ASSESSMENT OF GROUNDWATER QUALITY AND COMMUNITY'S EXPERIENCES IN RELATION TO WATER QUANTITY AND QUALITY CHALLENGES IN LEPHALALE MUNICIPALITY, WATERBERG DISTRICT, LIMPOPO PROVINCE IN SOUTH AFRICA

By

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Declaration

I, Mulaudzi Lusani, hereby declare that the dissertation for the masters' degree project titled **"Assessment of groundwater quality and community's experiences in relation to water quantity and quality challenges in Lephalale Municipality, Waterberg district, Limpopo province in South Africa"** at the University of Venda, hereby submitted by me, has not been submitted previously for a degree at this or any other University, that it is my own work in design and in execution, and that all reference material contained therein has been duly acknowledged.

Signature ……………………………….. Date: …06/12/2020………………….

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Abstract

The aim of this study was to assess the water quality of groundwater utilized for domestic and irrigation purposes in Lephalale Municipality, interrogate the community's experiences and issues related to water quality and supply in Lephalale local municipality, Waterberg district in Limpopo province of South Africa. The results showed that the mean values of major cations and anions were in the order; $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}$ and $HCO_3^{-}>Cl^{-}>NO_3^{-}>SO_4^{2-}>F^{-}$, respectively. About 36% of the sampled groundwater had F- higher than the recommended limit of 1.5 mg/L. For microbial pollutants, 27 % and 41 % of the boreholes were above the threshold set by the World Health Organisation (WHO) in terms of total coliform and faecal coliform, respectively. This can pose health risks to consumers. The hydrogeochemical facies revealed the dominance of mixed Ca-Mg-Cl and Ca-Cl water type which indicated the governance of rock-water interaction. About 19 % of participants from Mmatladi village indicated that they spend over a month without running water in their taps. Households have members suffering from fluorosis (28 %), and most of them do not have knowledge on water quality (78 %). The results revealed that the developed water system could treat 1.68 L of groundwater with 30 g of Al/Fe oxide Diatomaceous Earth (DE) which shows a great potential. The study recommends continuous groundwater quality monitoring in Lephalale Municipality. Due to lack of knowledge amongst the participants concerning water quality, there is a need for public awareness campaign in the area. The developed material for water treatment system needs to be enhanced to increase the adsorption capacity and minimise leaching of elements.

Keywords: *Groundwater, hydrogeochemical characteristic, Lephalale local municipality, community perspectives, bucket water system, Al/Fe oxide, diatomaceous earth, defluoridation*

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Chapter 1: Introduction

1.1. Background

Water scarcity is a worldwide problem affecting millions of people mostly in developing and underdeveloped countries (Masante et al., 2018). The World Health Organisation (WHO) has estimated that over 2.1 billion people worldwide lack safe water in their homes. Of these, 263 million travel more than 30 minutes per trip to collect water. Moreover, up 884 million people in the world do not have basic drinking water services while 159 million drink unsafe water from the surface sources such as lakes and rivers (UNDP, 2017; WHO, 2017). Groundwater is often perceived as a safe source of water supply by the public with about one-third of the world's population depending on it as the main source of drinking water (Grönwall and Danert, 2020). In some cases, groundwater is found to be contaminated by chemical species such as fluoride, arsenic, and nitrates and also by pathogens (Raju et al., 2011; Dhanasekarapandian et al., 2016; Rao et al., 2019).

The chemistry of subsurface water is controlled by natural processes and anthropogenic factors. Natural factors that have control over water chemistry include precipitation pattern and amount, geological features of watershed and aquifer, meteorological factors, and various rock and water interaction processes in the aquifer (Singh et al., 2015; Raju et al., 2016). Human activities that influence water chemistry include dumping solid waste, domestic and industrial waste, and mining and agricultural activities. In some areas, the concentration of constituents in groundwater exceeds the drinking water standards (Talabi and Kayode, 2019).

