impregnated Porous Pot Filter
CWF	Ceramic Water Filter
PLWH	People Living With The Human Immunodeficiency Virus
UF	Ultra Filtration
CBOs	Community-Based Organizations

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CHAPTER 1

1 Introduction

1.1. Water management as reported at the RTD

The fact that South Africa is a water scarce country makes it imperative to develop optimal methods of water and wastewater management. This inevitably requires development of skills needed to tackle emerging challenges related to, in particular, sustainable water and wastewater management techniques. Some of the modern techniques link water and energy management. Water is a key resource for electrical- and bio-energy generation. The efficient management of water and wastewater influences the quality of life in general. In the generation of electricity, coal is burnt to generate steam that drives the turbines that produce electricity. Further, wastewater can be anaerobically digested to produce bioenergy in form biogas. Both of these technologies still require research to optimize the operating conditions. Moreover, the fact that water is a raw material in virtually all sectors of is a clear indication that its management can be left with the local government alone. Instead, the various sectors must play their part to complement what the local government is doing.

1.2. The science and politics of water management

1.2.1. *Global perspective*

Municipalities are the custodians of the public water management and invariably take the blame for the problems of lack of water. However, the public in this context includes the illiterate person on the street and the Nobel laureate in a science laboratory. We agree that the municipalities must take responsibility because we pay rates and taxes. However, the public, too, must know both their rights and responsibilities. There is a shared responsibility when it comes to delivery of services. The scientists in the lab could play their role by developing environmental friendly products and low-cost water treatment technologies. The common person in the street, similarly, would use water and the infrastructure responsibly. The sense of responsibility can be developed in a forum like that of the RTD, in which stakeholders are given a platform to air their views.

The Vice-Chancellor of the Vaal University of Technology, Professor Irene Moutlana, who gave a succinct global perspective of the partnership and defined our role as South Africans in global efforts to address the problem of water provision to all. She explained the concept of optimal and fair utilization of critical resources like water and that the underpinning notion of water are stated or unstated power relations or space. If these power relations are not checked, they culminate in what the world is experiencing in terms of imbalances, turbulences, inequalities and highly volatile and conflict situations. This brings to the fore the issue of distributive justice; who gets what, when and why? She added that potential trans-boundary impacts and conflicting interests can best be solved by cooperation as we are trying to do now, providing adequate legal and institutional frameworks, joint approaches to planning and sharing of benefit and related costs. Yet at the same time, these differences open up opportunities for capacity development, technical, social, legal and economic cooperation.

Prof Moutlana went ahead to mention that approximately 40% of the world's population lives in a river and lake basins that comprise two or more countries and over 90% live in countries that share water bases Water more often unites than divides people in societies. Since 1948, history shows only 37 incidents of acute conflict over water, while during the same period approximately 295 international water agreements were negotiated and signed, but were they followed? The vice-chancellor of the Vaal University of Technology (VUT) gave her views when she opened the RTD. Making her contribution during the RTD. She asserted that despite the centrality of the issue of water, the legislations governing water distribution are often made without due consideration of the most venerable group. The result is both kind and cruel, come tumbling down and a highly conflicted situation comes on. There is an underlying profit motive in the whole thing. These are the politics of water. Distributive justice, who gets what, why, when and how. In cases involving once sided water policy situations, financial transfers often fail because ordinary people see themselves unfairly treated and are unable to gain domestic acceptance for the goals at stake.

1.2.2. *National perspective*

The social construct and historical background of South Africa influences the way we conduct our business at domestic and institutional levels. Inherently, there is a tendency of working in silos. In this way we inadvertently duplicate efforts, squander the opportunities to leverage on the existing initiatives and miss opportunities to develop synergies among the innovative research outputs. It was reported by Chief Executive Officer of the Water Research Commission, Mr. Dhesigen Naidoo, that South Africa is ranked 18^{th} in the world on research productivity in water resources. This is good news for a country whose 2013 gross domestic product (GDP) is ranked 33^{rd} in the world.

With this impressive contribution in water research, one obvious question one would ask is how much of this is relevant to our circumstances? Secondly, for that which is relevant, how much of it do we apply to address our problems? These are the kind of questions that a platform like the one created by VUT-LGSETA partnership and by extension the round table discussion forum seeks to provide answers for. In this context, this project will leverage on exiting projects or structures and use existing skills and data to develop region specific technologies.

The main custodian and prime driver of water management still remains the responsibility of the technicians of the local government who must implement the ideas and identify the priority issues in water management in South Africa. Such issues include non-revenue water, aging infrastructure and skills development.

1.3. Challenges and approach

1.3.1. *Non-revenue water*

Non-revenue water may be considered as the cost of providing the water service. It consists of mains leak and bursts, unbilled low cost houses, metering inaccuracies, theft, unbilled standpipes, reservoir overflows. In South Africa, 33% of the water purified represents non-revenue water (Hosting and Jacoby 2013). This is very high compared to a country like Namibia where the same account for only 10% of the water purified.

1.3.2. *Aging infrastructure*

Aging infrastructure including leaking pipes contribute a high proportion of non-revenue water. In many municipalities there is a backlog build-ups and inadequate maintenance of infrastructure. This kind of backlog is likely to lead to "dry up" similar to the Eskom blackouts. The issue of aging infrastructure can be attributed to the following problems (Hosking and Jacoby 2013):

a) Lack of political will at the local government level
b) Low budget priority
c) Lack of capacity and skills
d) Flawed water service tariff and accounting structuring
e) Insufficient capital
f) Loss of institutional memory.

Among these factors, the one that needs urgent attention is skills development. Skilled staff will be able to lay down strategies that will address the rest of the other problems.

1.3.3. *Growing demand and changing life style*

There is an increasing trend in rural-urban migration, which has resulted in an increase in demand for services including water and sanitation. Additionally, the lifestyle of the people living in the urban areas is changing very fast. These changes include the chemical products used at home and food preference. An increase in meat consumption, for example, leads to an increase in the number of animals slaughtered and consequently an increase in the volume in abattoir wastewater discharged into the municipal wastewater treatment plants.

An expanding South African population growth has created a growing demand for recycled water in agriculture. Urban communities in particular perceive treated wastewater effluent as an accessible water and fertiliser source for food production. Optimal use as well as control of recycling of treated wastewater has become critical in order to protect public health.

Seeking solution to these problems requires the participation of the local communities, industries, government institutions and water bodies. The role of the LGSETA can catalyse the process to obtaining sustainable solutions.

1.4. The LGSETA mandate

In the context of water management and skills development in the LGSETA the role of the LGSETA is pivotal. This was eloquently explained by the Administrator of the LGSETA, Mr. Ngaba Nqandela. He explained that SETAs are supposed to become for their sectors, thought leaders and they are supposed to be repertoires of knowledge, information and wisdom on skills matters for their sectors. He reported that according to the 2011 census, 73.4% of households in South Africa had access to pipe water in a dwelling or yard, which was a significant improvement to what was in 2001, which was 61.3. This is an improvement of 12% or 24 million people in 10 years; something that some people may want to celebrate. However, what remains a challenge is access to water in some parts of our country, Limpopo, North West, Eastern Cape and KZN record less than 20% access to piped water. In fulfilling its mandate, the LGSETA - among others - facilitates skills development to enhance service delivery at local government sector.

Mr. Ngaba Nqandela went ahead to say that we cannot take comfort in the generalized national figures however rosy they may appear. Indeed, water is key to supporting better human development both in the urban and rural areas. It is entrenched in our bill of rights, our constitution, which says that everyone has the right to have access to sufficient food and water. The Mayor of Ekhuruleni Municipality, Cllr Mondi Gungumbele, added that the municipality has adopted a risk level 2%. This means that the municipality can supply water for 98 year out of 100 years.

1.5. Sanitation and legislation

The interrelation between water and sanitation is well captured by the slogan of the Water affairs: "Water is life and sanitation is dignity". The availability of water determines the quality of life in general and most importantly sanitation.

Poor sanitation is a major cause of diseases through contamination of water bodies from which raw water is abstracted for subsequent treatment and use. Sanitation systems such as latrine are known to contaminate ground water. This can be a serious problem if a borehole is in close proximity. In Asia, small scale systems referred to as Eco – tanks have been used in the rural areas. These are small scale sewage treatment systems that use anaerobic bacteria to transform waste into non contaminated effluent. Eco-tanks do not use electricity and can treat sewage from up to 508 people/day (Naidoo et al., 2013).

Matters relating to municipal by-laws are captured by section 21 of the water service Act 108, 1997. A municipality must adopt by-laws that contain terms and conditions for water service delivery. The conditions provide for: the standard of service, the technical condition for supply and the determination of tariffs in accordance with section 10 of the water services amendment act 108,1997 (Act 108,1997) (Hosking and Jacoby 2013).

1.6. Conclusions

It was reported that there are factors that obstruct the establishment of the benefit sharing and service delivery at the national level, and these include:

(a) Working in silos;
(b) Weak administrative capacities of the service providers;
(c) Lack of public awareness of their responsibilities and high volumes of non-revenue water;
(d) Lack of futuristic approach to water management as well as inability to spend;
(e) Lack of skills and competencies in science, engineering and technology (SET);
(f) Wrong priorities, especially concerning maintenance and capital investment;
(g) Lack of information on the location of some water distribution lines and
(h) Emerging contaminants and pollution loads into water treatment plants

1.7. Way forward

It was recommended that there is a need to form a multi-sectorial team that will provide leadership and skills development platform (to create opportunities for re-skilling) and information sharing among the stakeholders. The stakeholders include industries, municipalities, water management organs and academic institutions. There should be a continuous process to consolidate the ideas of the stakeholders as captured in the RTD and integrate them with the planned activities to identify technology and skill gaps.

CHAPTER 2

2. Water management

2.1. Introduction

Treatment of wastewater is aimed at removing compounds that have negative impact on life and environment. Such compounds find their ways into water bodies mainly as a result of human activities at small and large scales. At small scale, wastewater is generated from different house hold units. The characteristics of the wastes from different households are generally similar; however, the precise composition and quantity depend on the life styles of the individual units. In particular, the relatively affluent households produce higher quantity of wastes with varying characteristics than the less affluent homes. At large scale industrial and agricultural activities are the main sources of waste. There are different agricultural and industrial activities in different parts of the country, and for this reason wastewater characteristics may be region dependent.

In South Africa, Gauteng province has the highest population density and has the highest industrial activity. Studies carried out in 1998 reported that Gauteng generated the highest volume of general waste in SA and had the highest per capita waste generation of 2.44 m^3/capita/annum (PDG, 2004). In another study carried out in 2003, the waste production for Gauteng was reported to be 480 kg/capita/annum (http://www.environment.gov.za). Moreover, Gauteng has a large number of food processing industries, which produce huge tons of wastewater every year. The large volumes of wastewater produced from the high industrial and domestic activities may have negative impact on the environment if not well managed.

The efficiency of both industrial and domestic activities is influenced by the availability and affordability of energy. In the recent past, the availability of energy to all sectors has been a major concern as the lack of energy impacts negatively on the economy. For this reason, there has been a justifiable demand for renewable energy, especially in form of biofuels such as biodiesel, bioethanol and biogas. The technology for renewable energy is still not fully developed. However, among other fuels, it has been established that one of the feasible waste beneficiation efforts is the generation of biogas from wastewater, especially those that are produced by food processing industries. Such industries include those that are involved in dairy, fruit juice and distillery products. All these including slaughter house wastes end up in municipal wastewater treatment plants. As such, the performance of the municipal wastewater treatment plants is influenced by the characteristics of the inlet streams. The quality and quantity of the feed streams may change with seasons, depending on factors such as the availability of the rainfall. One of the challenges facing designers of wastewater treatment facilities in Gauteng and the world in general is how to achieve an optimal generation of energy and reduction of pollution at the same time.

Water is a vital natural resource to sustain life and to process products. An efficient Management of water requires skilled human capital and energy utilization. The different stages (Fig. 1) of water treatment require different skills and competencies to optimally manage and sustain the processes. The motivation for the renewed focus on water and wastewater management stem from the fact that there are emerging challenges in terms of new pollutants and new technologies.

2.2. Water treatment

Water is abstracted for a number of uses that inherently affect the quality and subsequent usability of the water. Some of the anthropogenic contaminants are not necessarily linked to use but rather management of wastewater and sewage. The quality of surface and ground water is affected by aspects such as mining activities like effluent discharge, water treatment works; water abstraction for agricultural uses, agricultural activities, and coal combustion and high density urban areas. During the CREW and LGSETA organized round table submit, speakers reflected on various treatment methods and value adding to wastewater. The ultimate aim of the wastewater treatment technologies is to ensure that after treatment the water is restored to the potable state and where not feasible that it may be fit for use in agricultural production.

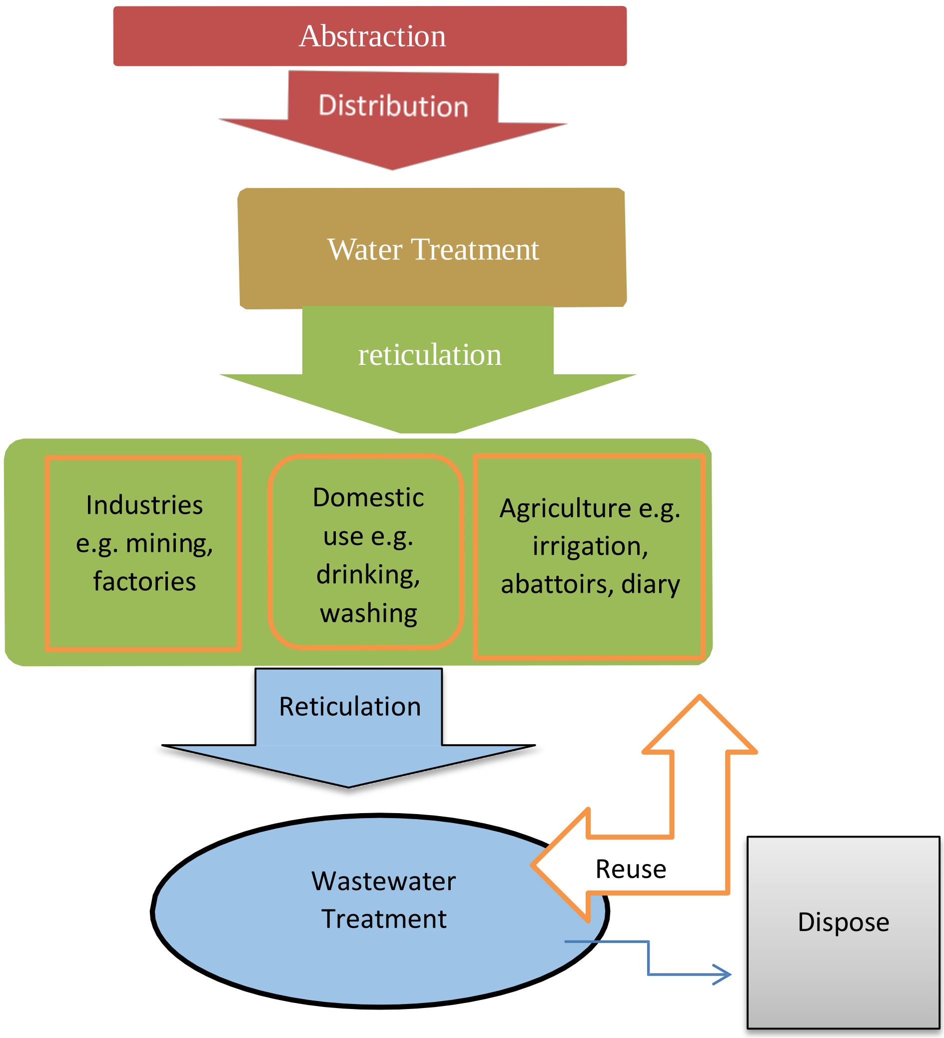

Figure 1 Water supply Chain, Adapted from Frost and Sullivan, 2011

Wastewater treatment plants were primarily designed for treatment of domestic wastewater or sewage (human excreta, laundry and food preparation), however industries emerged gradually and some directly discharge their untreated wastewater into the municipal treatment plants. The wastewater from the industries is highly diverse in organic quality and quantity.

2.2.1. *Municipal water treatment plants*

In a survey involving 181 water treatment plants across 7 provinces of South Africa: Mpumalanga, Limpopo, North West, Free State, KwaZulu-Natal, Eastern Cape and Western Cape, owned by district municipalities, it was noted that most of them use only the conventional water treatment processes: coagulation, flocculation, sedimentation, filtration and disinfection. Due to this compliance to SANS 241 was not achieved. The treatment systems were found to be affected by operational problems: inability to appropriately determine the flow rate, chemical dosage and turbidity, lack of chlorine residual at the point of use and lack of water quality monitoring. To produce safe drinking water, appropriate operational practices and appropriate water treatment technologies must be implemented in all small water treatment plants.

2.2.2. *Water distribution and pricing*

In the South African context, passive competition over water can heighten tensions and even lead to open conflicts between the consumers and service providers. This is exactly what we are experiencing today and the situation is not likely to get better without well-coordinated intervention.

It has been reported (Edwards et al., 2013) that a survey of 14 countries including Canada, the USA, Australia, UK and nine EU countries shows that South Africa is no 13th in terms of the cost of water. A more worrying trend is the fact during the period 2003 to 2008, Edwards et al. (2013) report that, comparing the rate at which water prices in these countries increase, South Africa was rated third. While this represents a 9.2% increase in the year 2006/200, there have been warning that double digit annual increase would cause a crisis.

At the RTD, it was reported by Cllr Mondi Gungumbele that the Ekhuruleni municipality is committed to reducing non-revenue water from the current level of 37.7% to less than 20%. This is indeed a very good initiative. However, compared to the Namibian's achievement of less than 10% non-revenue water, that goal is good but not good enough considering South African's investment in water research. To try to unravel these paradoxes, the input of different stakeholders was solicited in the RTD. The stakeholders gave their views on the challenges and possible interventions. These figures are far better than the South African ones, however, they are still not as good as the Japanese ones (2-5%). It is therefore a wise and strategic decision that the Department of Science and Technology and Hitachi have decided to send offer scholarship to South African water engineers and technologists to train in Japan from late this year (2015).

2.3. Water quality guidelines

One of the main indicators of the environmental pollution is the quality of water, which has an immediate effect on life. For this reason, wastewater treatment facilities must reduce pollution to the levels prescribed by the local and national authorities. The prescribed limits are set on the basis of the required water quality standards of a given water body and the characteristics of the wastewater discharged. Water quality guide lines for Gauteng in Table 1 show variation of guidelines for different rivers. This is due to the variation of activities in the river catchment areas. The wastewater streams with high energy potential are those that are rich in nutrients such as nitrates and phosphates. The concentration of these nutrients, which cause eutrophication, as well as those of the toxic chemicals and microorganisms in rivers is strictly controlled according to water quality guidelines. It can be seen in Table 1 that the values of water pollution determinants obtained from Gauteng rivers are higher than those prescribed by the Department of Water Affairs and Forestry (DWAF). On the basis of electro-conductivity (EC) and faecal coliform counts, Klip River is the most polluted followed by Vaal Barrage. The high EC values can be caused by industrial pollution whilst the high faecal coliform count is caused by the discharge from sewage wastewater treatment plants.