Consumption of contaminated drinking water can cause harmful health effects to human beings (Henry et al., 2013; Khan et al., 2018). Drinking water containing fluoride concentration above WHO permissible limit of 1.5 mg/L causes dental fluorosis and still higher fluoride concentration leads to severe health impacts such as skeletal fluorosis in some cases (Abiye et al., 2018). Fluorosis is reported to be endemic in countries like Argentina, Algeria, Canada, China, India, Kenya, Sri Lanka, Tanzania, South Africa, Ethiopia, Kenya, Libya, and the United States of America (Edmunds and Smedley, 2013; Mumtaz et al., 2015; Rasool et al., 2018; Chowdhury et al., 2019; Kimambo et al., 2019; Kabir et al., 2020). In South Africa, cases of fluorosis have been reported in provinces such as North West, Limpopo, Northern

Cape, and KwaZulu Natal Province where groundwater is reported to have higher fluoride concentration (Ncube and Schutte, 2005; Odiyo and Makungo, 2012, Abiye et al., 2018).

Groundwater with arsenic of more than 10 µg/L is a worldwide concern because of its effects on human health after prolonged exposure. Health effects that have been linked to consumption of high arsenic water are cancer, skin lesions, diabetes, circulatory disorders, and kidney diseases (Abiye and Bhattacharya, 2019, Mudzielwana et al., 2020). Concentrations of arsenic above the WHO recommended threshold of 10 µg/L has been reported in countries such as China, India, Bangladesh, Pakistan, Germany, Greece, Sweden, Switzerland, Sri Lanka, Thailand, Vietnam Zimbabwe, Botswana, Ghana, Nigeria, and South Africa (Fatoki et al., 2013, Choudhury et al., 2017, Singh and Singh, 2018, Sanjrani et al., 2019, Horn and Ramudzuli, 2020, Jha and Tripathi, 2021). In South Africa, groundwater contamination by arsenic has been reported in Gauteng, Northwest, Limpopo, Northern Cape, and Eastern Cape (Abiye and Bhattacharya, 2019, Mudzielwana et al., 2020).

The contamination of groundwater by arsenic is the main concern worldwide due to its implications on human health after prolonged exposure. Exposure to arsenic has not only been linked to cancer but also several health problems such as kidney diseases, diabetes, skin lesions, circulatory disorders, and neurological complications (Mandal and Suzuki, 2002; Kapaj et al., 2006; Ayotte et al., 2015). The contamination of groundwater often results from weathering of arsenic-bearing minerals of sulphide, silicate, and carbonate minerals (Rahman et al., 2021). Concentrations of arsenic beyond 0.01 mg/L in groundwater have been reported in countries such as Bangladesh, India, China, Burkina Faso, Zimbabwe, and South Africa (von Bromssen et al., 2008; Fatoki et al., 2013; Kempster et al., 2007; Sharif et al., 2008; Bretzler et al., 2017).

In South Africa, the information about the distribution of arsenic is limited despite the occurrence of arsenic-bearing minerals in various parts of the country. This was supported by Kempster et al. (2007) who the arsenic guidelines for drinking water quality. In their report, they cited concentrations of arsenic beyond 10 µg/L in parts of Gauteng, Northwest, Limpopo, and Eastern Cape based on the survey conducted by the Department of Water Affairs and Forestry (DWAF).

Drinking water containing more than 10 µg/l of arsenic can also cause health effects such as skin problems which can lead to skin cancer at a later stage (Mudzielwana et al., 2020). The high concentration of arsenic in groundwater has been reported in Southeast Asia, Africa, the USA, Latin America, and Europe (Nriagu et al., 2007; Herath et al., 2016). Haematological abnormalities caused by high consumption of arsenic in groundwater have been reported in South Africa, in Northern Cape, and Limpopo province (Abiye and Bhattacharya., 2019).

Up to 80% of illnesses in developing and undeveloped countries are related to unsafe drinking water and inadequate hygiene (Mkwate et al., 2017). Consumption of microbially contaminated water has caused over 2.2 million deaths each year where the majority are children under the age of 5 (WHO, 2017). South America, Eastern Europe, the Indian subcontinent, Malawi, Kenya, Madagascar, Uganda, Zambia, and South Africa have been reported to have high diarrhoea, fever, cholera trends due to poor sanitation (Traore et al., 2016).