Table 1 Water quality guide lines for Gauteng rivers (Rand Water, 2001)

	EC	TDS	NO_3+NO_2	NO_3	PO_4	Faecal coliforms
	[redacted]	mg/l	mg/l	mg/l	mg/l	counts/100 ml
DWAF national domestic Quality guide lines	77	450	6		1.0	<1
Klip river	<80			<2	<0.2	<1000
Blesbokspruit&Suikerbosrand	<45			<0.5	<0.2	<126
Vaal Barrage	<30			<1.0	<0.25	<131
Vaal dam	<0.1			<0.1	0.05	<10
Wonderfonteinspruit	40	280	5		0.1	-

Vaal Barrage is an important river not only in the Gauteng region but also in other parts of South Africa, and as such requires special attention. Table 2 shows that the level of pollutants from Vaal Barrage catchment background are of acceptable levels as prescribed by the Rand Water guide lines. Among the heavy metals reported in Table 2, zinc concentration is the highest, and this obviously points to a possible effect of an industrial source.

Table 2 Vaal Barrage reservoir water quality guidelines (Rand Water, 2001)

Variables	Units	Catchment Background	Management Target	Interim Target	Unacceptable
Conductivity	μS/m	< 18	18 – 30	30 – 70	> 70
Dissolved Oxygen	%		> 6.0	5.0 -6.0	<5.0
pH		7.0 – 8.4	6.5 – 8.5	6.0 – 9.0	<6.0; >9.0
COD	mg/l	<10	10- 20	20-30	>30
Phenols	mg/l		<0.01	0.01-0.1	>0.1
Iron	mg/l	NA*	<0.5	0.5-1	>1
Zinc	ug/l	<50	50-100	100-200	`>200
Copper	mg/l	<0.05	0.05-0.1	1-2	>2
Nitrate	mg/l	<0.5	0.5-3	3-6	>6
Phosphate	mg/l	NV	<0.03	0.03-0.05	>0.05

*NA- Not available

2.4. Alternative sources of water

In South Africa, like in many countries in the world, some communities rely directly on rainfall to sustain their livelihoods. Unevenness in timing and distribution of rainfall may leave many communities without access to water for even the most basic daily requirements. Unpredictable changes in climate in the future may result in greater irregularities in the availability of water for daily use.

There are eleven different types of water sources for households in South Africa that are grouped in piped and non-piped categories (Table 3). Most communities rely on a single source thereby impacting negatively on the reliability and health of users. Diversification of water sources, with one being domestic rain water harvesting (DRWH), offers greater prospects of reliability and good hygiene.

Table 3 Existing type of water sources in South Africa (Statistics SA, 2006)

Category	Types of water source
Piped	Piped water (tap) inside dwelling
	Piped water (tap) inside yard
	Piped water on community stand: distance ≤200 m from dwelling
	Piped water on community stand: distance > 200 m from dwelling
Non	Borehole
Piped	Spring
	Rainwater tank
	Dam/pool/stagnant water
	River/stream
	Water vendors
	Other

2.4.1. *Rain Water Harvesting*

(a) Rain Water Harvesting

Rain Water Harvesting enhances water productivity by mitigating temporal and spatial variability of rainfall and provide water for basic human needs and other small-scale activities (Kahinda et al., 2010). In areas with dispersed populations or where the costs of developing surface or groundwater resources are high, RWH and storage have proved to be an affordable and sustainable intervention (Mati et al., 2006). For planning and implementation purposes, it is critical to be able to identify areas suitable for RWH. However, the potential of this type of water supply has not been fully exploited in South Africa to date.

Several municipalities now use roof rainwater harvesting to meet domestic needs. These have been found to be effective when used in conjunction with other water supply options. At the RTD it was reported by Dr Mwaka, Director Water Resource Planning System (DWS) in the Department of Water and Sanitation, that water harvesting, piping and pumping station are among the challenges facing water resources management in South Africa. Thus there is a need to address the situation and come up with the optimum solutions.

(b) Challenges on Implementation of RWH

One of the challenges water managers are facing is to define water harvesting (Figure 4). Prinz (2002) distinguishes the following WH groups: fog–dew, rainwater, floodwater and groundwater harvesting. Thus, WH encompasses RWH as it also includes floodwater harvesting. The challenges facing RWH technology include:

- it generally requires high labour input during their implementation phase
- High capital investment (in a rural context) is required to implement RWH.
- The South African water related legislations do not give a clear legal framework for the adoption of RWH, making it illegal by strict application of the law.
- The sustainable implementation of RWH requires institutional innovations. The lack of a national umbrella body that coordinates RWH not only hampers the expansion of RWH but also makes documentation of the practice difficult (Kahinda et al., 2005).

Moreover, there are studies that have been done on the socio-economic impact, and techniques of RWH, hence there is a need to fast track the knowledge base and guidelines generated by different researchers all over South Africa.

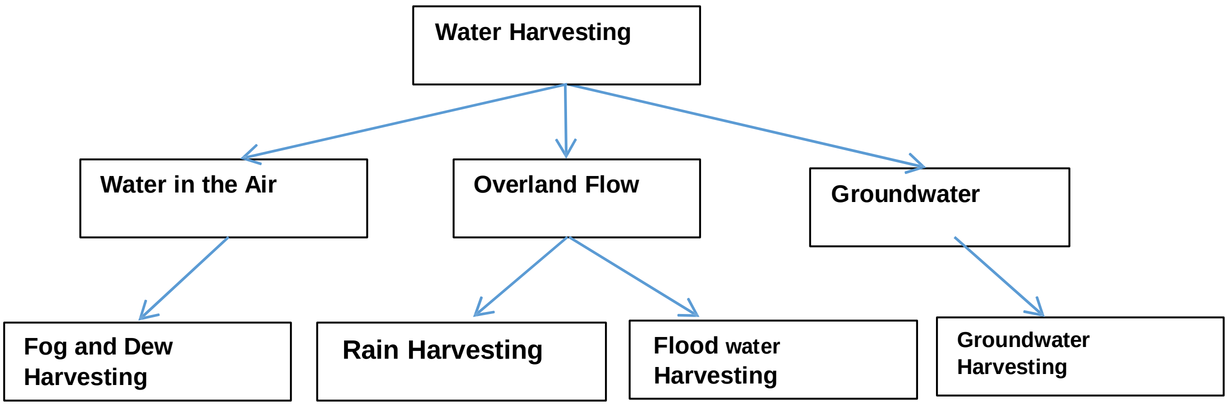

Figure 2 Subdivision of water harvesting (Pritz, 2002)

2.4.2. *Groundwater as other source of water supply*

(a) Groundwater management

The importance of groundwater resources to society has been well understood with increasing evidence of the variety of services that groundwater provides. However, the groundwater itself has remained a poorly understood and managed resource, possibly due to its 'hidden' nature and the lack of adequate knowledge and physical data pertaining to aquifer characteristics and behaviour such as recharge, discharge, base flow and aquifer dependent ecosystems. Most groundwater quality and quantity problems worldwide are related to human activities such as industry (e.g. infiltration of chemicals and toxins) and mining (e.g. acidification and increased metal content). Additional problems include urban pollutants (e.g. salinization, eutrophication and microbial effects) and the intensification of agricultural practices (e.g., sedimentation, infiltration of agro-chemicals and salinization through irrigation return flows).

The complexity of the issues surrounding groundwater management is due to many distinctive characteristics of groundwater resource. In order to avoid misallocation of this resource, the following issues must be taken into consideration; availability of resource in terms of time and space and accessibility of resource to users by proper rights. However, after the promulgation of the new National Water Act, groundwater was declared a public resource with shared entitlements to use, therefore exposing the resource to further exploitation. Although provision was made for the management of groundwater resources under the Department of Water Affairs, the motivations behind the regulations and guidelines have been difficult to account for and implement on a regional level and subsequently are largely overlooked or neglected. Thus, there are still many challenges to overcome in order to achieve the sustainable management (Knüppe, 2010).

Historically, groundwater has been given limited attention, and has not been perceived as an important water resource in South Africa. Public perception prevails that groundwater is not a sustainable resource for bulk domestic supply and cannot be managed properly. Despite this, a growing number of municipalities utilise groundwater on a regular basis, and provide examples of successful management of this resource (Riemann et al., 2011). Groundwater is the main source of potable water for some urban and many rural communities in South Africa. It is about 15% of the country's total water consumption is supplied by groundwater sources; most of the times the communities depend upon groundwater because they have no other feasible sources of water supply. The value and vulnerability of groundwater represent a strategic component of the water resources of South Africa. Groundwater occurs widely and, geographically. Security of groundwater supplies is thus essential and protection of groundwater has become a national priority. Lack of proper understanding of the occurrence, movement and recharge of groundwater have led to this resource not being utilized in a sustainable manner. It is estimated that about 90% of the local groundwater in South Africa occurs in secondary aquifers consisting primarily of shallow zones of weathering and fracturing. The resulting failure of boreholes in some instances has unfortunately promoted the view that groundwater is un-reliable source of water supply that should be replaced as soon as possible by more reliable surface-water supplies. However the growing importance of groundwater is fortunately strongly reflected in the National Water Act.

(b) Challenges on groundwater management

Groundwater management faces different challenges; the most significant challenge is education and awareness, and the collaboration among stakeholders on the importance of sustainable and efficient groundwater use (and monitoring). The first step should be awareness and understanding by the users will help to assist in the proactive management of groundwater in different areas in South Africa. Hence this project aims to investigate the groundwater management practices in South Africa and to identify the challenges and issues they face in order to propose potential solutions.

2.4.3. *Point- of- use treatment systems*

Conventional approaches involving large scale, long-term, capital-intensive projects will not be sufficient to fulfil the imminent need to provide millions of people with safe water in a cost-effective manner. There is an urgent need to consider other options, particularly in the light of technological advances that have opened up low-cost, highly effective alternatives that can be employed in a sustainable fashion. One such option is point of use (POU) systems, which are designed to treat small amounts of drinking water for use in the home. In rural settings like those in Limpopo province, water contamination occurs mainly at the point-of-use (POU), or household level and hence water purification poses a huge challenge. In South Africa, due to varied nature of rural water quality, there is an urgent need to implement POU systems to the rural population. Currently, there is hardly any point of use systems under the control of national or local government. Most existing point of use systems are supplied by commercial enterprises. Individuals buy and use these systems on their own volition and there is no documented evidence of the numbers and spread of these units that can allow for monitoring. There is therefore a need to standardize and regulate the use of such devices, which if not used properly could be a source of water contamination.

2.5. Water-energy-food nexus

The concept of water re-use is not complete without looking into the main deterrents and motivations for this. The main deterrent is the cost of making water re-usable. This cost is largely due to the energy required. In contrast, the motivation is that the treated water can be used for activities such as irrigation for food production. This water-energy-food nexus need to be understood and modelled on the basis of region specific imperatives. This is a sustainable approach to addressing water problem in general and it requires partnerships and collaboration. In this context, during the RTD, the mayor of Ekhuruleni, Cnll Mondi Gungumbele observed: “This partnership that has been struck by the VUT and the local government SETA is a very important step as we seek an academic and scientific answer to the challenges we face around the issue of waster in South Africa”. Further, the CEO of the Water Research Commission, Mr. D Naidoo, emphasized the importance of deriving the benefit of the interrelation between water and energy. He added “this is the reason we are very keen to continue partnering with the Centre for Renewable Energy and Water (CREW) at the VUT”.

2.6. Conclusion

It is critically important to understand the water supply chain in order to comprehend wastewater management in South Africa. The role of other stakeholder such as Rand Water, WRC and Academic institutions have to find a place within the wastewater management at the local government spheres. This will help identify, within the supply chain, the required critical skills to improve service delivery. The value and vulnerability of groundwater represent a strategic component of the water resources of South Africa. The complexity of the issues surrounding groundwater management is due to many distinctive characteristics of groundwater resource. There is a need to standardize and regulate the use of point of use devices, which if not used properly could be a source of water contamination. Considering the technological advancement in South Africa in comparison to other African countries, the proportion (33%) of unaccounted water and degenerated infrastructure are issues of great concern.

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CHAPTER 3

3. Point-of-use systems for water treatment

3.1. Introduction

Provision of quality drinking water is a big challenge in South Africa. It has been reported that contaminants such as fluoride, nitrate, manganese and biological contaminants exist in a number of drinking water sources at elevated levels, which are above the drinking water standards. The situation is further exacerbated by insufficient quantity of available water resource and skills shortage in the water sector. In rural areas, the water supplied rarely meet the SANS241guideline for drinking water quality. In a number of areas, there is hardly any supply of water due to scattered nature of the dwellings and topography that does not allow piped water to reach the population. Meanwhile some households may be connected to the water supply mains but perceive water they receive to be unsafe. In environments of these nature, point-of-use (POU) water treatment systems provide the best option to access clean drinking water.

POU can refer to several different types of units: plumbed-in units; plumbed-in units with separate faucets for the POU device; faucet-attached units; and faucet-connected counter top units (US-EPA, 2006). Within the South African context, POU systems can include devices that treat water at household and community levels. These systems can be used to improve the quality of water that reaches our taps or can be used in cases where no treatment (see Figure 3 taken at a site in Limpopo Province) is implemented such as water from a spring or borehole. POU systems vary in design and their applications are restricted by site-specific water quality issues. In fact a one-technology-suits-all approach may not apply to POU systems as water quality parameters vary from site to site. Consequently, before such a system is deployed, it is necessary to perform water quality analysis and do pilot testing to explore performance of the system to treat water at a specific site. From here a screening strategy can be developed to evaluate the POU systems. Such strategy should include cost, ability to reduce contaminants to meet maximum allowable concentration guideline, technical skills requirements and whether or not the technology adds load to the environment (Onyango & Matsuda, 2006).

Once a device has been selected for a specific site, implementation strategy must be adopted. This requires determination of project costs, skills requirements, establishing best practices, following time lines, working with local and national authority and considering operation and maintenance requirements.

The South African constitution recognises water as a right. By this every citizen must have access to cleaning drinking water. Lack of (clean) water as a vital commodity has led to a number of service delivery protests in many local authorities. Consequently local authorities play a vital role in water provision and which by extension the uptake of devices, in the foregoing the POU systems, that provide clean drinking water. The authority is expected therefore to engage with community, district and regional leaders to strengthen local ownership of the POU devices and support operation and management costs associated with inspection, maintenance and monitoring of POU systems.

Figure 3 Untreated water used as a source of drinking water at Tshaanda-Limpopo Province. Such water may not meet SANS241 guidelines for chemical and biological contaminants

Historically a large number of rural communities in South Africa did not have opportunity to acquire sound education. Even in the post-apartheid South Africa the situation has not improved to the extent expected. Whereas access to education has improved, lack of basic skills still bedevil historically disadvantaged communities. A number of POU systems require skills in operation and maintenance and monitoring the water quality arising thereof from the systems. This therefore calls for expertise with post-secondary education in critical areas such as plumbing, controls and water quality monitoring that the local government must invest in order to have a sustained operation of POU systems in any site.

We present some of the POU technologies used in South Africa especially in treating water in rural areas where communities are not connected to centrally treated water due to a number of limiting factors such as rugged terrain, scattered nature of dwelling and poverty. The technologies under consideration include those for fluoride, nitrate and microbial contaminants. A screening strategy is provided to aid in choosing site specific technology. Moreover, implementation strategies and challenges thereof are discussed. Skills gap that is relevant to the local government is critically analysed. We believe that the information provided can aid local government officials in their mandate to provide clean drinking water to all as mandated by the South African constitution.

3.2. Point- of- use (POU) systems for water treatment

The profile of point- of -use systems currently used in South Africa must relate with the identity of the commonly found contaminants in drinking water sources. It has been recognised that in environments where there are no water treatment or where treated water do not meet national standard, that biological contaminants are inevitable present in such water. Also, contaminants such as fluoride, nitrate and manganese are reported in a number of drinking water sources. We provide analysis of some POU systems currently in use and others that may be implemented to ameliorate water quality with reference to biological, nitrate and fluoride removal.

3.2.1. *POU technologies for fluoride*

The problem of high-fluoride ion concentration in groundwater is one of the most important health-related issues in many developing countries including South Africa (Anonymous, 1998). Groundwater is the most appropriate and widely used source of drinking water for many rural communities in South Africa (Ume & Josie-Perez, 1995). Pilot studies and surveys conducted by the Department of Water Affairs and Forestry (DWAF) indicated that in general, groundwater is of acceptable quality except for some areas in which elevated levels of natural groundwater fluoride is associated with the occurrence of dental fluorosis in most communities using the groundwater for domestic use (Fayazi, 1994). Several research projects showed that the problems of high fluoride ion concentrations are currently concentrated in the Limpopo, Northern Cape, North-West and KwaZulu-Natal provinces. These provinces have a high population still living in rural areas and prior to 1994 most of them used untreated ground- and surface water for drinking purposes (Ginster & Fey, 1995; WRC, 2001).

A number of technologies have been developed for the removal of fluorides from groundwater resources. The conventional methods are mostly based on adsorption onto activated carbon, or ion exchange onto resin, activated alumina or bone char. In the past decade, reverse osmosis membranes have offered another option. All these technologies have significant disadvantages when implemented in small rural supplies where capital, maintenance and operational expertise are at a premium (Pelpoa et al, 1992). These drawbacks include: high implementation cost, high operational and maintenance costs, low capacity for fluoride removal, lack of fluoride selectivity, undesirable effects on water quality, generation of sludge that is difficult to handle, and complicated procedures. Therefore more suitable approaches particularly suited for isolated and marginalized rural settlements are required to tackle the removal of this contaminant (Bjorvatn et al., 1997).

Currently, there are different Point of Use (POU) water treatment methods available for removing fluoride in water. One of the methods is precipitation with alum and lime followed by coagulation (Meenakshi & Viswanathan, 2007). This method is suitable for water that has very high levels of fluoride. It however fails to produce treated water with fluoride concentration below 1.5 mg/l as specified in the WHO guideline. Another available method that can be used for fluoride removal is membrane technology. The suitable membrane for dissolved substances like fluoride is reverse osmosis. However reverse osmosis membranes cannot be used in some rural areas because of high membrane cost. Moreover, electrical power is required to pump the water through the membrane (Chauhan et al., 2007).

Adsorption is one other method that can be used for fluoride removal. There are different adsorbents that have been applied for fluoride removal such as activated alumina, activated carbon, activated saw dust, activated coconut shell carbon, activated fly ash, ground nut shell, coffee husk, rice husk bone char coal (Meenakshi & Viswanathan, 2007) . However the main problem with most adsorbents is that they are not selective towards fluoride and other substances may occupy the adsorption site, reducing the efficiency of the adsorbent.

In South Africa, little information and practical field use of POU systems are available yet a number of water resources contain elevated fluoride levels. Recently, Schoeman (2009) showed in Madibeng Municipality that an activated alumina based process can remove from 6 to 8 mgF/L to less than 1.5 mgF/L of fluoride. No reduction in plant output was experienced over 6 service cycles. No significant operational problems were experienced during commissioning and the system was found to perform satisfactorily. In another work, Murutu et al. (2012) showed the potential of two adsorbent-based POU system designs in treating fluoride contaminated water. The water was obtained from Lesodi Motlata rural area of Limpopo province and was sufficiently treated to meet the local standard of 0.75 mgF/L. No further information is available on the use of these systems in fluoritic areas.

In general, there is a need to implement several communities in South Africa efficient point- of- use systems for fluoride removal that are robust, capable of producing enough volumes of treated water to be used by a family or community for cooking and drinking. The treated water should be within acceptable quality irrespective of feed concentration or operator skills.

3.2.2. *POU technologies for nitrate*

In South Africa, many small communities living in remote areas use untreated groundwater exposing them to nitrates contamination. It has been established that drinking water from groundwater supplies tends to contain high nitrates levels than in surface water supplies (Kempster, 2005). Infact it has been observed that South Africa has some of the highest natural nitrate levels in the world (>500 mg/L N-NO_3) exceeding the WHO recommended limit of 10 mg/L, thus making such water unfit for drinking. Nitrate levels above 10 mg/L in drinking water can be harmful to young babies and pregnant women and may cause methoglobinemia, nausea and fatigue. There are also links to longer-term human reproductive and cancer risks and if levels go beyond 100 mg/L they may be harmful and toxic to ruminant animals (Fewtrell, 2004).

In a study by Tredoux et al. (2001) it was noted that about 5000 (27%) groundwater abstraction points in South Africa yield groundwater with nitrate-N exceeding 20 mg/L. In another study by Ratikane (2013) after assessment of water quality from boreholes in Bainsvlei and the Woodland Hills Estate of Bloemfontein in the Motheo District Municipality-Free State, it was established that nitrates displayed measurements that were non-compliant with the SANS 241 guideline (DWAF, 2011). This was also the case with groundwater samples reported by Murutu et al. (2012). Recently, a press release by Lawyers for human rights reported high levels in nitrate when tests were conducted on two boreholes, one at the mosque in Carolina and one at a mosque in Silobela. Separately, Esterhuizen et al. (2015) demonstrated that in central South Africa (districts of Motheo, Xhariep and Lejweleputswa in the central Free State) more than 50% of the dairy farms water sources studied had high levels of nitrate in drinking water exceeding 40 mg/L. Yet in another study, samples were collected from community drinking water sources in a village that is located in close proximity to a platinum mine in the Limpopo province. All samples of village drinking water supplies exceeded the South African Drinking Water Standard. The concentration of nitrate (57.6 mg/L NO_3-N) in the sample taken from the borehole used by the Primary School was almost tenfold the recommended limit.

To mitigate nitrates contamination problem, different commercial and domestic technologies are either in place or have been proposed. The most common technology is denitrification-a process whereby nitrogen is removed from water. When employed in water quality improvement technologies, denitrification treats water to reduce its nitrate-nitrogen content to potable levels. There are three principal approaches to nitrate removal: ion exchange and chemical reduction and biological denitrification. Conventional nitrate removal methods like reverse osmosis and ion-exchange in South Africa have been reported, although the methods are said to be expensive and user unfriendly. Research is also underway at CSIR on the reduction of nitrogen levels in groundwater using slowly degradable carbon sources for denitrification. Research studies have also indicated that adsorption is a potent technology for nitrates removal from water especially when using natural derived materials such as zeolites (Onyango et al., 2010).

Different processes can be employed in point-of-use applications for nitrates removal. The following are examples of the types of processes that are used in home applications and in home treatment devices: membrane filtration, ceramic- cartridge and drum filtration; softening processes (home ion-exchangers) and adsorption processes (DWAF, 2002). However, there is no clear information on whether such systems are available in use for nitrate contaminated drinking waters in the aforementioned areas in South Africa. There is an urgent need due to public health effects to implement appropriate POU systems especially in rural areas.

3.3. POU technologies for biological contaminants

Water obtained from boreholes, protected wells, protected springs and harvested rainfall often requires little or no treatment. However, as a precautionary measure and to minimise biological activity in the storage reservoirs and pipelines, even such waters should be chlorinated before distribution. South Africa successfully achieved the Millennium Developmental Goals target of halving the proportion of people without access to safe water. But there are still challenges amongst communities living in rural settlements who still lack access to water supply and acceptable basic sanitation. The scattered nature of rural settlements presents major challenges for providing sustainable services (UNESCO, 2006). The water quality of various surface water systems has been deteriorating and has become an alarming situation for the country. Many rural communities of South Africa, particularly those living in areas with resource-poor settings, are forced to use untreated water from surface water sources like rivers and groundwater as an alternative supply. The microbial quality of these surface waters are usually compromised by surrounding industrial and agricultural plants that channel their waste directly into rivers (Abia et al., 2015). Microbiological pollution is introduced into water mostly from human and animal activities such as unsewered settlements, on-site sanitation, cemeteries, waste disposal and feedlots (Mpenyana-Monyatsi & Momba, 2012). Water-borne diseases are a direct indication of deterioration of water quality. Improved water supplies such as household connections, public standpipes, and boreholes may not have microbiologically safe water which is often contaminated with pathogens causing infectious diseases such as cholera, enteric fever, dysentery and hepatitis as has been experienced in South Africa. Moreover, during storage, the water deteriorates to a quality often not safe for human consumption (Sobsey, 2005). In 2004, there were reported 2,780 cholera infections with 35 fatalities and 9,503 hepatitis A infections with 49 fatalities, and 894 recorded cases of shigella dysenteriae. Each year, some 2.5 million people fall ill with bilharzia (schistosomiasis), and 10% are severely infected, although few die of the disease. Schistosomiasis infections are highest (up to 70 percent) amongst children living in lower-lying areas of Limpopo Province, Mpumalanga and KwaZulu-Natal.

In areas without proper water distribution infrastructure, a number of potential and established POU water treatment to control biological contaminants have been instituted. One such POU system treats water with the use of solar irradiation, commonly referred to as solar disinfection (SODIS). In this technique transparent polyethylene terephthalate (PET or PETE) bottles are filled with aerated source water and exposed to solar UV and heat energy outside during the sunlight hours of the day (Figure 4).

Figure 4: Solar disinfection using sunlight during the day

Another POU systems is porous ceramic (fired clay) media used to filter microbes from drinking water by size exclusion. The silver-impregnated porous pot filter (SIPP) was developed as part of a project commissioned by the Water Research Commission of South Africa (Figure 4) and tested in rural areas of Limpopo Province. Similarly, Abebe et al. (2014) explored the performance of a household-level ceramic water filter (CWF) impregnated with silver nanoparticles (Figure 1Figure 5) and associated safe-storage containers as intervention to improve drinking water quality and decrease days of diarrhoea in people living with the human immunodeficiency virus (PLWH) in rural South Africa. The CWFs were found to be acceptable technology that can significantly improve the quality of household water and decrease days of diarrhoea for PLWH in rural South Africa.

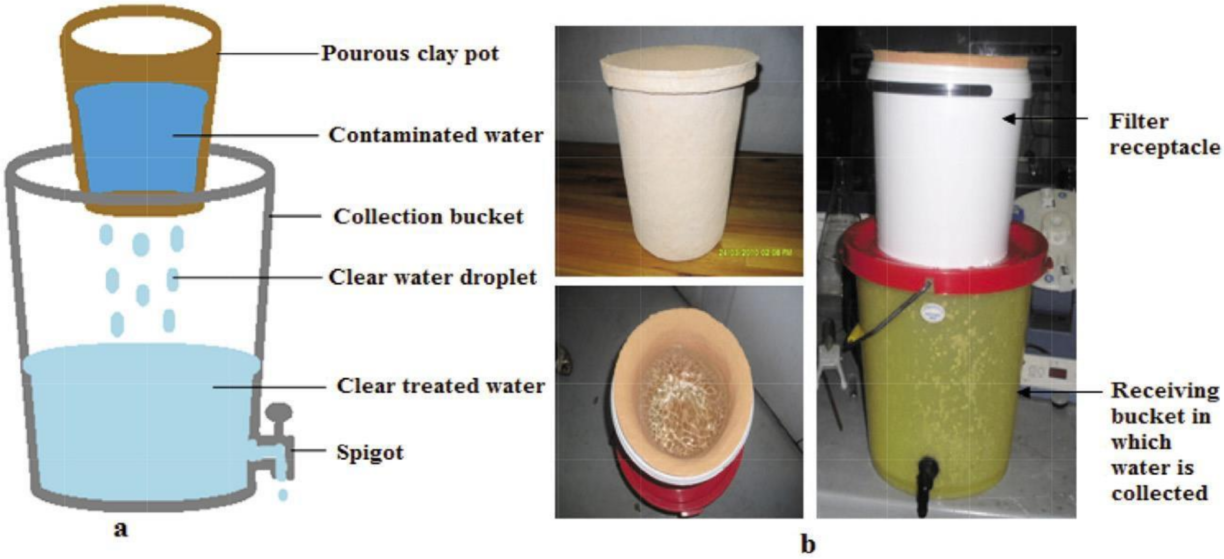

Figure 5: A schematic diagram and a photo of a silver-impregnated porous pot (Mwabi et al., 2011; Mwabi el al., 2013).

A third kind of POU system is the ceramic candle filters (Figure 6) which have been manufactured and used in Venda in Limpopo province household water purification (Malapane et al., 2012).

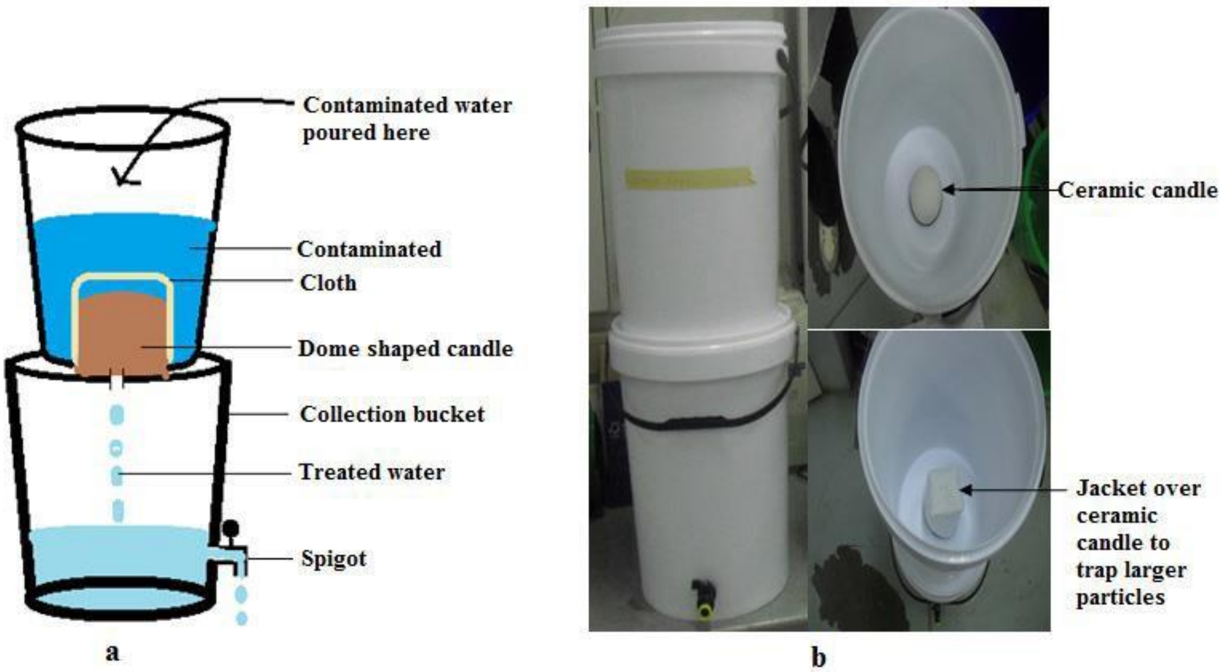

Figure 6 Schematic diagram; and (b) photograph of the ceramic candle filter (CCF) (Mwabi et al., 2011; Mwabi el al., 2013).

A fourth POU system is the biosand filter (BSF) (Figure 7) designed as a modification of the large-scale, continuously operated slow sand filter, and allows for intermittent water dosing for household use.

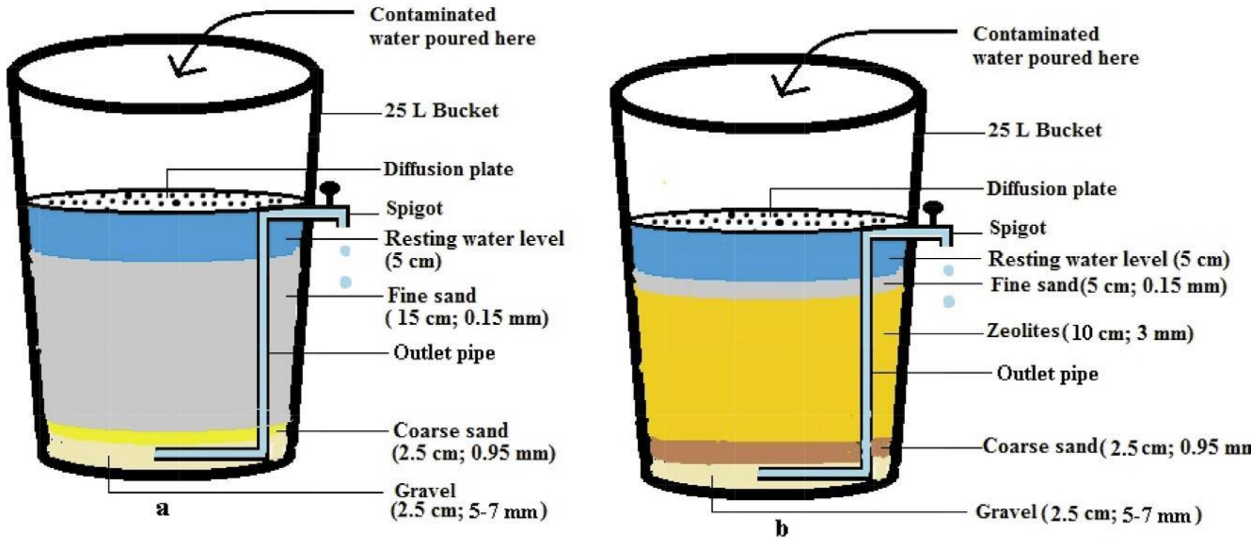

Figure 7: Schematic diagram of plastic biosand filters; (a) biosand filter-standard (BSF-S); and (b) biosand filter-zeolite (BSF-Z) (Mwabi et al., 2011; Mwabi el al., 2013).

Meanwhile a pilot plant based on the principle of gravity-driven membrane disinfection has been designed and built in 2009-2010 in rural settlement of Ogunjini, KwaZulu-Natal in collaboration with Veolia, and Umgeni water works (Peter-Varbanets et al., 2011). A similar system is also used in Tshaanda-Vhembe District and is discussed in detail in the subsequent section.

3.4. Case study: tshaanda pou water treatment system

Recently a number of studies have shown that water quality in rural areas do not meet SANS 241 guidelines (Mpenyana-Monyatsi et al., 2012). In Tshaanda in Vhembe District, Limpopo provinnce (Figure 8) for instance, drinking water is obtained from a unprotected spring. The village is impoverished and excluded from the mainstream water network in Vhembe and it is unlikely that the village will be connected to the mainstream water infrastructure in the future because the mountains (Figure 9) that are surrounding it make Tshaanda difficult to access (Molelekwa et al., 2014).

Figure 8: Location of Tshaanda Water Treatment in Limpopo Province (Molelekwa et al., 2014)

Figure 9: Rugged terrain in Tshaanda Rural Community

Figure 10: Tshaanda water treatment system

Due to a critical need of clean water in this remote area, the Tshwane University of Technology together with KU Leuven University has identified a need for improved water treatment technologies. Consequently, a membrane system using ultra filtration (UF) (Figure 10) has been built to serve the community of approximately 800 people and 150 households. Though the UF pilot plant in Tshaanda produces safe drinking water, there is still much work to be done before this technology could be rolled-out countrywide. Key aspects that require consideration include: evidence of sustained use, positive health impact, water quality over extended periods of use, operation and maintenance, cost-effectiveness, system performance and optimization (considering seasonal variations), and water quality monitoring, whereby the frequency of water testing will be increased.

3.5. Screening strategies of POU systems used in a specific site

The POU systems mentioned above are those that are widely reported in rural areas in South Africa. Their application in a specific geographical region depends on a number of factors. In discussing these factors, our argument will be biased toward application of the various techniques in rural areas because these regions bear the highest occurrence of water quality issues. Moreover, these factors may also be used as the basis of a decision framework for helping local governments, communities or individuals in determining the most appropriate technique.

3.5.1 Consideration of cost

South Africa is a medium income country with high level of unemployment. Most environments where POU systems are required are dominated by unemployed or people with very low income. Consequently, the issue of affordability of POU systems cannot be underestimated. Application of a given technology will depend on the cost of that technology. It should be noted that without any doubt implementing a POU treatment strategy is substantially less expensive than building, expanding, or upgrading a central treatment plant since only a portion of water used in the household is treated to a higher level using POU system. Where local government provides POU systems, both capital and O&M costs associated with a device and factors that impact cost must be understood in order to help in identifying and evaluating an appropriate alternatives. These factors include but not limited to (EPA, 2006):

-Maintenance frequency

-Emergency maintenance contingencies

-Monitoring frequency

-Public education

-Residual disposal

-Insurance costs

3.5.2 Regulatory compliance

SANS 241 guidelines set the maximum allowable concentration of contaminants in water. The performance of the POU technologies considered depends on the quality of the water to be treated. In selecting these POU systems, the target contaminant(s) must be reduced to acceptable level as per national guidelines.

3.5.3 Appropriateness of the technique

A given technology of choice should be tailor-made to suit the local conditions of the region in which it is intended. The local conditions include the fact that most of the contaminated water are obtained from springs, tube wells, that the wells are scattered all over the region where in some cases there is no electricity, that the users are mainly women with no strong education and no sound incomes (Muscot, 1999). In considering these factors, POU systems such as those based on membrane technology that require medium- to high-level skills to operate are automatically require critical appraisal before implementing. Moreover, those that require electricity cannot be applied to areas where there is no supply of electricity or alternative power source.

3.5.4 Environmental burden

The consideration of secondary wastes that a given POU systems may release in the environment is very important before a decision is made to adopt such a system. Unfortunately a number of POU systems may result in secondary wastes whose treatment must also be taken into account. For instance, POU systems based on membrane processes reject a large amount of water, while those based on ion exchange produce highly concentrated brine. Based on these assessments, these technologies will all impact negatively on the environment. Even where POU system is based on adsorption non-hazardous spent regeneration solution is produced and thus an additional chemical handling facility would be required. Proper assessment of all POU systems is required for a specific site where it is to be applied.

3.5.5 Public perception and acceptance

Public perception and acceptance is critical to the success of a given POU water treatment technology. To make a POU system popular, there must be an understanding of local socio-cultural inclination. Systems that have cultural connotation such as those based on clays/ceramics used for biological contaminants control may be easily accepted by rural communities. Consequently, a thorough social study must be conducted to explore the perception and acceptability of a given POU system before it is deployed for use in a given community.

3.6. Technology implementation of POU systems for water treatment in rural areas

It may be neither economically nor technically viable to set up a reliable water distribution network in rural areas. Consequently, novel decentralised water systems that are robust, low-cost and as independent as possible from chemical and energy requirements should be promoted (Boulestreau *et al.*, 2012). Such system (point-of- use system) intervention presents an attractive and effective way of providing portable water to rural communities in most developing and transition countries. The low levels of capital investment of the approach makes it particularly attractive due to reduced/limited resources available (Peter-Varbanets *et al.*, 2009).

Critical evaluation of past projects and experiences in other areas of the world can provide needed insight for planning future applications of POU system in South Africa where widespread use is non-existent. Starting from the premise that decentralization itself will not necessarily improve demand responsiveness, there is a need for flexibility and capacity building. Effective decentralization takes time, political will, and development of specific skills and clear articulation of the legal institutional roles of each stakeholder. In addition, financial and functional responsibilities must be decentralized together for decentralization to be effective. Some of the critical implementation considerations of POU system include project cost and best practices.

3.6.1 Determining project costs (project planning)

WHO categorizes costs for POU systems as low, medium and high on a worldwide basis including the poorest people (Varbanets *et al.*, 2006). Capital costs are reported to depend not only on the raw source water quality and the plant capacity but also on the year of construction. Several parameters explain this rapid capital cost reduction which includes the standardization of the systems and therefore a lower manufacturing cost, a higher production volume, and also an optimization of the process itself (Laîné *et al.*, 2000). Other costs include salaries for engineers, organizing community meetings and training mechanics.