WHO has encouraged the development of water treatment systems and routine monitoring of water sources in order to decrease water-related illnesses. Moreover, the United Nations (UN) has set a target to provide clean water for all by 2030 through Sustainable Development Goals (SDGs), Goal 6 (UN, 2017). Several methods have been developed for groundwater treatment, these include precipitation (Onyango & Matsuda., 2006), Ion-exchange (Meenakshi & Viswanathan, 2007), adsorption (Gitari et al., 2013); coagulation (Sandoval et al., 2014), Nano-filtration membrane process (Pervov et al., 2000; Waghmare and Arfin., 2015), reverse osmosis (Trikha & Sharma, 2014), boiling, solar disinfection, sedimentation (Chaurasia &Tiwari, 2015).

Lephalale Municipality located in the north western part of Limpopo Province is one of the water-scarce regions in the country where groundwater is used as the main source of water for domestic and agricultural purposes. Department of Water Affairs (DWA) (2016) reported that the groundwater quality in Lephalale is poor and is found to be contaminated by various chemical species such as fluoride, Nitrate (Sonnekus et al., 2015), and microbial contaminants (DWA, 2010) and is supplied without any pre-treatment. This may increase the chances of residents being exposed to waterborne diseases. Unfortunately, there are no recent reported waterborne diseases in Lephalale Local Municipality. This is not a surprising matter since not all outbreaks are recognized, investigated, or reported, and there is no way to know how many outbreaks go undetected (Reintjes and Zanuzdana, 2009).

To accelerate the UN-SDG No 6, which aims to provide clean water for all and to support the WHO recommendation for monitoring water quality as well as developing affordable water treatment techniques, this study will assess the water quality in boreholes used for drinking water purposes in Lephalale Municipality as well as the suitability for drinking and irrigational purposes. Moreover, the study will investigate the community's perspective on water quality and further test the feasibility of applying Fe/AL oxide modified DE cartridges for water treatment at the household level.

1.2. Problem statement

Groundwater is the main source of water for communities within Lephalale Municipality due to the lack of surface water. However, reports have indicated that groundwater in Lephalale is highly contaminated by fluoride concentration of up to 17mg/L, nitrate contents of 48 mg/L and Total Dissolved Solids (TDS) of up to 1100 mg/L (DWA, 2010; Sonnekus et al., 2015; DWA, 2016; Lephalale IDP., 2017). Apart from chemical species, the presence of *E-coli* has been reported within the area with Total colony-forming units of 6 counts per 100 mL (Veltman & Botha, 2010; DWS, 2014).

As such, cholera outbreaks have been reported in 2009 in Lephalale municipality due to unsafe drinking water, the Medupi coal power plant ended up shutting down due to a lot of people infected by *Vibrio cholerae* bacteria (Bruyn, 2009; Lephalale local municipality – annual report, 2016/17). Moreover, consumption of water with fluorite concentration beyond their permissible limit of 1.5 mg/L leads to serious health complications such as dental and skeletal fluorosis, kidney damage, cancer, renal diseases (Rasool et al., 2018, Zango et al., 2019).

Since groundwater remains the main source of water for drinking and irrigation purposes in Lephalale Municipality, there is a need to monitor water quality and assess its suitability for use for domestic and agricultural uses. Moreover, no study has been reported in the area showing the community's experience regarding water quality and water accessibility. This study, therefore, seeks to assess groundwater quality, identify socio-economic factors and challenges faced concerning water supply and develop an affordable and simple to use cartridge for the treatment of drinking water at a household level.

1.3. Objectives

1.3.1. Main objective

The main aim of the study is to assess the water quality of groundwater used for domestic and irrigation purposes in Lephalale Municipality and further investigate the community's experience and challenges related to water quality and supply.

1.3.2. Specific objectives

- To determine the water quality of groundwater in Lephalale Municipality and further determine the hydrogeochemical processes controlling the groundwater chemistry.
- To investigate challenges faced by Lephalale community dwellers as well as their perspectives with regards to water quality and quantity.
- To evaluate alternative sources of water and strategies used by community members to cope with water scarcity problems and water quality issues.
- To develop and test the applicability of Fe/Al oxide modified diatomaceous earth-based cartridge in household water treatment.

1.4. Research questions

- What are the characteristics and classification of groundwater quality using the hydrogeochemical method?
- What are the perspectives and current challenges faced by Lephalale residents regarding the water supply quality and quantity?
- Are there any alternative sources of water and strategies used by community members to cope with water scarcity problems and water quality issues?
- Will the developed water treatment module be suitable and sustainable for household use?

1.5. Significance of the study

Understanding the quality of groundwater is a very important factor in determining whether the water is suitable for human consumption and domestic use. As a scarce resource, groundwater must be monitored continuously through quality assessments and management for sustainable use and contamination protection.

Groundwater monitoring and hydrogeochemical assessment will bring out the quality of water in the study area and the data can be used for policy formulation in water supply and sanitation. Lephalale has been reported by Molefe (2018) that 87% of water is used on irrigation activities. It is significant to assess groundwater suitability for irrigation purposes because the obtained data can be used by decision-makers for better and productive farming. While understanding community members' experiences will outline the challenges they are facing and when and where to intervene. The advantage of using the water treatment module will be to reduce consumption of polluted water thus minimising waterborne disease. In addition, the study will promote the mandate of the NWA (Act 36 of 1998) which states to promote basic human needs for both present and future generations and the need to promote social and economic development. The Millennium Development Goals (MDGs) highlighted the proportion of people who are unable to reach or afford safe drinking water and to stop the unsustainable exploitation of water resources, which promote both equitable access and adequate water supply. And the Sustainable Development Goals (SDGs), goal 6 says that we must ensure availability and sustainable management of water and sanitation for all in order to improve the health and livelihoods of millions of people.

A well-established study on the assessment of social and economic aspects, borehole monitoring, and testing of water treatment modules at a household level has not yet been conducted in Lephalale. Therefore, this study seeks to assess water quality, hydrogeochemical characteristics, evaluate the water suitability for irrigation, evaluate the water challenges faced by the community members and develop an affordable and simple to use water treatment cartridge.

1.6. Thesis structure

This study consists of six chapters and is highlighted as follows:

Chapter 1: Introduction

This chapter entails a general introduction to the subject of the research. It includes the general background, problem statement, research objectives, research questions, and motivation of the study.

Chapter 2: Literature Review

This chapter consists of an overview of the concepts such as Groundwater as the main source of water, groundwater contamination, water treatment methods, and point of use water treatment technologies.

Chapter 3: This chapter determines the hydrogeochemical and microbial constituents of groundwater in Lephalale Local Municipality and further assess its suitability for domestic and agricultural uses

Chapter 4: This chapter entails the perceptions of Mmatladi rural community members regarding water quality and supply

Chapter 5: This chapter examinations the performance of Al/Fe oxide Diatomaceous Earth-based two bucket water treatment system for household use

Chapter 6: General conclusions and recommendations

This chapter states the conclusions and recommendations from this study

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Arid North East Region Of Ghana. Journal Of Geochemical Exploration, 207, 106363, pp. 1-21.

Chapter 2: Literature Review

2.1. Introduction

Water is the most precious natural resource among all-natural resources found on the Earth (Iqbal & Gupta., 2009; Maruyama et al., 2013). In the previous few decades, there has been an extraordinary increase in freshwater supply requirements as a result of an increase in population, industrialization, urbanization, climate change, and intense agricultural activities making it be a scarce resource (Raju et al., 2011; Dhanasekarapandian et al., 2016). Groundwater is naturally suitable for human consumption because of its good quality (Ahmad et al., 2020; UN WWAP., 2017). About 40% of the world's population uses groundwater as a main source of water supply and globally, up to 50% of the food production is produced using groundwater (Cao et al., 2019).

In developing countries, especially in rural areas groundwater is often the only possible source of good potable water. In Africa, groundwater is considered the most resilient source of drinking water (Lapworth et al., 2017, Molekoa et al., 2019). Moreover, groundwater has played a major role in accommodating domestic and irrigation demands in arid and semi-arid regions, where surface water does not meet the demand. In addition, it is an advantage that groundwater is commonly available in enough quantities to supply the needs of scattered communities (Rwanga et al., 2018). Groundwater contributes about 13% to the total water supply in South Africa and it is an unlimited significant strategy for a source of water (Molekoa et al., 2019). It is the foundation of rural water supplies, sustaining livelihoods for most rural areas (Oke & Fourieb., 2017).

The cost of the development of groundwater is cheaper than that of surface water and most have reasonably good quality which only requires minimal treatment. However, groundwater quality varies from one rock type to another and aquifers and from catchment to catchment (Potgieter et al., 2006; Taheri et al., 2017; Yetiş et al., 2019). Nonetheless, groundwater quality can also be altered as a result of anthropogenic activities such as land-use change, agriculture, as well as urbanization, and natural factors such as climate change or/and geology (Rwanga et al., 2018).