3.6.2 Establishing best practices

This can be achieved through involvement/working with sector experts; that is people who know which approaches are most effective to ensure that the programs utilize the best practices in the field.

a) Establish community buy-in

Consumer acceptance of safe water use largely depends on the perceived need for alternative water treatment/purification systems; when water distribution networks are inadequate, improved water treatment technologies applications are generally better accepted by the general public. The main reasons for establishing a communication process are to (a) inform and educate the public, (b) add public input to the development of the final approach, (c) raise issues early and avoid surprises, and (d) identify the project opponents and their issues. The communication process is best implemented by soliciting public input, developing a series of educational/information activities, sharing the decision-making and problem-solving responsibilities, and focusing on winning and maintaining the community support. A citizens' advisory committee, with a broad representation, serves to make a vital connection between the (local) government and citizens (Exall *et al.*, 2004).

b) Promote safe hygiene practices

Encourage behavioural change in water use practices amongst communities through education and health awareness programmes to address the challenges of skills shortage and thus stimulate learning, interest and support to ensure the necessary skills into the future to manage water services and resources.

c) Building water committee capacity to manage costs

3.6.3 Working with local government/authorities

Local government plays a major role in keeping water flowing. In the case of rural areas, local authorities (chiefs) engage with communities, district and regional leaders to plan out the project. This is in order to strengthen local ownership and help to build local capacity to maintain the project for years to come.

In rural areas of developing countries, the situation is comparable to that of the transition and developed countries. Differences exist in the acceptable level of costs for POU systems and the ability of the local community to safeguard maintenance and control of these systems. Overall, to ensure sustainability, investment should focus on forming strong water committees, partnering with local government, and training mechanics to perform repairs.

3.7. *Challenges in implementing POU systems*

3.7.1 Who bears the cost?

South African constitution clearly defines water as a right and hence all must have access or provided with clean water. The local government therefore carries the burden of financing POU system units to the community. It is doubtful though if this approach may work on long term basis. Experiences in South Africa have shown that local governments cannot deliver on a number of services. And worse if the service is free. This has led to a number of service delivery protests. A better option would though be for the local government to devise a cost-sharing method in which they provide POU systems and maintenance personnel but impose some tariffs to water users. This approach would provide sustainable use of the POU systems.

3.7.2 Ownership

Experience has shown that community water treatment systems hardly pass the test of time. This is partly due to a lack of sense of ownership by the user communities, resulting in indifferent attitude toward the operation and maintenance of these plants (Daw, 2004). To succeed, a holistic participatory approach should be adopted in dealing with POU units. The local government, private sector, community-based organizations (CBOs) and the local water users should form a concerted effort in mitigating the water problems and implementing treatment technologies. Women being the main users of POU treatment technologies in rural areas should not be isolated but should participate fully.

3.7.3 Operation and maintenance

POU devices require routine maintenance, mostly to change and dispose of spent media and evaluate the device's effectiveness using field sample kits. There is a clear connection between inadequate maintenance and deteriorating unit performance (Colorado Department of Public Health and Environment, n.d.). Also important to note is the fact that POUs have a life expectancy and therefore should not be used beyond the manufacturers recommenced period. In small communities, there will hardly be qualified personnel to perform routine maintenance. The local government must therefore invest Operation and maintenance therefore is an area the local government must invest heavily to ensure the success implementation of POU systems.

3.7.4 Monitoring

POU devices are short term solution to provision of portable water and only considered acceptable for use as interim measures, such as a condition of obtaining a variance or exemption to avoid unreasonable risks to health before full compliance can be achieved. Because a number of communities may not have supply of water from centralized treatment system in the near future, POU system must be advocated for in rural areas in South Africa. If implemented in such environments, the problem of monitoring treatment performance so that it is comparable to central treatment will be a key issue to consider.

3.7.5 Behaviour change

The provision of cleaning drinking water to all is a still a pipe dream even though water provision is recognized in the constitution as a right. In the South African context, a number of poor, those with low income and historically disadvantaged have developed a habit and inclination towards demanding for free goods from government. If uptake of POU systems are to be realized, then behaviour change must be tackled. This can be achieved through proper promotional activities, use of community meetings and getting support of respected community elders (Makutsa et al., 2001).The message sent to individuals and communities must be packaged in a manner as not to create wrong rumours about the intention of POU systems providers.

3.8. Skills development

3.8.1 Installation, operation and maintenance skills

To be successfully implemented POU devices must be owned, operated and maintained by the local government in collaboration with local community being served. Consequently, POU devices must be installed by an appropriately licensed plumber. An electrician may be required if the device requires power and the installation site is not supplied with adequate power. Once POU system is installed, it must be under the direct supervision of an operator certified at an appropriate level to do supervision. Moreover, the success of a POU treatment system is largely dependent on an aggressive and practical maintenance program. POU maintenance issues include routine maintenance, replacement of parts or devices, as well as emergency maintenance (Colorado Department of Public Health and Environment, n.d.). The local government will therefore need to have sufficient qualified plumbers, electrician and process operators for community level POU systems. In case of skills shortage, the local government may offer training programs on the use, operation and maintenance of POU treatment units. Meanwhile management of household POU systems are a bit complicated in nature and may or may not require plumbers, electrician depending on their level of complexity.

3.8.2 Monitoring water quality skills

The quality of water that comes from POU system must meet SANS241 standards since water may affect public health. Sampling of the water provided by the POU system is required both after initial installation and on a routine basis. Additional tests for bacterial and/or field-sampling may be required, depending on the type of POU device selected. The local government must therefore make available well trained process control and highly trained water quality monitoring personnel. A number of local governments don't have qualified personnel in relevant skills such as microbiology, analytical chemistry and chemical/environmental/civil engineering. Consequently, a lot of effort must be put in helping the local community to acquire these skills in order to manage the POU systems.

3.9. Conclusions

This study explored the extent of use and profile of various point-of-use (POU) water treatment systems with special focus to sites where local governments have mandate. The study revealed that whereas a number of drinking water sources do not meet SANS 241 standards, hardly any system to ameliorate the quality of water is instituted. This exposures those affected to various water borne diseases. Fortunately there are a number of developed and potential POU systems available commercially that can be used at sites where no centralized water treatment is available. A number of these systems are profiled in this study and screening strategies are provided that can help local governments in decision making to choose an appropriate system that may suit a particular site. A number of impediments to uptake of POU systems have been identified and strategies on how to implement POU systems discussed. It is also identified that skills deficiency in local governments in monitoring, and in operation and maintenance of the various POU systems need to be overcome to successfully implement these systems in rural areas. It is no doubt that South African sites that are not served with centralized treated water will need POU systems as a short to medium time solution to water quality problem.

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CHAPTER 4

4. Alternative Sources of Water Supply

4.1. Introduction

South Africa is a water scarcity country; most communities rely directly on rainfall to sustain their livelihoods. Unevenness in timing and distribution of rainfall may leave many communities without access to water for even the most basic daily requirements. Predictable changes in climate in the future may result in greater irregularities in the availability of water for daily use.

There are eleven different types of water sources for households in South Africa that are grouped in piped and non-piped (Table 4). Most communities rely on a single source thereby impacting negatively on its reliability and health of users. Diversification of water sources, with one being domestic RWH (DRWH), offers greater prospects of reliability and good hygiene.

Table 4: Existing type of water sources in South Africa (Statistics SA, 2006)

No.	Category	Types of water source
1	Piped	Piped water (tap) inside dwelling
2		Piped water (tap) inside yard
3		Piped water on community stand: distance ≤200 m from dwelling
4		Piped water on community stand: distance > 200 m from dwelling
5	Non Piped	Borehole
6		Spring
7		Rainwater tank
8		Dam/pool/stagnant water
9		River/stream
10		Water vendors
11		Other

4.2. Rain Water Harvesting (RWH) in South Africa

Rain water harvesting (RHW) is one of the major sources of water supply nowadays. The potential of rainwater harvesting (RWH) to mitigate the spatial and temporal variability of rainfall has brought about its revival during the last two decades. For planning and implementation purposes, it is critical to be able to identify areas suitable for RWH. However, the full potential of this type of water supply has not been fully exploited in South Africa to date.

Rainwater harvesting (RWH) is described as the collection, storage and use of rainwater for small-scale productive purposes (Goud, 1999). It has been identified at a number of international for a as one of the important interventions necessary towards meeting the Millennium Development Goals in Africa. RWH enhances water productivity by mitigating temporal and spatial variability of rainfall and provide water for basic human needs and other small-scale productive activities (Kahinda et al., 2010). In areas with dispersed populations or where the costs of developing surface or groundwater resources are high, RWH and storage have proved to be an affordable and sustainable intervention (Mati et al., 2006).

Rainwater harvesting (RWH) has thus regained its importance as a valuable alternative or supplementary water resource, along with more conventional water supply technologies. Much actual or potential water shortages can be relieved if rainwater harvesting is practised more widely. In many areas RWH has now been introduced as part of an integrated water supply, where the town water supply is unreliable, or where local water sources dry up for a part of the year. But RWH can also be introduced as the sole water source for communities or households. The technology is flexible and adaptable to a very wide variety of conditions. It is used in the richest and the poorest societies, as well as in the wettest and the driest regions on our planet.

In South Africa, where 2.1 million people have no access to water supply infrastructure, the Department of Water Affairs (DWA) has implemented a pilot domestic Rainwater Harvesting (RWH) project meant to improve food security in rural areas by providing water for home gardening (De Lange, 2006). Duncker (2000) pointed out that some households also use this water for drinking and other purposes. Mwenge Kahinda *et al*. (2007) discuss how domestic Rain Water Harvesting can be used to improve water supply in rural South Africa.

Rainwater harvesting provides immediate access to water by homesteads, especially those not located near to reticulation networks at basic level. The rainwater is collected from roofs and stored in tanks mainly for domestic use and production farming. Simple community built rainwater tanks provide the skills within the community to build and to carry out maintenance works on the tanks. It will also pass on the skills to neighbouring communities. Access to rainwater tanks is therefore unrestricted and not limited to qualifying for subsidy schemes (DWA, 2011)

If RHW system is designed well, it will require little or no electricity, chemicals or maintenance. RWH will offer benefits such as promoting self-sufficiency and appreciation of rainwater and it also encourages water and energy conservation. The water stored using rooftop RWH systems can be used for gardening, toilet flushing or even for car washing. If properly stored and boiled the water could be used for portable purposes with minimum treatment.

Several municipalities now use roof rainwater harvesting for domestic uses. These have been found to be effective when used in conjunction with other water supply options. However in order to effectively use RWH system, it is required that both government and non-government sectors promote the practice on regional community and families.

4.2.1. *Challenges on Implementation of RWH*

One of the challenges water managers facing is to define water harvesting (WH). There is little difference in literature about water harvesting (WH), its function and purpose in relation to domestic and agricultural uses (Denison and Wotshela, 2009). Prinz (2002) distinguishes the following WH groups: fog–dew, rainwater, floodwater and groundwater harvesting (Figure 11). Thus, WH encompasses RWH as it also includes floodwater harvesting.

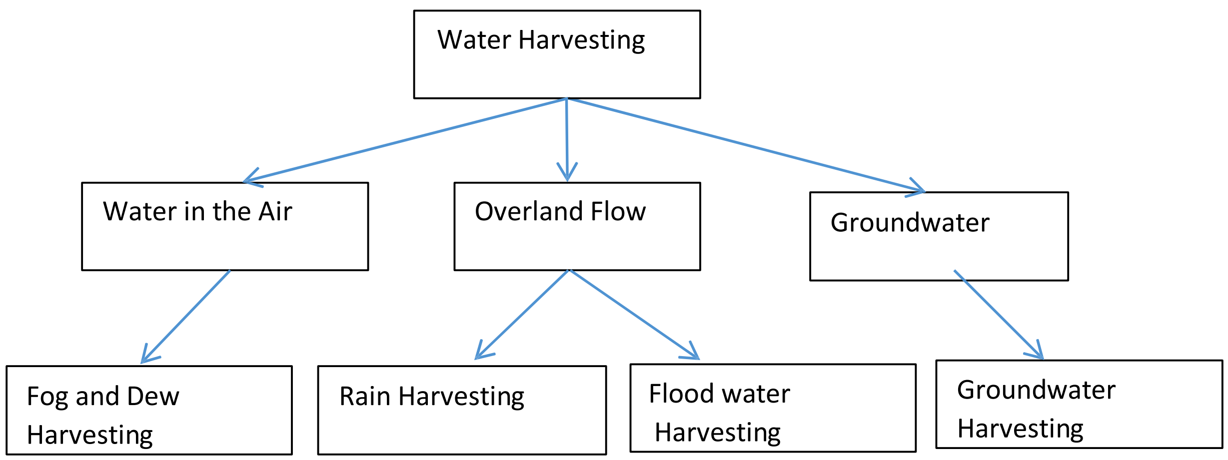

Figure 11: Subdivision of water harvesting (Prinz, 2002)

Another challenge facing RWH technology is that;

- It generally requires high labour input during their implementation phase
- A tight budget required (capital) to buy the necessary tools needed to implement RWH.
- The South African water related legislations do not give a clear legal framework for the adoption of RWH, making it illegal by strict application of the law.
- The sustainable implementation of RWH requires institutional innovations. The lack of a national umbrella body that coordinates RWH not only hampers the expansion of RWH but also makes documentation of the practice difficult (Kahinda et al., 2005).

Moreover, there has been researches done on the socio-economic impact, and techniques of RWH, hence there is a need to fast track the knowledge base and guidelines generated by different researchers all over South Africa.

4.2.2. *Methods of Rain Water Harvesting*

Broadly there are two ways of harvesting rainwater.

(i) Surface runoff harvesting

(ii) Roof top rainwater harvesting

Various methods of rainwater harvesting are described in this section.

Surface runoff harvesting: In urban area rainwater flows away as surface runoff. This runoff could be caught and used for recharging aquifers by adopting appropriate methods.

Roof Top rainwater harvesting: It is a system of catching rainwater where it falls. In rooftop harvesting, the roof becomes the catchments, and the rainwater is collected from the roof of the house/building. It can either be stored in a tank or diverted to artificial recharge system. This method is less expensive and very effective and if implemented properly helps in augmenting the ground water level of the area.

Techniques on RWH: Rainwater harvesting (RWH) is a simple technique that offers many benefits. It can be done very low-tech, doesn't cost much and is applicable at small-scale with a minimum of specific expertise or knowledge; or in more sophisticated systems at large-scale (e.g. a whole housing area).The most common technique in urban areas (besides storm water management) is rooftop rainwater harvesting: rainwater is collected on the roof and transported with gutters to a storage reservoir, where it provides water at the point of consumption or is used for groundwater recharge (see also surface and subsurface artificial groundwater recharge). Collected rainwater can supplement other water sources when they become scarce or are of low quality like brackish groundwater or polluted surface water in the rainy season. It also provides a good alternative and replacement in times of drought or when the water table drops and wells go dry. The technology is flexible and adaptable to a very wide variety of conditions. It is used in the richest and the poorest societies, as well as in the wettest and the driest regions on our planet (Hatum and Worm, 2006).

4.2.3. *Treatment of stored water from RWH*

Treatment of stored rainwater makes sense only if it is done properly. There are several possible treatment methods, the most common being sand filters, chlorination, boiling and exposure to sunlight (Hatum and Worm, 2006)

(a) Sand filters

Sand filters provide a cheap and simple method to purify water. Two filter types can be used: a filter can be connected to the tank to filter the water as it enters the tank. Such a filter can provide 50 litres of water per day – enough for the drinking and cooking needs of a small family. However, this filtering method is only suitable where the inflow is slow. The second filtering type is a so-called point of use filter, which unlike the first option is not located at the inflow point. Water for drinking purposes is filtered through a portable sand filter. This second type is highly recommended. In a sand filter, additional layers of gravel and charcoal are also commonly used to further improve the filtering capacity and thus the water quality. Sand filters do require careful operation and maintenance to ensure they continue to work effectively.

(b) Chlorination

Chlorination can be an effective way to purify the water. The chlorine will, however, affect the taste of the water and over-application can cause health problems. If you suspect the water in your tank is contaminated, adding calcium hypochlorite or sodium hypochlorite should treat it. The initial dose should be 7 g of calcium hypochlorite or 40 ml of sodium hypochlorite per 1000 litres of water in the tank. The water should be stirred and left to stand for 24 hours (no additional water may enter the reservoir). To maintain a safe water supply after this initial dosage, 1 g of calcium hypochlorite or 4 ml of sodium hypochlorite per 1000 litres should be added to the rainwater tank weekly and the mixture should be allowed to stand for at least two hours before use. Stabilised chlorine (chlorinated cyanurates) should the water as it enters the tank. Such a filter can provide 50 litres of water per day – enough for the drinking and cooking needs of a small family. However, this filtering method is only suitable where the inflow is slow. The second filtering type is a so-called point of use filter, which unlike the first option is not located at the inflow point. Water for drinking purposes is filtered through a portable sand filter.

This second type is highly recommended. In a sand filter, additional layers of gravel and charcoal are also commonly used to further improve the filtering capacity and thus the water quality. Sand filters do require careful operation and maintenance to ensure they continue to work effectively.

(c) Boiling

Boiling water for two or three minutes normally ensures that it is free from harmful bacteria or pathogens. However, boiling requires a lot of energy and in some areas this might be a problem due to shortage of fuel or wood. Many people do not like the flat taste of boiled water and it takes time for it to cool down before you can drink it. Additionally there are a wide variety of systems available for treating water either before, during and/or after storage (e.g. biosand filter, SODIS, chlorination; or in general HWTS). (Thomas and Martinson, 2007)

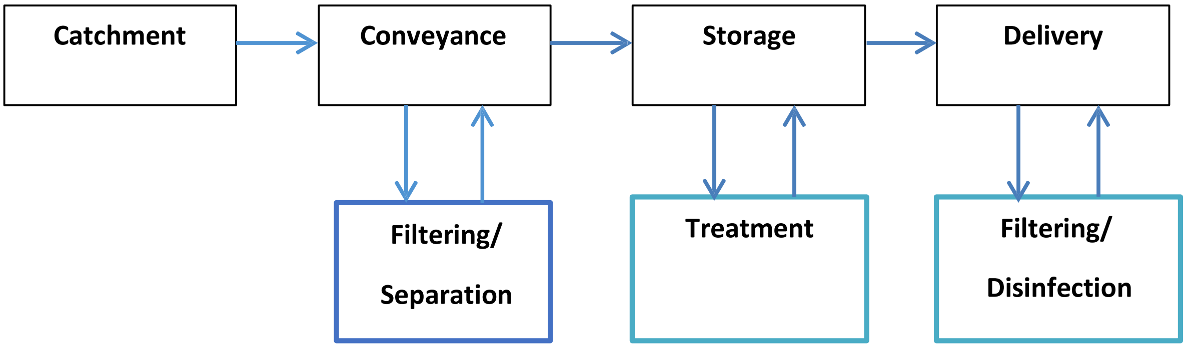

Figure 12 Process diagram of a drinking water RWH system (Thomas and Martinson, 2007)

In conclusion, rainwater harvesting, in conjunction with other alternative methods of exploiting water sources can greatly benefit people at the rural community areas in South Africa. RWH is already often being done with no prior technical knowledge or external assistance but simply as a common sense response to a lack of water. Rainwater harvesting depends on an often unpredictable and sometimes unreliable source, namely rain. However, the potential of this common sense exploitation of a water source should be recognised. The implementation of simple design and technical criteria will optimise the quality and quantity of water. The upgrading of rainwater harvesting systems in South Africa would benefit from the official support of the South African government to give this alternative water source political credibility. There are NGOs who are developing skills in the rainwater harvesting sector, but they are few and far between. With increasing demands being placed on South Africa's scarce and finite water sources, rainwater harvesting, an ancient practice, needs to be rediscovered and utilised.

4.3. Groundwater as other source of water supply in South Africa.

Groundwater is the main source of potable water for some urban and many rural communities in South Africa. It is about 15% of the country's total water consumption is supplied by groundwater sources; most of the times the communities depends upon groundwater have no other feasible sources of water supply. The value and vulnerability of groundwater represent a strategic component of the water resources of South Africa. Groundwater occurs widely and, geographically, almost two thirds of South Africa's population depends on it for their domestic water needs. Security of groundwater supplies is thus essential and protection of groundwater has become a national priority.

Historically, groundwater has been given limited attention, and has not been perceived as an important water resource in South Africa. Public perception prevails that groundwater is not a sustainable resource for bulk domestic supply and cannot be managed properly. Despite this, a growing number of municipalities utilise groundwater on a regular basis, and provide examples of successful management of this resource (Riemann et al., 2011). Lack of proper understanding of the occurrence, movement, and recharge of groundwater; have led to this resource not being utilized in a sustainable manner. It is estimated that about 90% of the local groundwater in South Africa occurs in secondary aquifers consisting primarily of shallow zones of weathering and fracturing. The resulting failure of boreholes in some instances has unfortunately promoted the view that groundwater is un-reliable source of water supply that should be replaced as soon by more reliable surface-water supplies. However the growing importance of groundwater is fortunately strongly reflected in the National Water Act.

4.3.1. *Challenges on groundwater management*

Managing water resources certainly requires knowledge of the relevant physical sciences and technology. The importance of groundwater resources to society has been well understood with increasing evidence of the variety of services that groundwater provides. Groundwater is most important source of fresh water worldwide. Groundwater resources can be supplied under extremely scarce conditions and can be sustainable stored in many years of scarcity.

Despite our confidence on groundwater, it has remained a poorly understood and managed resource, possibly due to its 'hidden' nature and the lack of adequate knowledge and physical data pertaining to aquifer characteristics and behaviour such as recharge, discharge, base flow and aquifer dependent ecosystems. Most groundwater quality and quantity problems in worldwide are related to human activities such as industry (e.g. infiltration of chemicals and toxins) and mining (e.g. acidification and increased metal content), urban development (e.g. salinization, eutrophication, microbial effects) and the intensification of agricultural practices (e.g., sedimentation, infiltration of agro-chemicals and salinization through irrigation return flows).

The complexity of the issues surrounding groundwater management is due to many distinctive characteristics of groundwater resource. In order to avoid misallocation of this resource, the following issues must be taken into consideration; availability of resource in terms of time and space and accessibility of resource to users by proper rights. However, after the promulgation of the new National Water Act, groundwater was declared a public resource with shared entitlements to use, therefore exposing the resource to further exploitation. Although provision was made for the management of groundwater resources under the Department of Water Affairs, the motivations behind the regulations and guidelines have been difficult to account for and implement on a regional level and subsequently are largely overlooked or neglected. Thus, there are still many challenges to overcome to achieve the sustainable management (Knüppe, 2010).

Groundwater management faces different challenges; the most significant challenge is education and awareness, and the collaboration between stakeholders on the importance of sustainable and efficient groundwater use (and monitoring). The first step should be awareness and understanding to users (Figure 13) will help to assist on the proactive management of groundwater in different areas in South Africa.

4.3.2. *Groundwater Contamination*

Groundwater can be contaminated on different ways. Groundwater pollution differs from surface water contamination in several important respects. Among them, it does not typically flow to a single outlet. It can affect people through wells dug in a contaminated aquifer, as it can flow into streams or lakes. Groundwater pollution also occurs on a different timescale than surface water contamination. Groundwater pollutants include substances that occur as liquids like petroleum, dissolved in water like nitrates, bacteria. Movements of water within the aquifer are then likely to spread pollutants over a wide area making the groundwater unsafe to use.

Groundwater contamination can be classified as having either natural or anthropogenic sources. Natural groundwater contamination is mainly due to geological formation with shallow groundwater mass (water–rock interaction in cold waters), infiltration from low-quality surface water bodies (streams, rivers, lakes), seawater intrusion, or due to the effect of geothermal fluids (water– rock interaction in hot waters). Anthropogenic groundwater contamination is generally ascribed to extreme use of agricultural pesticides and fertilizers, mining wastes, disposal of industrial wastes, waste disposal sites, and imperfect well construction.

4.3.1. *Dangers of Contaminated Groundwater*

Drinking water contains not only microbial contaminants, but also chemical contaminants that range from organic to inorganic compounds. Examples of organic chemicals that can be toxic are the polychlorinated and polybrominated biphenyls (PCBs and PBBs) as well as benzenes. Symptoms of acute toxicity can include diarrhoea, nausea, convulsions, blurred vision, and difficulty in breathing. These contaminants pose public health risks at high concentrations (DWAF, 1996).

Figure 13 Villagers washing around borehole at Gakgole village in Polokwane

Figure 14 Footsteps of animals around borehole at Mankweng in Limpopo

Organic pollutants may also cause arteriosclerosis, heart diseases, hypertension, emphysema, bronchitis, and kidney and liver dysfunction (Leivadara et al., 2008). Inorganic chemicals are also associated with health problems once they enter the human system. Nitrates accumulate in the blood stream and result in methemoglobinemia, of which a conspicuous symptom is a bluish skin. High concentrations of phosphate can cause health problems such as kidney damage and osteoporosis (Rose et al., 1996). Other chemical contaminants such as chloride, magnesium, iron, aluminium, copper, arsenic and lead can also be present in drinking water.

Drinking contaminated groundwater can have serious health effects. Diseases such as hepatitis and dysentery may be caused by contamination from septic tank waste or from animal wastes (Figure 14). Poisoning may be caused by toxins that have leached into well water supplies. Wildlife can also be harmed by contaminated groundwater. Other long term effects such as certain types of cancer may also result from exposure to polluted water.

4.3.2. *Potential Sources of Groundwater Contamination*

(a) Septic Systems

Onsite wastewater disposal systems used by homes, offices or other buildings that are not connected to a city sewer system. Septic systems are designed to slowly drain away human waste underground at a slow, harmless rate. An improperly designed, located, constructed, or maintained septic system can leak bacteria, viruses, household chemicals, and other contaminants into the groundwater causing serious problems.

(b) Landfills

Landfills are the places that our garbage is taken to be buried. Landfills are supposed to have a protective bottom layer to prevent contaminants from getting into the water. However, if there is no layer or it is cracked, contaminants from the landfill (car battery acid, paint, household cleaners, etc.) can make their way down into the groundwater.

Since groundwater is part of the hydrologic cycle, contaminants in other parts of the cycle, such as the atmosphere or bodies of surface water, can eventually be transferred into our groundwater supplies. Agricultural activities fertilizers and pesticides are commonly used in modern agriculture. This increases the risk of groundwater contamination, especially when the agricultural fields are exposed to hazardous chemicals for lengthy periods. Improper built wells can result in contaminated groundwater, by establishing a pathway or a conduit for pollutants entering a well from surface drainage or by allowing communication between aquifers of varying quality.

Unused wells sometimes are abandoned or truncated just below the groundwater surface and ploughed over, or otherwise destroyed improperly. Such wells can contaminate groundwater in many ways:

- Contamination enter the wells from the surface
- The well casing can corrode, allowing poor quality water
- The well might be used for direct an illegal disposal of waste

The widespread use of chemicals is another source of potential groundwater contamination. Chemicals include products used on lawns and farm fields to kill weeds and insects and to fertilize plants, and other products used in homes and businesses. When it rains, these chemicals can seep into the ground and eventually into the water.

4.3.3. *Characteristics contaminants in groundwater*

Groundwater will normally look clear and clean because the ground naturally filters out particulate matter. But, natural and human-induced chemicals can be found in groundwater. As groundwater flows through the ground, metals such as iron and manganese are dissolved and may later be found in high concentrations in the water.

Appendix 1 shows the contaminants found in groundwater, their potential sources of pollution to groundwater and health and other effects. The information was obtained from USGS water science school website and from (Waller, 1982).

4.3.4. *Characteristics contaminants in groundwater*

(a) ***Fitness-For-Use Categories***

The water quality guidelines as developed by the DWA, South Africa (DWAF, 1996 - South African Water Quality Guidelines Volumes 1 to 7 (second edition)) were used as the main set of criterion for the evaluation process. The guidelines provide a “description” of the impact that the water quality will have on the “usability” of that water. This “description” is a set of cut-off values, for each of the different fitness-for-use categories.

Water quality does not suddenly change from “good” to “bad”. Instead there is a gradual change between categories and this is reflected by the fitness-for-use range which is graded to indicate the increasing risk of using the water. Water quality criteria are discrete values that describe a specific effect as a result of a particular set of conditions. These criteria are then used to develop guidelines, which describe the effect on a user who is exposed to an ever increasing concentration or changing value. Water quality criteria are used to describe the fitness-for-use. The fitness-for-use range can be divided into four sections which are classified as four categories, ranging from "ideal" to "unacceptable" (DWA, 2012). These categories are described as:

Ideal: the user of the water is not affected in any way;

Acceptable: slight to moderate problems are encountered;

Tolerable**:** moderate to severe problems are encountered; and

Unacceptable*:* the water cannot be used under normal circumstances.

The fitness-for-use range is colour coded for ease of interpretation of information during the assessment of the groundwater quality (Table 5**).**

Table 5 User Specific Guidelines domestic (DWA, 2012) for variables of concern

Variable	Units	Ideal	Acceptable	Tolerable	Unacceptable
Domestic SA					
Nitrate/Nitrite	mg/l N	< 70.00	70.00 to 150.0	150.0 to 370.0	> 370.0
Chloride	mg/l	< 100.00	100.0 to 200.0	200.0 to 600.0	> 600.0
Magnesium	mg/l	< 70.0	100.0 – 200.0	200.0 – 400.0	> 400.0
Sulphate	mg/l	< 200.00	200.0 to 400.0	400.0 to 600.0	> 600.0

4.3.5. *Salts in groundwater*

The target ions of concern include; Chloride (Cl), Nitrite (NO_2)/Nitrate (NO_3), Sulphate (SO_4), Magnesium (Mg), Phosphate (PO_4). Refer appendix 1 for their sources of pollution and effects.

Chloride (Cl): Chloride (Cl): is an indicator of the nature of the salinity. It is an indicator of salty taste, and also corrosivity with respect to household appliances and irrigation equipment. In some water bodies' sulphate has the same effect as chloride and the two should be assessed in conjunction with each other. Effects on the aquatic ecosystem as a result of salinity will be detected long before chloride in itself becomes problematic, and chloride can therefore be ignored when assessing water quality in this respect. Some crops, specifically deciduous trees such as citrus, are sensitive to chloride as it builds up in the leaves and causes leave sclerosis. This is probably the most sensitive use with respect to chloride.

Nitrite (NO_2)/Nitrate (NO_3): Nitrogen refers to all inorganic nitrogen forms present in water, that is, ammonia, ammonium, nitrite and nitrate. Ammonia (NH_3) and Ammonium (NH_4) are the reduced forms of inorganic nitrogen and their relative portions in water are governed by water temperature and pH. Nitrite (NO_2) is the inorganic intermediate and nitrate (NO_3) the end product of the oxidation of organic nitrogen and ammonia. Nitrate is the more stable of the two forms, and usually, by far, the more abundant in the soil and water environment. In view of their co-occurrence and rapid interconversion, nitrite and nitrate are usually measured and considered together (DWAF: Irrigation, 1996). Nitrate/Nitrite (NO_3/NO_2): has a health effect on humans, and is also an indication of contamination from human activities in the catchment, notably the discharge of treated waste water. Nitrite has a toxic effect on aquatic organisms, particularly those organisms that breathe under water.

Phosphate (PO_4): Phosphorus can occur in numerous organic and inorganic forms, and may be present in waters as dissolved and particulate species. Elemental phosphorus does not occur in the natural environment. In unimpacted waters phosphorus is readily utilized by plants and converted into cell structures by photosynthetic action. Phosphorus is considered to be the principle nutrient controlling the degree of eutrophication in aquatic ecosystems. Natural sources of phosphorus include the weathering of rocks and the subsequent leaching of phosphate salts into surface waters, in addition to the decomposition of organic matter.

South Africa, phosphorus is seldom present in high concentrations in unimpacted surface waters because it is actively taken up by plants. Elevated levels of phosphorus may result from point-source discharges such as domestic and industrial effluents and from diffuse sources (non-point sources) in which the phosphorus load is generated by surface and subsurface drainage. Non-point sources include atmospheric precipitation, urban runoff, and drainage from agricultural land, in particular from land on which fertilizers have been applied.

Phosphorus concentrations are usually determined as orthophosphates, total inorganic phosphate or total dissolved phosphorus (which includes organically bound phosphorus and all phosphates). The dissolved forms are measured after filtering the sample through a prewashed 0.45 μm filter. Concentrations of particulate phosphorus can be calculated from the difference between the concentrations of the total and dissolved fractions (DWAF: Ecosystems, 1996). Phosphate (PO_4): has no direct effect on the use of water, but is an indicator of contamination from activities in the catchment such as waste water discharge and fertilisers from agricultural activities.

Sulphate (SO_4): Sulphate is a naturally occurring substance that contains sulphur and oxygen. It is present in various mineral salts that are found in soil. Sulphate may be leached from the soil and is commonly found in most water supplies. Magnesium, potassium and sodium sulphate salts are all soluble in water. Calcium and barium sulphates are not very easily dissolved in water.

There are several other sources of sulphate in water. Decaying plant and animal matter may release sulphate into water. Numerous chemical products including ammonium sulphate fertilizers contain sulphate in a variety of forms. Human activities such as the combustion of fossil fuels and sour gas processing release sulphur oxides to the atmosphere, some of which is converted to sulphate.

Sulphate is generally considered to be non-toxic. The consumption of drinking water containing high amounts of magnesium or sodium sulphate may result in intestinal discomfort, diarrhoea and consequently dehydration. This laxative effect is often observed when someone drinks water that contains greater than 500 milligrams per litre (mg/L) of sulphate. Over time, individuals appear to develop a tolerance to higher concentrations of sulphate. Diarrhoea and dehydration are often observed when individuals accustomed to drinking water with low concentrations of sulphate consume water with high amounts of sulphate. It is not advisable to use water that contains high concentrations of sulphate for infant feeding.

4.4. Project areas groundwater quality analysis

(a) North West

Water in the North West Province is obtained from ground and surface water sources. The latter are mostly non-perennial and include rivers and inland lakes. Groundwater is thus a major source and is used for domestic, agriculture and mining purposes mostly without prior treatment. Moreover, there are several pollution impacts (example; nitrates, organics, microbiological) that are recognised but are not always addressed. Elevated levels of inorganic substances could be due to natural geology of areas but may also be due to pollution. On the other hand, elevated organic substances are generally due to pollution from sanitation practices, mining activities and agriculture. Water quality data are, however, fragmented. A large section of the population of the North West Province is found in rural settings and most of them are affected by poverty.

Poor water quality in dense settlements has a wide range of significant impacts on human health, social development, and environment and down-stream use values. This is usually as a result of low standards of water supply and poor sanitation which is a feature of almost all developing areas such as is in many of the urban areas of Northwest Province. The diseases that arise as a result of inadequate water services contribute to a large proportion of infant and child death and too many of the diseases in adults (DWAF, 2001). Human consumption of contaminated water is highly costly in terms of disease costs, lost productivity costs and mortality costs. Water service providers therefore are particularly vigilant about treating water to acceptable portable standards. The cost of treatment increases dramatically with the presence of pollution from dense settlements (DWAF, 2001).

Apart from the few surface water resources, the NWP has a large reservoir of subterranean water in the form of fractured aquifers and dolomitic compartments (DWAF, 2002; Woodford *et al.*, 2005) of which more than 80% of the rural community solely depend on as a source of water, especially the more arid western region. Sixty Percent of the Province's population resides in rural settlements (NWP-SOER, 2008). Anthropogenic activities, which increase with population growth and urbanization, exert strong pressures on groundwater resources (Murray *et al.,* 2004; NWP-SOER, 2002;2008; Usher *et al.*, 2004) and due to the limited surface water resources in the Province (especially the arid western region of the Province), it is imperative to protect the groundwater resources of the North-West Province from further degradation.

North West Groundwater Quality Analysis

The groundwater quality data covering the period 2014 to 2015 was obtained from Department of Water affair and sanitation database. In this project four parameters of concern were selected to provide an indication of the suitability for use of groundwater resources by the designated user groups of Northwest Province. The parameter includes: Chloride, Magnesium, Sulphate and Nitrate/Nitrite. The analysis was done through the use of Geographical information system (GIS) software ArcGIS.

For the purposes of this discussion only domestic use will be discussed. The guidelines provide a description of the effect that changes in water quality will have on the use and not an interpretation of whether this is acceptable or not. From these guidelines the cut-off values for the different fitness-for-use categories have been set. The water quality guidelines identified for the abovementioned water uses for the variables of concern are summarised in Table 5**.**

Groundwater quality mapping

Parameters of concern like Chloride, Nitrate/Nitrite, Sulphate and Magnesium were analysed in the groundwater samples used for drinking purposes and their levels in different locations of the study area (Figure 15).

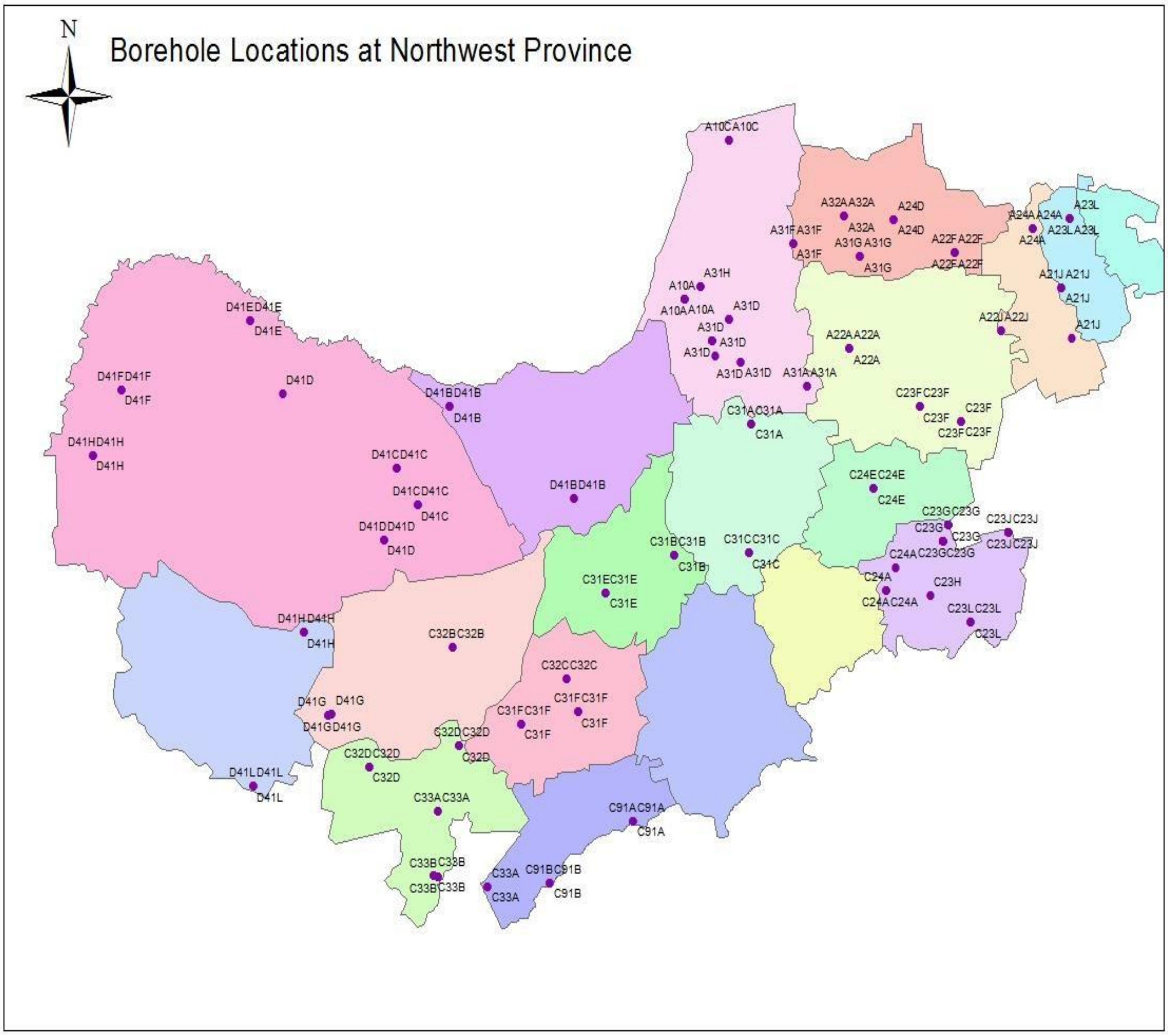

Figure 15 Location of analysed boreholes at Northwest for 2014 – 2015

Due to analysis some groundwater samples were found to have chloride, Magnesium nitrate and Sulphate values above desirable limits. The thematic maps were generated for groundwater quality for the parameter of concern at Northwest Province (Figure 15 to Figure 19).