This chapter takes an account of the literature used in understanding the concept of groundwater quality, factors affecting groundwater quality, and all other factors related to the subject. It also includes an overview of concepts such as water treatment methods, point of use water treatment technologies and

2.2. Groundwater contamination

Earlier groundwater was considered safe as compared to surface water (Madhava et al, 2018). However, groundwater can be contaminated via natural processes and anthropogenic activities. Human activities such as dumping solid waste, domestic and industrial waste, mining, and agricultural activities influence groundwater chemistry (Singh., 2002; Raju et al., 2007; Raju et al., 2016; Wu et al., 2020). And natural processes include the dissolution of ions in soils, sediments, and rocks. These activities end up contaminating groundwater with chemical pollutants such as iron, manganese, arsenic, chlorides, fluorides, or sulphates; and microbial contaminants such as *Salmonella spp, Escherichia coli, Klebsiella pneumonia,* and *Cryptosporidium* (Madhava et al., 2018; Cooray et al., 2021).

2.2.1. Pathogens

Groundwater for a long time has been alleged to be completely free of microbial contaminants and viruses, believing that vertical transport times are long enough and microbial survival too short to reach the aquifers (Mahagamage et al., 2019). Today, there is no doubt that pathogenic microorganisms and viruses can be found everywhere in the environment (Sorensen et al., 2016). Groundwater is contaminated by pathogens from different sources such as animal manure and compost, leakage from on-site sanitation systems, sewage sludge, and disposal systems (Krauss and Griebler., 2011; Khan et al., 2018).

Common microbial species found in groundwater are *Escherichia coli, Salmonella* SPP*, Vibrio cholera, Shigella spp, Campylobacter jejuni, Pseudomonas aeruginosa, Shigella spp*, *Yersinia spp,* and *Legionella spp* (Krauss and Griebler, 2011, Cooray et al., 2021). Exposure to these microorganisms can lead to diarrhea pneumonia, endocarditis, meningitis, pericarditis, reactive arthritis, cholera, gastroenteritis, dysentery, reactive arthritis, Guillain-barre syndrome, urinary tract infections, bacteremia (Mahagamage et al., 2019).

Cases of these waterborne have been reported in countries such as India (Sorensen et al., 2016), Kenya (Mzuga et al., 1998), Nigeria (Adekunle et al., 2004; Plappally et al., 2011), Zimbabwe (Dzwairo et al., 2006) and South Africa (Holland, 2011; Traoré et al., 2016) where groundwater is the major source of drinking water. Up to 4 billion cases of water-related disease are reported annually causes of 3.4 million deaths worldwide which is a leading cause of death especially for children under the age of 5 who die of waterborne diseases.

In South Africa, Limpopo, Mpumalanga, and KwaZulu Natal Provinces were reported to be alleged to be experiencing a high number of children under the age of five years suffering from diarrhoea, cholera, and typhoid fever every year (DWAF., 2001; Potgieter et al., 2006, Traoré et al., 2016; Edokpayi et al., 2018). A study was done by Edokpaye et al., (2018) observed the presence of Total coliform and E. coli in wet and dry seasons. The results showed the presence of E. coli of up to 2200, 200, and 10 CFU/100mL in the rainy season for rivers, community systems, and boreholes, respectively. For Total coliform, a maximum of 30 000, 13 000, and 12 000 CFU/100mL were observed in water sampled in rivers, community systems, and boreholes in a wet season. A mean of 99 CFU/100mL for Total coliform and 7 CFU/mL for faecal coliform was observed in North west boreholes in a study conducted by Mpenyana-Monyatsi (2012). This indicates that the water used by people in these areas is highly polluted with microbial contaminants.