After analysis a number of the values of the different variables show a water quality that is an "ideal" or "acceptable" water quality for use. Sulphate levels falls from ideal to acceptable (Figure 16), chloride levels in the study area ranges from acceptable to "tolerable" (Figure 17) that means slight to moderate problems are encountered. However Magnesium (Figure 18) and Nitrate/Nitrite (Figure 19) levels range from ideal to unacceptable. For the boreholes which have unacceptable situation, it means the water cannot be used under normal circumstances.

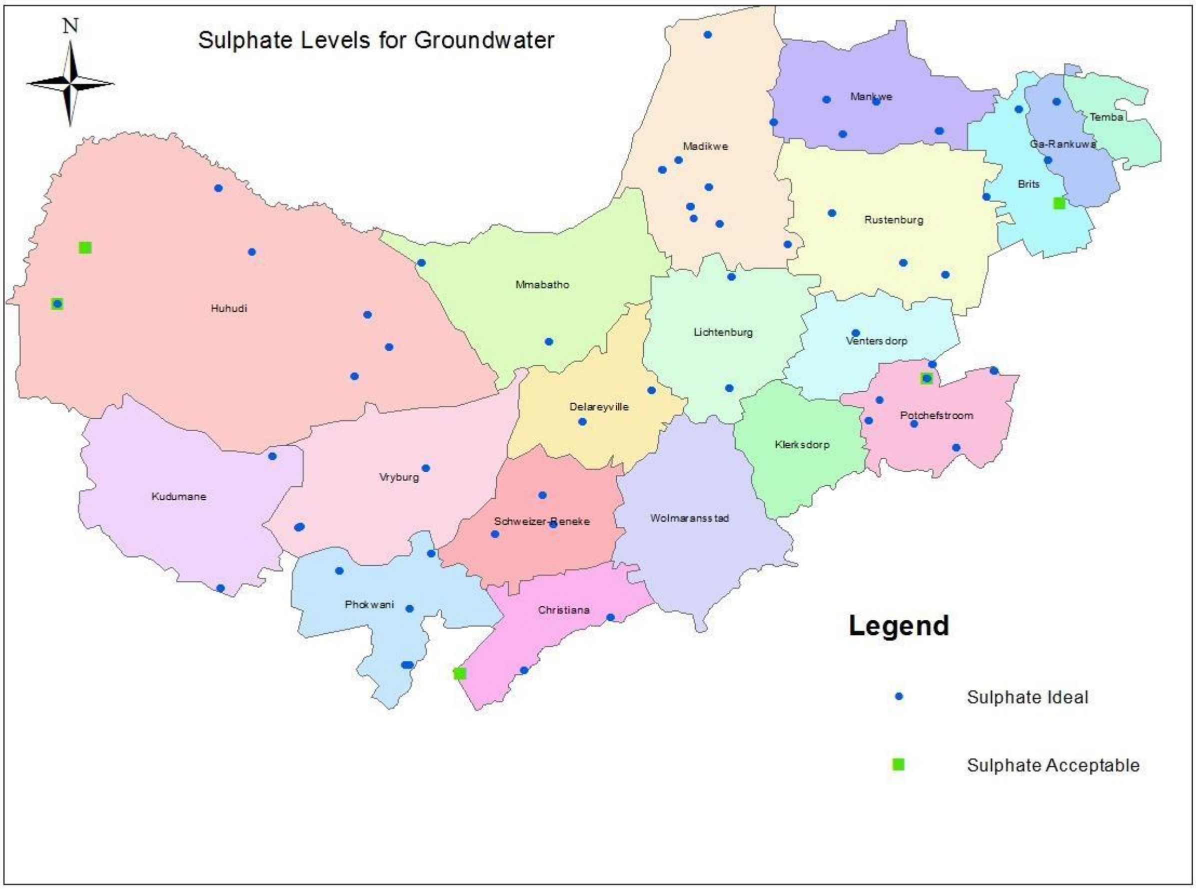

Figure 16 Map for Sulphate levels for Northwest 2014 – 2015

This higher nitrate concentration can be due to an increase in pit latrines in rural areas together with the rapid population growth of informal settlements contributed to the latter nitrate loading of ground waters (NWP-SOER, 2008). The main sources of nitrate and other pollutants of urban groundwater is sewage and nitrate can reach the aquifer by sewer leakage and, on-site disposal systems such as septic tanks. Urban sources of nitrate may have a high impact on groundwater quality because of the high concentration of potential sources in a smaller area than agricultural land (Wakida and Lerner, 2005).

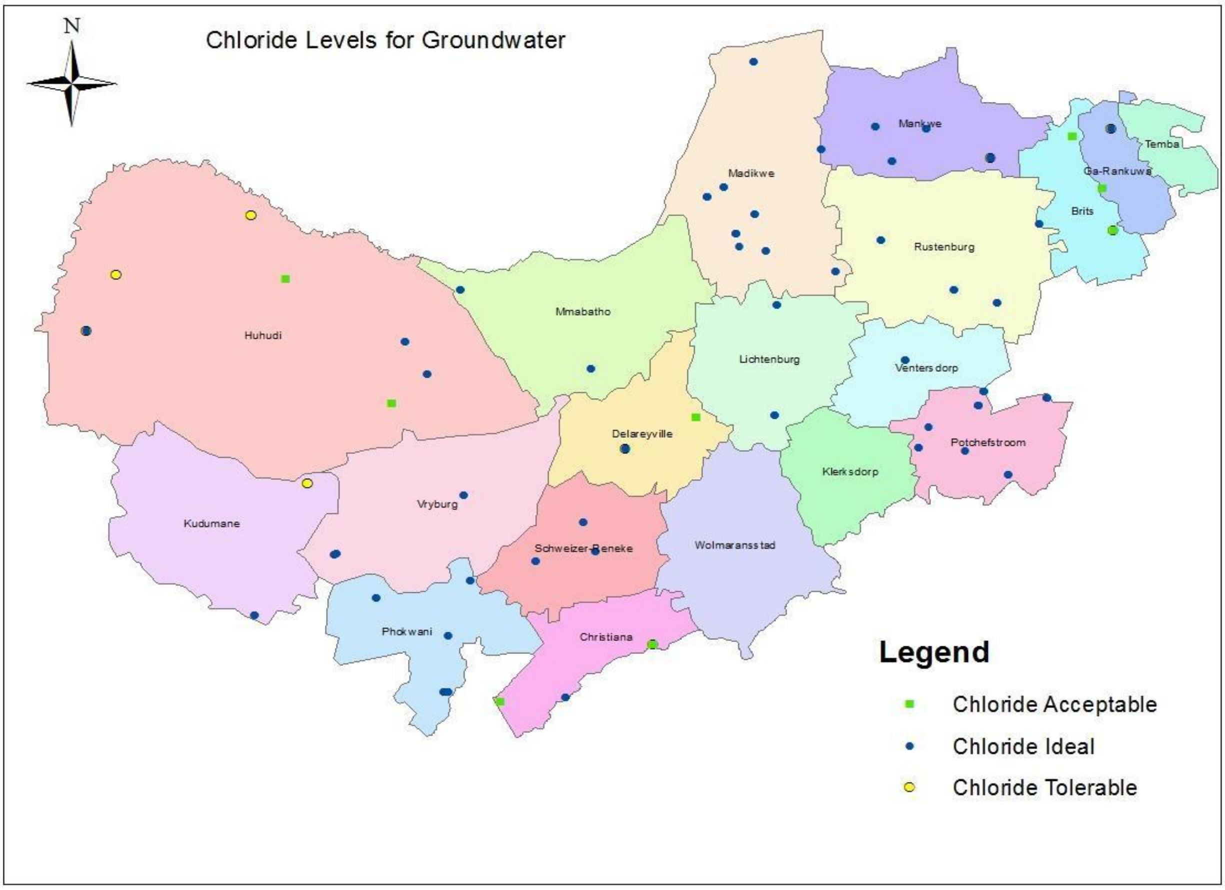

Figure 17 Map for Chloride levels for Northwest 2014 – 2015

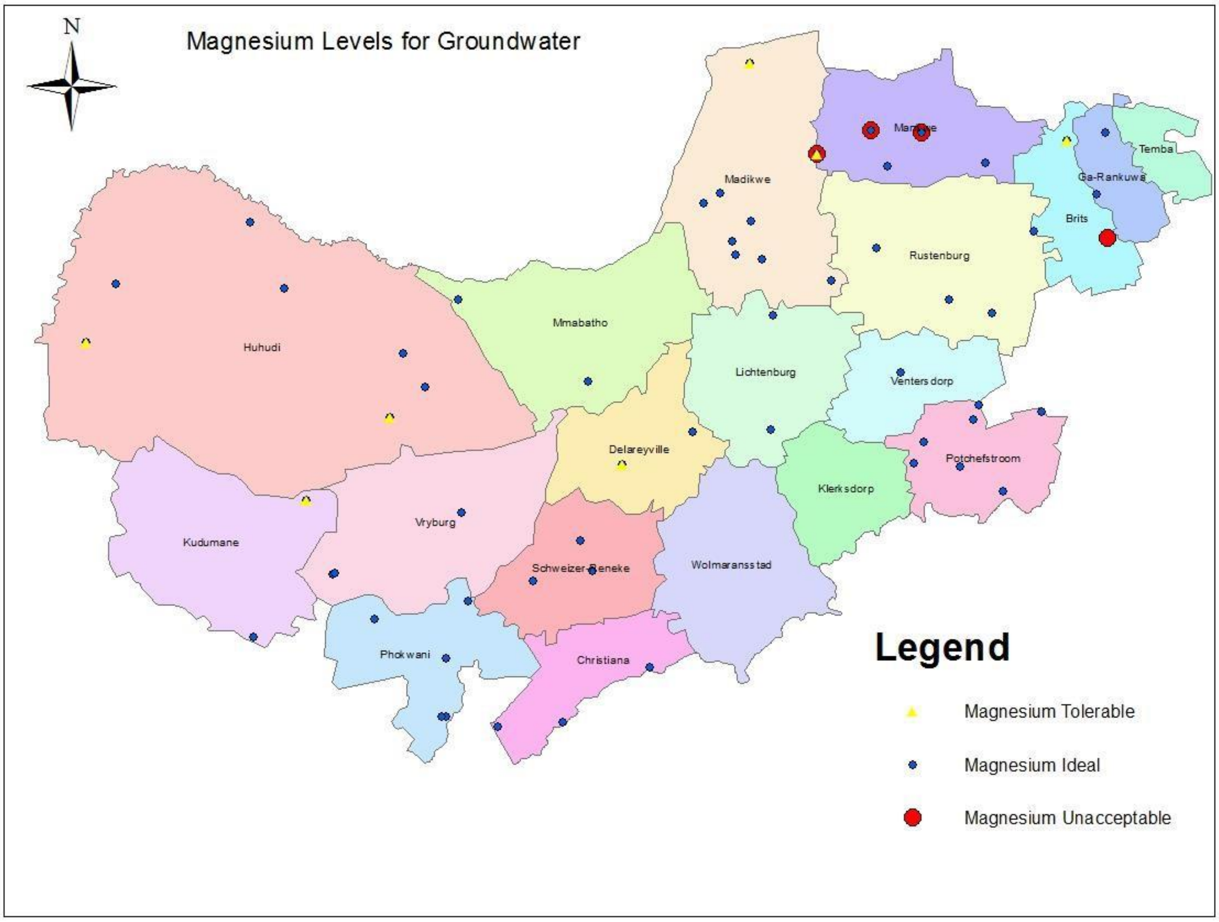

Figure 18: **Map for Magnesium levels for Northwest 2014 - 2015**

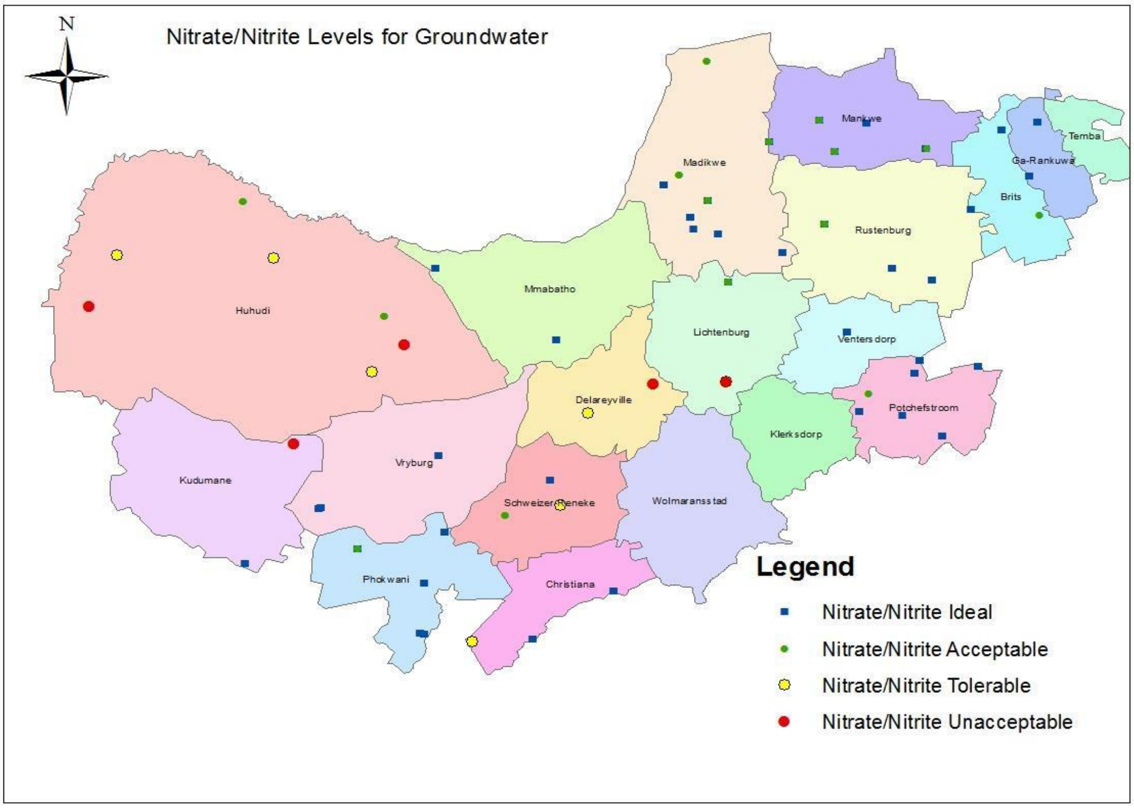

Figure 19 Map for Nitrate/Nitrite levels for Northwest 2014 - 2015

(b) Free State

Groundwater is currently not utilised as a water resource for the supply of potable water to Free State. However, groundwater is used by individuals for irrigation of gardens in residential areas. Groundwater is used extensively for agricultural purposes in other areas of the province and also utilised by small industry for bottling of water as well as micro irrigation of vegetables and nurseries (garden centres), which are in close proximity to the city limits.

Increased pressure is placed on groundwater resources especially within the Free State province due to over exploitation of groundwater resources within the agricultural and industrial sectors and the eradication of buckets systems. In many instances certain towns within the Free State province are left without any drinking water due to the depletion of a water resource. Therefore certain municipalities are faced with the challenge of sighting, developing, supplying groundwater, and sustaining good water quality and quantity within a short period of time. The decanting of old mine works and known and unknown hazardous waste storages poses also a major threat to groundwater resources within the Free State Province and throughout South Africa (Kotze et al, 2012).

Free State Groundwater Quality Analysis

Groundwater data is obtained through the measurement of borehole water levels, borehole locations, groundwater quality, and other parameters. The DWA currently keeps groundwater data in a database called the National Groundwater Database (NGDB), which contains data on boreholes.

For this project, the groundwater quality data covering the period 2014 to 2015 was assessed. Three parameters of concern were selected to provide an indication of the suitability for use of groundwater resources by the designated user groups of Free State Province. The parameter includes: Chloride, Magnesium and Nitrate/Nitrite. The analysis was done through the use of Geographical information system (GIS) software ArcGIS.

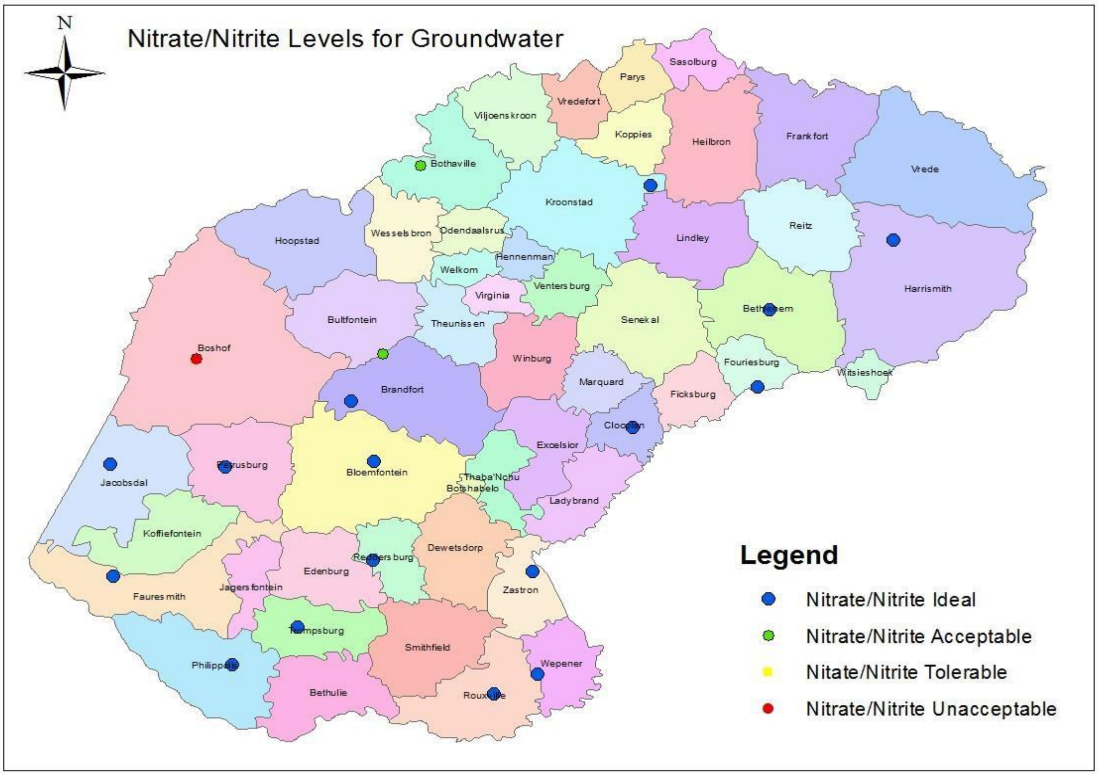

Figure 20 Map for Nitrate/Nitrite levels for Free State 2014 – 2015

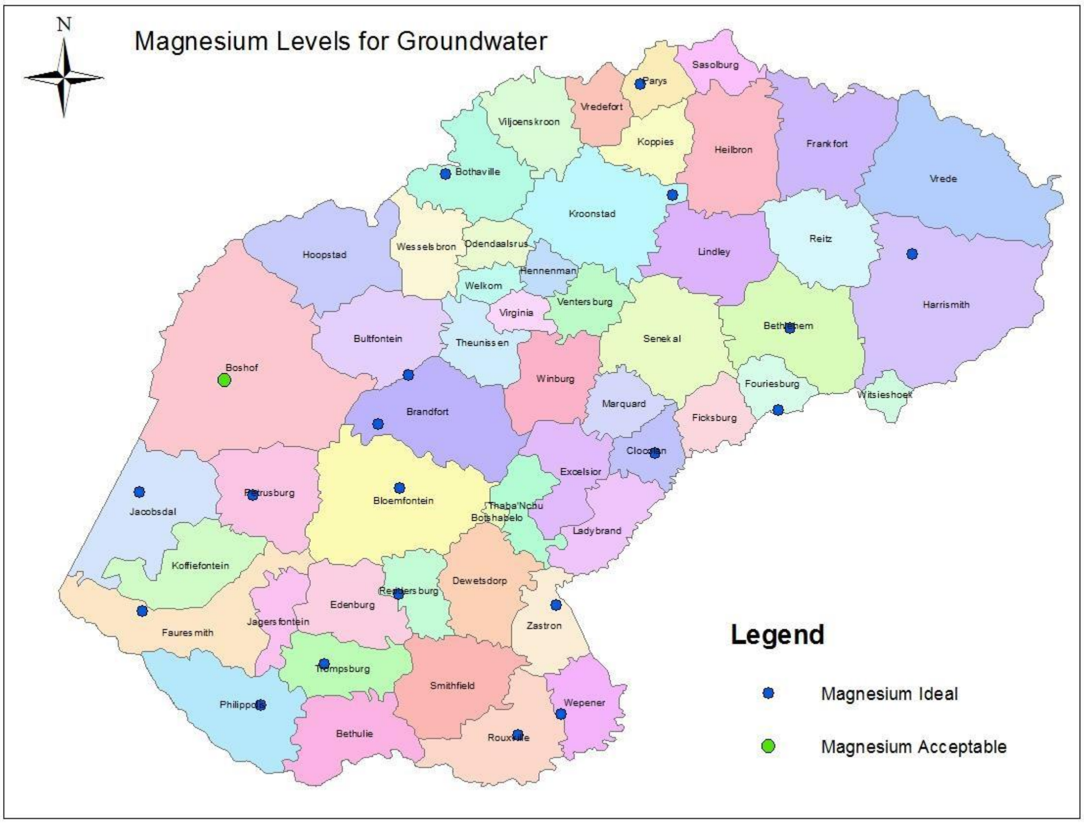

Figure 21 Map for Magnesium levels for Free State 2014 – 2015

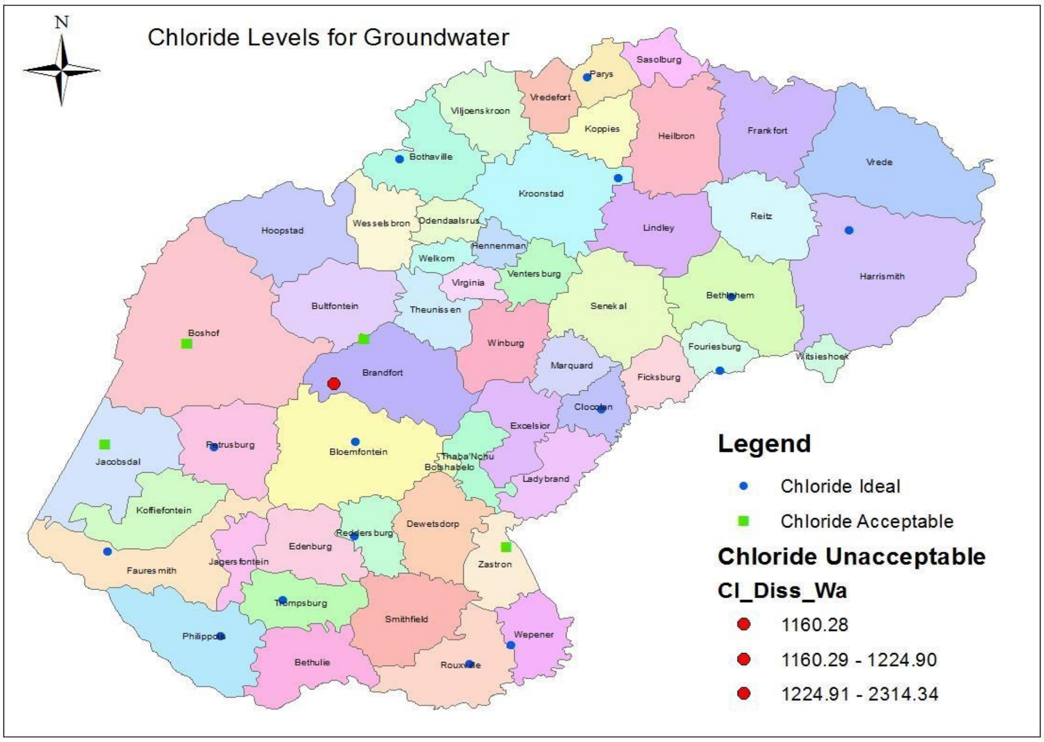

Figure 22 Map for Chloride levels for Free State 2014 – 2015

The levels of Nitrite/Nitrates in the study area are from ideal to tolerable ranges (Figure 20Figure 19Figure 19) except for Boshof which indicate the high level of Nitrate/Nitrite in groundwater (unacceptable). Moreover Magnesium level are from ideal to tolerable (Figure 21) range while chloride ranges from ideal to acceptable (Figure 22) except for Brandfort which shows the high level of chloride up to 2314.34 mg/l of chloride which is far above 1200 mg/l. At this level water is unacceptably salty, nausea and disturbance of the electrolyte balance can occur, especially in infants, where fatalities due to dehydration may occur.

Limpopo Province Groundwater quality analysis

Groundwater data is obtained from a database called the National Groundwater Database (NGDB), which contains data on boreholes. However only data obtained for two areas which are Thabamoopo and Pietersburg. A lack of reliable groundwater data makes it difficult to make accurate assessments of the quality and quantity for the whole province.

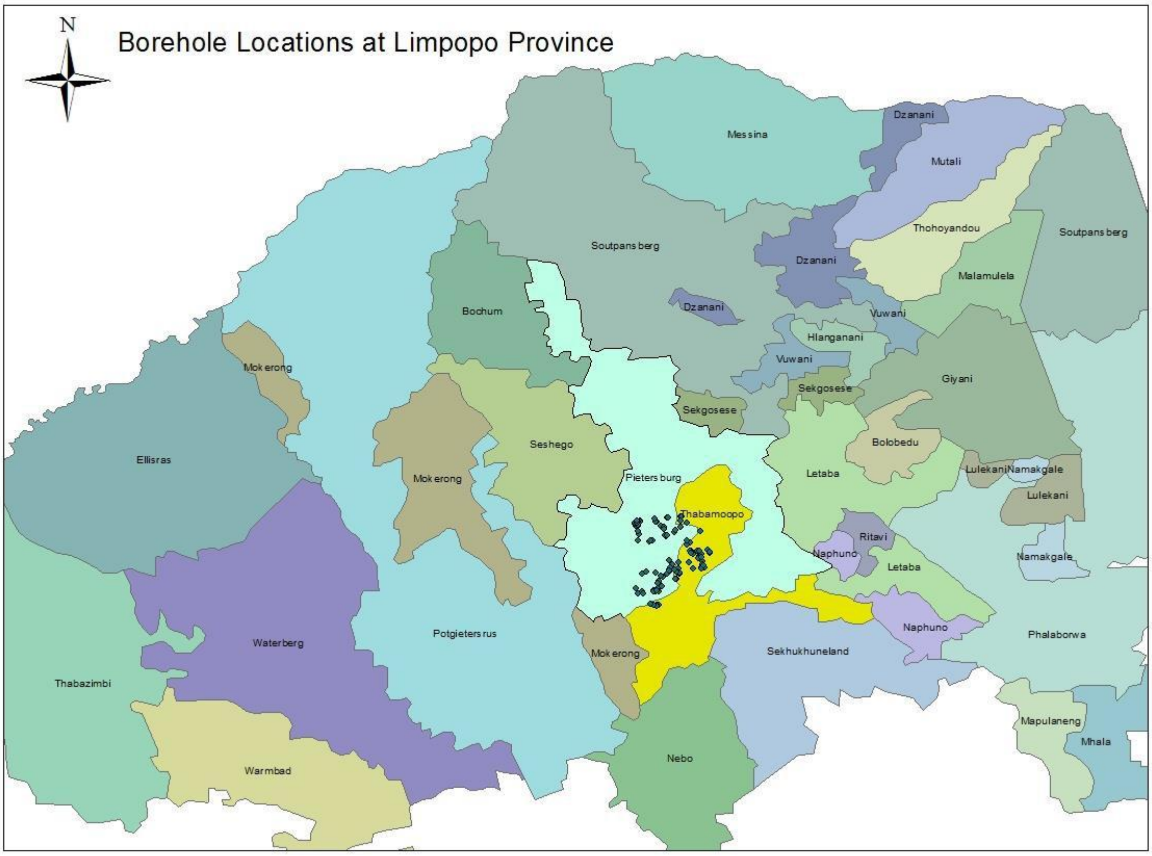

Figure 23 Map for Borehole location for Limpopo 2012 - 2014

Figure 24 Un monitored borehole at Sebayeng village in Limpopo

Figure 25 Groundwater used for agriculture activities at Mokgolobotho village in Limpopo

For this project, the groundwater quality data covering the period 2012 to 2014 was assessed. Six parameters of concern were selected to provide an indication of the suitability for use of groundwater resources by the designated user groups of some areas of Limpopo Province. The parameter includes: Chloride, Magnesium, Nitrate/Nitrite, Sodium, Calcium and mercury. The analysis was done through the use of Geographical information system (GIS) software ArcGIS.

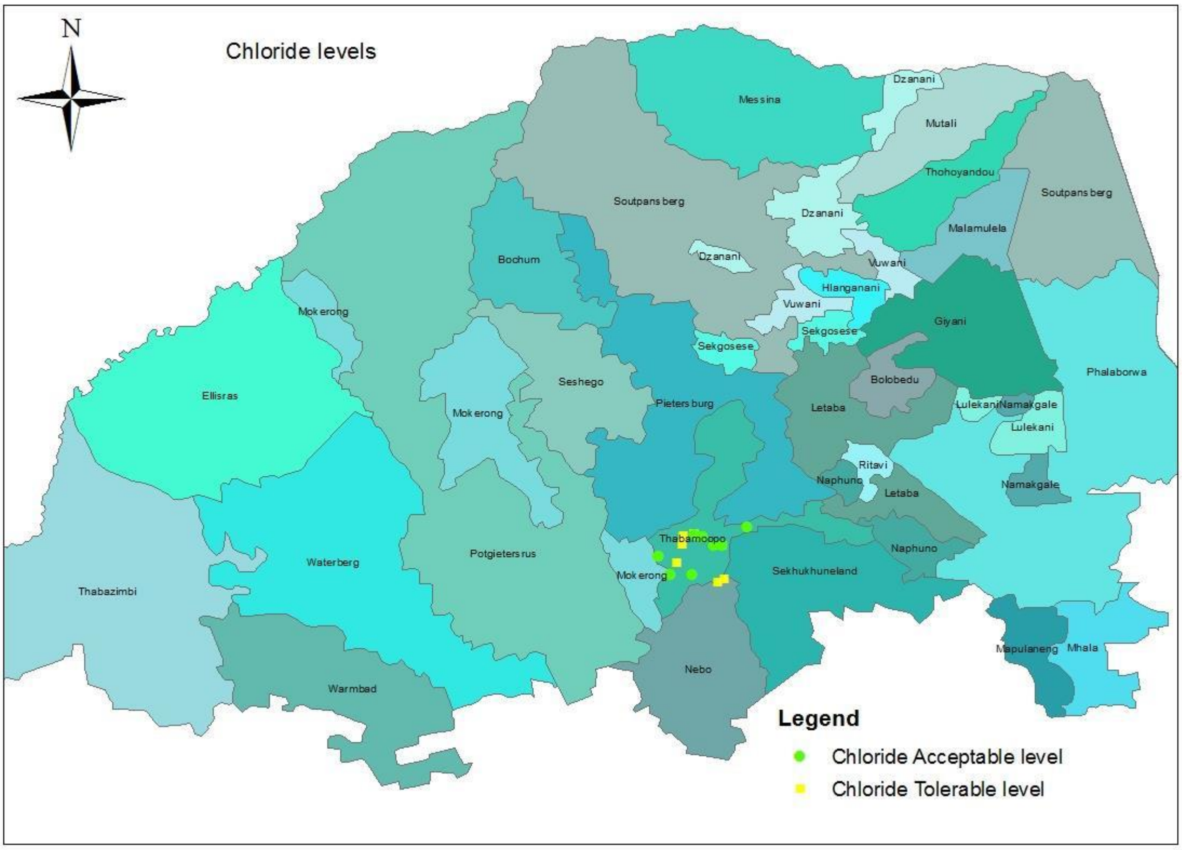

Figure 26 Map for Chloride levels for Thabamoopo 2012 – 2014

Chloride ranges from acceptable to tolerable (Figure 26). At this level water has a distinctly salty taste, but no health effects Likelihood of noticeable increase in corrosion rates in domestic appliances. The levels of nitrite/nitrates in the study area are within ideal ranges. All other parameters where analysed however fall under ideal to tolerable range with no health effect. Since only few data were obtained for the study area, thus we cannot conclude that the groundwater quality is safe to drink, however we can recommend further research to be conducted in Limpopo province.

In conclusion, groundwater is a major water source for domestic and agriculture purposes. Most municipalities' supplies groundwater without any treatment. Groundwater quality has received little attention because of the perception that this water has filtered through several layers of soil and rock and should be free from pollutants. Results presented in this report reveal that several quality issues, with respect to water, in particular groundwater, exist. These include elevated levels of other parameters like Nitrate/Nitrite in areas like Huhudi, Kudumane, Lichtenburg and Delareyville in Northwest and Boshof in Free State. Magnesium has also observed to reach an unacceptable level on areas like Brits and Mankwe in Northwest. Moreover Chloride has also increased the recommended levels in some areas like Brandfort in Free State. All of these pollutants could impact on disease burden of the population. For this reason there is a need to check the boreholes water quality and monitoring under supervision of skilled personnel.

4.4.1. *Groundwater Treatment*

In situ removal of nitrate from groundwater treatment: Most methods of nitrate removal that have been applied for in situ groundwater treatment are based on chemical and/or biological denitrification. The methods apply redox reactions, often with biological catalysis, to reduce nitrate to nitrogen gas. The appeal of using denitrification reactions for in situ application lies mainly in the fact that the main products of the reactions are gaseous and do not accumulate as hazardous by-products in the subsurface. Some of the techniques also do not require highly sophisticated technology. This literature has adopted from (Tredoux et al., 2004)

A series of factors influence the denitrification reactions and the most important ones for biological denitrification are listed below:

- Temperature, preferably near 35°C;
- pH, preferably neutral to alkaline;
- Organic carbon present as substrate for bacteria;
- Carbon:nitrogen ratio of 1:25;
- Presence of other nutrients such as phosphate;
- Presence of sufficient denitrifying bacteria;
- Low oxygen content, i.e. anoxic or anaerobic conditions;
- High soil water content;
- Control over anthropogenic activities disrupting the chemical equilibria, e.g. by disturbance of the soil.

The efficiency of denitrification may not be of too great concern for in situ treatment systems, as long as the product water complies with drinking water specifications. Porosity and permeability in the aquifer are additional system related factors that affect the efficiency of denitrification. Ion exchange, reverse osmosis and electro-dialysis have also been used in nitrate treatment plants, but have not been developed for in situ application. These methods remove anionic nitrate without the need for redox conversions, but they result in concentrated water treatment wastes that need to be disposed of.

Review of in situ groundwater treatment

Although in situ groundwater treatment is still being researched and developed, it has shown potential for the removal of a large range of inorganic contaminants, including arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se), technetium (Te), uranium (U), vanadium (V), nitrate (NO_3^-), phosphate (PO_4^-), and sulphate (SO_4^{2-}). Organic compounds can also be removed by *in situ* treatment methods.

4.4.1.1. Treatment methods

The most important *in situ* groundwater treatment methods for nitrate and many other contaminants can be divided into the following three main groups:

- *Permeable Reactive Barrier (PRB) methods*
- *Biological methods*
- *Electrochemical methods*

Permeable Reactive Barrier (PRB)

Permeable reactive subsurface barrier is defined as: an emplacement of reactive materials in the subsurface designed to intercept a contaminant plume, provide a flow path through the reactive media, and transform the contaminant(s) into environmentally acceptable forms to attain remediation concentration goals downgradient of the barrier (Powell and Powell, 1998; Powell and Puls, 1997a).

Permeable Reactive Barrier (PRB) techniques (also called "passive treatment walls") involve the physical placement of a barrier, consisting of reactive material, into a trench excavated in the aquifer. In other cases, a chemical reagent (e.g. a reducing agent) is injected into the aquifer to create the reactive barrier. This technique is called In Situ Redox Manipulation (ISRM). The barrier created with ISRM can be placed at much greater depths in the aquifer than with a trench-filled PRB. For these methods to work efficiently, especially for remediation operations, a primary aquifer is needed with well-defined, impermeable lower boundary.

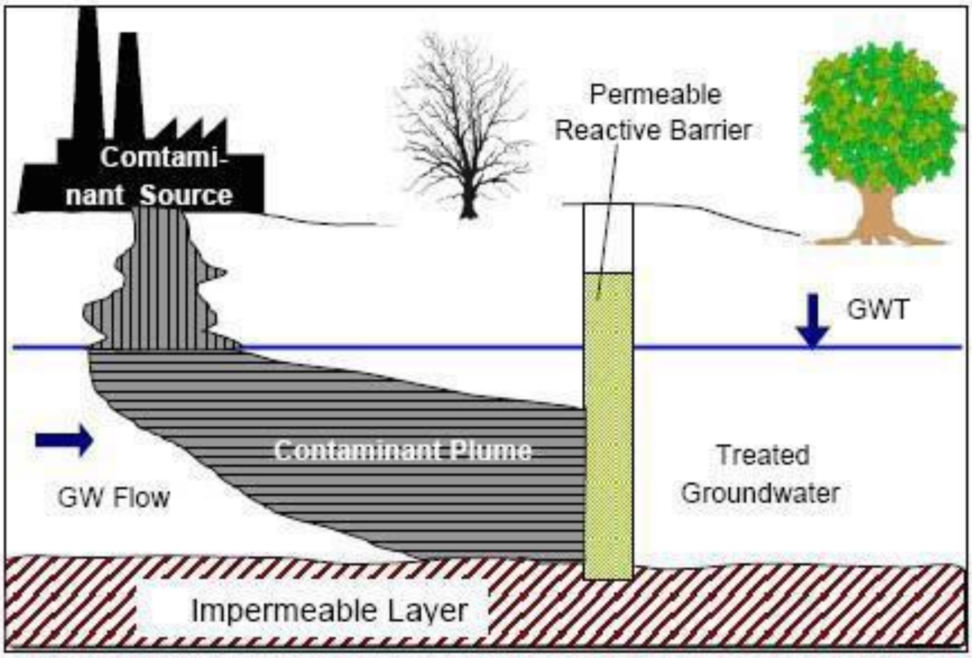

Figure 27: Diagrammatic representation of a PRB (Geranio, 2007)

PRB techniques, specifically zero-valent iron walls, are widely used for aquifer clean-up operations in preference to pump-and-treat methods. A wide range of contaminants, including arsenic, cadmium, chromium, copper, mercury, iron, manganese, molybdenum, nickel, lead, selenium, technetium, uranium, vanadium, nitrate, phosphate, and sulphate, can be removed in this way. Field studies of in situ treatment using PRBs have been completed for most of these contaminants.

Table 6: The advantages and limitations of the PRB technology (Shabalala et al, 2014)

Advantages	Limitations
(a) Results in reduced costs due to the semi-permanent installation, low energy input, focused clean-up on only the area of contamination, conservation of clean water, and continued productive use of the site almost immediately after installation (b) They have the potential to mitigate the spread of contaminants that have proven difficult and expensive to manage with other clean-up methods	(a) It can be expected that the long-term performance would be inhibited by clogging and armouring by aluminium and manganese precipitates. Armouring with aluminium hydroxide or manganese oxides would decrease the reactive surface area and may cause clogging of the pore spaces, restricting the flow of groundwater through the PRB
(c) Allows for treatment of multiple contamination plumes since more than one barrier can be used (d) Requires occasional monitoring to ensure that barriers are functioning properly (e) They typically rely on passive processes, and are considered an environmentally sustainable treatment technique	(b) Design flaws such as improper hydraulic and/or geological characterization of a site prior to PRB installation can result in limited capture of the plume, diversion and partial or total by-pass of the groundwater around the PRB and, overall, loss of hydraulic control
(f) Minimise volume of soils and groundwater that need to be physically handled	(c) Limited field data concerning longevity of Barriers
(g) They have potential operational lives of decades	(d) Reactive media may have to be removed or be replaced during operation (e) Long time-frames (decades) may be required to manage risks associated with a long-lived or persistent contaminant source (f) Deeper plumes can present problems for construction and monitoring

In Situ Biological Denitrification (ISBD: Another treatment is called In Situ Biological Denitrification (ISBD). This method generally requires the introduction of a carbon source into the aquifer that serves as a substrate for the bacteria. This may be in the form of methanol, ethanol, glucose or even sawdust or wood chips injected via one or more boreholes. The Nitredox method is a special case of ISBD, involving the introduction of a carbon source and later oxidation of iron and manganese by-products.

Biological methods are widely used for removal of nitrate and degradable organic compounds. This treatment method is a viable option when the rate of contaminant biodegradation is faster than the rate of contaminant migration.

Electrochemical methods are more complex than PRB or biological methods, but are considered here because they are reputed to be applicable to fractured aquifer environments. Various electrochemical systems, applying enhancements such as electrokinetics and electro osmosis, have been described for groundwater treatment. These systems generally use an electrical current, applied via two in situ electrodes to control the movement and redox chemistry of ions and water in the subsurface. Electrochemical methods can be used as an enhancement of other PRB systems, e.g. by combining electrodes with iron walls to remediate nitrate contaminated groundwater and soils abiotically.

Electrokinetic methods appear to have been developed with a focus on remediating spills or leaks of organic chemical products. Much of the emphasis is on mobilising contaminated pore water and there is an expectation that the abstracted water would require additional *ex situ* treatment. It was stated in the literature that nitrate removal could be improved by coupling the electrokinetic method with an iron wall. However, no information was provided comparing the efficiency of electrokinetics on its own, or that of a coupled system, with non-electrical methods.

Advantages of *in situ* treatment: In situ treatment of contaminated groundwater uses the aquifer as a subsurface "treatment plant" to improve the quality of groundwater supplies. This has several advantages over conventional *ex situ* treatment technologies (pump-and-treat systems), including:

- Cost and time savings on capital expenditure, maintenance, operator expenses, etc.
- Exposure to chemical reagents, where these are used, is limited.
- Many of the systems can operate for long periods (anything from 5 to 30 years) without need for reagent/substrate addition i.e. they are extremely low maintenance.
- Less stringent control of operating conditions is needed, which simplifies management of such systems.
- The systems are more robust and require less plumbing than surface-based treatment plants.
- Redox-based systems can often remove other contaminants e.g. chromate and organic chemicals, if these are also present.
- Abstracted water can be used directly with minimal or no extra treatment.
- The natural filtration processes in the aquifer provide additional water quality improvements.

Side effects of in situ treatment: Some *in situ* treatment methods for removing groundwater contaminants may cause undesirable side effects, of which the most common problem is clogging in the subsurface. In the case of removal of organic compounds, the products of the treatment reaction may cause clogging of the aquifer due to biofilm build-up. If metals are removed by precipitation, the solid precipitates in the aquifer matrix may reduce the permeability of the aquifer over the long term. The specific hydrogeological conditions and the contaminant load will determine the extent of these phenomena. Side effects need to be managed to maintain the efficiency of the scheme and increase the treatment lifetime.

Depending on the environmental conditions, denitrification reactions may not always run to completion, i.e. nitrate nitrogen is not always fully converted to nitrogen gas. This can lead to the accumulation of other undesirable nitrogen species, such as nitrite or ammonium, in the groundwater. Nitrogen immobilisation may also retard the appearance of nitrate, but will not remove the nitrogen source from the aquifer and nitrate may re-develop at a later stage. Where potentially toxic reagents (e.g. dithionite, methanol) are introduced to the subsurface and not fully recovered or consumed by the reactions, groundwater quality may be adversely affected.

Possible side effects of *in situ* nitrate removal methods include clogging or loss of effective permeability in the aquifer as a result of factors such as:

- Biofilm build-up in the aquifer, e.g. in biological systems.
- Mineral precipitates forming during the redox processes, e.g. iron or manganese oxides.
- Gas bubbles from nitrogen and carbon dioxide generation.

4.4.1.2. Potential for in situ treatment applications in South Africa

The literature review shows that *in situ* groundwater treatment has significant potential for application in South Africa. Internationally, researchers are enthusiastic about the potential of in situ treatment for addressing various problems regarding chemical constituents found in pollution situations but also those in natural groundwater environments. *In situ* treatment systems for iron and manganese removal have been used successfully for many decades while *in situ* nitrate removal has been in place for approximately two decades.

The countrywide distribution of nitrate levels in groundwater was compared with the various hydrogeological terrains of South Africa and the towns or rural communities where groundwater constitutes the sole water supply source. This assessment has indicated that there is some agreement between high nitrate concentrations, sole source areas and hydrogeology. High nitrate concentrations are fairly well correlated with aquifers composed of unconsolidated deposits, weathered basalts, and dolomites over an area extending from the Northern Cape Province all the way to northern Mpumalanga, including parts of North West and the Limpopo Province. Areas that are sole source areas with high groundwater nitrate concentrations have priority over other areas for remediation. These include towns such as Marydale, Leliefontein, Reivilo, Rietfontein in the Northern Cape, and others, largely located in the rural parts of Northwest and Limpopo Provinces.

Iron and manganese, occurring naturally in groundwater, may cause significant clogging problems in boreholes when redox conditions change and iron bacteria start multiplying. In primary aquifers, *in situ* treatment by oxygenation may provide a viable solution, e.g. by using the Vyredox process.

4.4.1.3. Recommendations

The analysis of existing methods and systems worldwide, together with the preliminary cost analysis, shows that in many instances in situ groundwater treatment methods will provide a viable, cost-effective alternative to ex situ water treatment. In view of the success abroad, it is strongly recommended that such systems be tested both at field scale and full scale in South Africa. Particularly those systems that require a low capital investment, low running costs and limited know-how should be tested and installed without delay. For each potential site a feasibility study should be undertaken and cost estimates calculated. Three to five sites should be developed as demonstration units, for technology transfer and obtaining local experience with this technique.

It is recommended that all four methods, i.e. permeable reactive barriers (PRB), in situ redox manipulation (ISRM), *in situ* biological denitrification (ISBD) and electrokinetics are tested at suitable locations. All methods are suitable for groundwater denitrification, but also for the removal of other contaminants such as heavy metals or organic compounds. All four methods would be viable in the town water supply context but only some of them, e.g. PRBs, would be compatible with the rural setting. The availability of infrastructure and technical know-how would make the Nitredox and Vyredox methods viable for nitrate, iron and manganese removal in town water supply applications.

4.4.1.4. Recommended denitrification systems

Permeable reactive barriers (or "treatment walls"): PRBs can be constructed from cheap, readily available materials and would be relatively simple for communities to install with limited training. They provide long-term treatment without maintenance and no power source is required.

In situ redox manipulation: ISRM should be tested for deeper primary aquifers in South Africa. The dithionite chemical reagent should be readily available, since it is used in the pulp and paper industry. Laboratory testing would be recommended for the first phase followed by field-testing for those instances with promising test results.

In situ biological denitrification: Internationally ISBD is probably the most widely used in situ treatment method for the removal of nitrate from groundwater. The configuration of the injection and abstraction boreholes is flexible and can be adapted to suit the specific treatment problem. Various conventional and organic substrates and cheaper locally available options could be tested for potential application in rural treatment systems. The injection of microbes would not be recommended at this stage.

Electrokinetics: Various electrochemical techniques might be useful as an enhancement for the first two methods above, as the electrochemical techniques do not appear to be completely efficient for nitrate removal on their own. More information would need to be collected on the electrode composition and installation, applied voltages, etc. and extensive testing conducted before electrokinetics could be applied in the field. The electrokinetic method is, however, the only one found that has been claimed to be suitable for fractured rock environments, which would make it worth testing for South Africa. This is the main reason why this method is recommended for testing despite the higher levels of technical skill and know-how that is required.

4.4.1.5. Water treatment Technologies for rural communities

In rural areas where the population is sparse and homesteads are wide far apart, it becomes costly to the local authority to provide piped potable water to the people. These people end up relying on ground and surface water sources which may be microbially and chemically contaminated and thus exposing themselves to water related diseases. In the case whereby local authorities fail to provide safe drinking water, the people may be advised to set up a separate dual water supply system or ensure household treatment for potable water; otherwise they will bear the consequences of drinking contaminated water. A number of household treatment systems are readily available in the market. For more information on types and methods applicable read (Mahlangu, 2012) and (Mamba et al., 2013).

4.5. Skills shortages in water sector – South Africa

South Africa is a country with high rate of population increase. The rapid increase in population puts pressure on resources and services such as water due to high water demand for domestic and industrial use. Due to scarcity, some part of South Africa receives very little rainfall throughout the year.

South Africa uses a number of water transfers where it purchases water trough schemes such as Lesotho Highlands Water Project which transfers water from Lesotho to South Africa. With development on the increase as well as the desire for better living standards of people, there is a need for increased water supplies and water demand management to conserve the available resources in order to meet the needs of the rapidly growing population.

The major problems facing the water sector is lack of qualified and trained workers. Most Municipalities have aged workers who have matric results only. The shortage of skilled workers is a serious issue which should be taken into considerations. Skills issues includes lack of coordinated mechanisms of planning and the delivery of quality assurance, the absence of a skills intelligence hub, the gap between higher education training, qualifications and professional registration, as well as inadequate human resource planning in the water sector.

The water sector is experiencing a critical scarce skills shortage, owing to an insufficient skills base and fierce competition in the labour market for skilled personnel, said the Department of Water Affairs (DWA) acting director- general (Balzer, 2014) “An ongoing scarce skills shortage in the water sector is a threat to achieving water and sanitation delivery, meeting compliance targets and implementing sustainable water resources management, and the country needs the correct skills to manage water resources.

In South Africa most water professionals are employed in the local authorities, water boards, Department of water Affairs, Department of Environmental Affairs, Provincial Government related departments, research councils or institutes, industry and consulting. Registered engineers, scientists and engineering technologists find employment easily in the sector. While this situation persists, local municipalities face enormous challenge to get professional.

One of the main obstacles to quantifying water sector skills needs is the availability, and probably even existence of data. Many organisations do not have data on skills shortages, whereas others do not have numbers. And this poses big challenges to researchers who are trying to identify the need and solve the problems.

Moreover section 27(1) (b) of the South African Constitution stipulates that “everyone has the right to have sufficient water”. However, despite making strides in terms of improving water security and access to sanitation facilities, challenges persist, as noted in a South Africa- Netherlands Water Network report released in 2010, which highlights a number of challenges, including:

- That many municipalities are not served by water boards and do not have the money and skills to increase their sources of supply – this limits municipalities' ability to respond to demand for additional water and improved service levels.
- Significant skills gaps in many municipalities, which compromise service delivery; the pricing of water across the value chain (from source to tap and back), which remains problematic, leading to inequitable tariff structures, as well as the under recovery of the real costs of sustainable water services.

The water sector of South Africa has been engaged in capacity building and skills development as a critical aspect of building a sustainable, water conscious society. Yet, it has been agreed by all sector stakeholders that capacity building is the single most critical challenge facing the water sector, as it is currently facing critical skills shortages in fields such as engineering, science and the technical and artisan areas. It is expected that the gap will continue to grow at an accelerated rate as many of these critical skills lie with an ageing workforce. By its nature, skills development is a long-term process and thus sustained and efficient interventions are necessary to achieve enduring sustainability of the water sector. Still, there are immediate and pressing skills needs ("priority skills") that need to be addressed to keep the sector healthy and thriving. Furthermore another common theme for solving the problem of skills shortages is strategic planning that links the education system with sector specific technical and management skills needs.

With current and future high level mobility of scarce skilled professionals such as registered engineers, workplace skills and staff development, and staff retention strategies become of paramount importance to ward off competition for these scarce skills. Salaries, working and living conditions will be future determinants of recruitment. Any strategies to recruit scarce water sector skills such as engineering, technical, scientific and water business management professionals should be looked at within the context that South Africa will compete with other more developed countries on the international market for these skills. To be successful, a skills development programme should be linked to the formal education pipeline system to meet the needs of all sectors of the economy for sustainable and health risk-free socio-economic development as a prerequisite of political stability of any country.

4.5.1.1. Key focus areas for skills *development*

Research conducted by the Water Research Commission (WRC) in 2006 on behalf of DWA titled "Assessment of Training Programmes and Capacity Needs for the Water Services Sector" involved an assessment of the current skills development programmes and capacity needs for the Water Services Sector, in particular the Water Service Authorities (WSA) and the Water Services

Providers (WSP) indicated that a need for skills existed in the following areas: engineering professionals; technical skills; Health and Hygiene practitioners; financial skills; strategic management and leadership specifically management of a water business; and developmental local government skills

Local government and water service authorities as agents of local economic development and poverty eradication require employees with skills in community engagement for participatory development. Hence there is a need to identify the skills need in each local municipality in order to come up with strategies which can help to solve the problem. However some researches done through WSLG Skills Development Task Team came up with focus areas and their strategic objectives for skills development as:

a. Engineering and Sciences: In the immediate, medium and long term, strategies to increase engineering capacity in the sector to deal with the backlogs and to improve the system to ensure sustainable production of engineering capacity.

b. Management: Through immediate responses and longer-term, systematic actions, guarantee sufficient and capable managers (with strategic, financial and developmental skills) in the water sector.

c. Socio-economic and Environmental Health: Ensure enough skilled and capacitated people to address socio-economic, environmental health and other "soft" issues with all new water services infrastructure provision and water resources interventions, and on an ongoing basis as total environmental health contributions to the water sector as a whole.

d. Artisans and technicians: Address strategic and practical constraints in the water sector skills development arena to ensure employable, skilled artisans and technicians (with workplace experience) to contribute to sustainable implementation of water sector operational activities.

4.5.1.2. Water Training and Skills Development

The challenges facing local government and municipality are overwhelming though, with millions of South Africans who have either no access to basic water supply, or access to water that does not meet the basic services standard. This situation rises from a complex set of situations of which an essential element is the technical skills levels of the staff responsible for the operation and maintenance of water treatment plants. There is a devastating need for training which is exacerbated by a mismatch between qualifications and job requirements. Moreover there is lack of collaboration between the water sector and other institutions responsible for education, training and skills development.

Municipalities have an increasing demand for service delivery, but remain unable to meet the demand for numerous reasons, including poor skills levels, unavailable technologies, and labour force dynamics. The public and private sector, consisting of more than 358 organizations, is diverse and the associated occupational groups require skills at all levels, from general workers and artisans, to scientists and engineers. The planning for the skills required and the education provision available is not aligned and as a result various disconnections manifest themselves in the water sector. In most of municipalities, actual statistics on occupational profiles and the number of employees needing training are not available. The short term challenge for the water sector is to train and re-skill employees to increase performance. Due to an expected economic growth potential in South Africa and the policies already in place to improve water services, the number of vacancies will increase, as well as the level at which performance will be required.

Table 7 Skills Priorities

- Basic plumbing skills training of unemployed youth to fix leaks.
- Skills development to monitor regulates, enforce and support WC and WDM.
- Artisans for maintenance of the water infrastructure.
- Training of councillors in water conservation and water demand management.
- Training of municipal staff in metering, billing and cost recovery.
- Management, leadership, project and leadership skills.
- Artisan development.
- Operations and plant maintenance skills.

Source: Department of Water Affairs National Water Resource Strategy (June 2013, 2nd edition), "Water for an equitable and sustainable future". Water Research Commission (2012). The state of non-revenue water in South Africa.

Skills needs reported during site visitation for Northwest, Limpopo and FreeState

	Skills required	**Requirements**
a)	Process controller	Training is need on advanced level for process controllers
b)	Plumbers	Advanced trainings on plumbing
c)	Engineers (Mechanical, Chemical and Civil)	Registered engineers with qualification boards
	Laboratory technicians	NQF level 7
d)	Environmental Scientists	Tertiary levels
e)	Instrumentations controllers	Qualified instrumentation controllers
f)	Electro mechanicals	Training on repairs
g)	Energy production technologists (example for biogas)	Tertiary level
h)	Chemistry specialist	Tertiary level
i)	Horticulture specialist	Tertiary level
j)0	Environmental healthcare specialist	Tertiary level

The study shows that most of the municipalities face a lack of skilled staff and as such they have to train their people. Some main reasons that the skills-problem is not solved yet are the insufficient basic education of the staff; minor financial support from the SETA's; and a shortage of quality providers offering appropriate courses. Hence the major problem confronting local authorities seems to be that there are too many training providers offering short term courses that show hardly any improvement in the performance of their staff and have little if any lasting impact on the organisation (Wits-DBSA study, 2004).

The water sector itself has to become more visible and attractive by offering career paths and international collaboration. The availability of enough and good quality water staff now and in the future can only be realized by an integrated approach of three main parties: the water sector, the education sector and training provision.

4.6. Conclusion

South Africa, a water-stressed country, requires careful management of the demand for water, and its judicious use is a topic which can no longer be avoided. South Africa ran out of natural resources of water supply, hence there is a need to explore on different alternative sources. One of the alternative source of water supply is rain water harvesting. Rainwater harvesting, in conjunction with other alternative methods of exploiting water sources can greatly benefit people at the rural community areas in South Africa. Rainwater harvesting depends on an often unpredictable and sometimes unreliable source, namely rain. However, the potential of this common sense exploitation of a water source should be recognised. One of the major constraints in managing water demand is the absence of well-structured education and training programmes suitably targeted to stakeholders in the water management chain. Thus the report highlighted the information on skills shortage in water sector in South Africa, key focus areas for skills development and water training and skills development.

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