2.2.3. Fluoride

Groundwater contamination by fluoride occurs when water interacts with a fluoride containing minerals such as fluorspar, apatite, cryolite, and hornblende are high (Henry et al., 2013; Malago, et al., 2017). The concentration of fluoride in drinking water of about 0.7 mg/L has been reported to be beneficial as an essential component for the mineralization of bones and the formation of dental enamel. However, the world health organization has set a guideline of fluoride concentration in drinking water to not exceed 1.5 mg/L. Globally higher fluoride concentration has been reported in countries such as China, India, Indonesia, Iran, Pakistan, Canada, Mexico, Sweden, Argentina, Ethiopia, Uganda, Kenya, Tanzania, Ghana, Malawi, Nigeria, and South Africa (Puntoriero et al., 2014; Berger, 2016; Jacks, 2016; Rentería-Villalobos et al., 2017; Malago et al., 2017; Wimawansa, 2020) as shown in Figure 2.1.

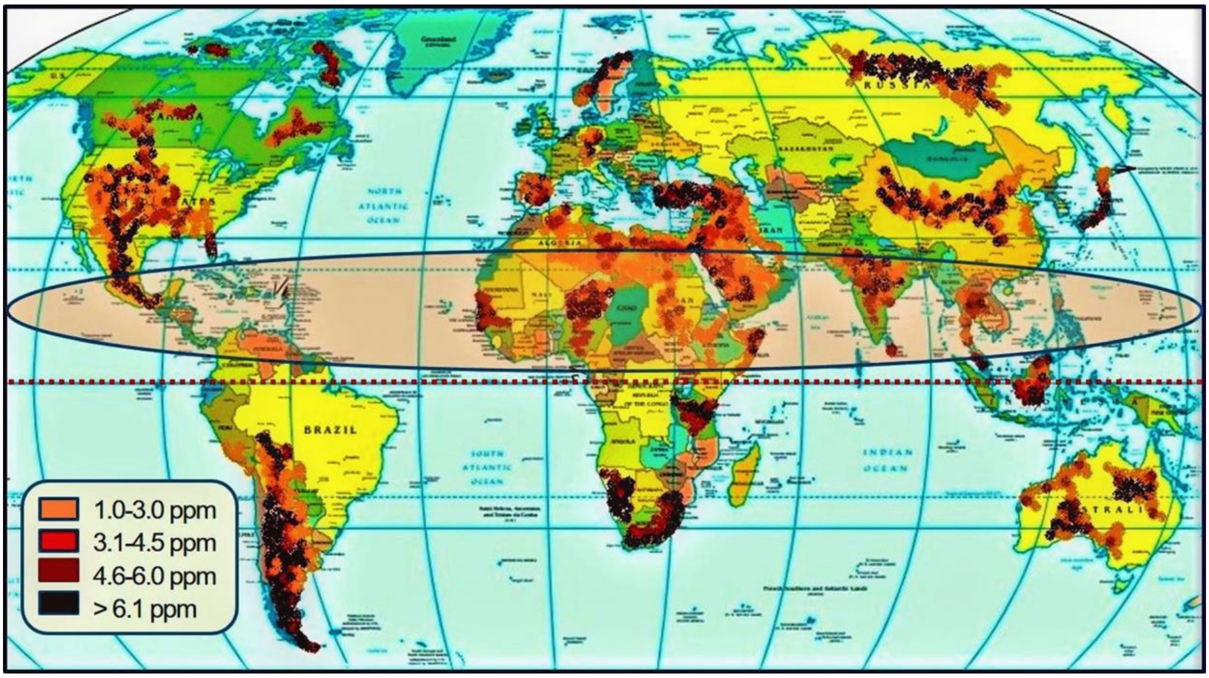

Figure 2.1: Global map of the distribution of groundwater fluoride (Wimalawansa, 2020)

A high concentration of fluoride in drinking water can cause fluorosis diseases that target teeth and bones (Gitari et al., 2017). A minimum of 2 mg/l of fluoride in drinking water can cause dental fluorosis if the water is consumed for long period (Choubisa et al., 2011; Qanungo et al., 2014). This is characterized by yellow patches on teeth and may turn black and affect the whole tooth (Revelo-Mejía et al., 2021). Skeletal fluorosis can be caused by the consumption of water with a minimum fluoride concentration of 3mg/l and its symptoms are stiffness and severe pain in the backbone, joints, hip, and paralysis (Choubisa et al., 2011; Gitari et al., 2017).

Srivastava and Flora (2020) reported that over 100 million people worldwide are suffering from dental and skeletal fluorosis and majority of them are located in Africa and Asia. High fluoride levels above WHO standard in South Africa have been reported in several areas including Free State, Limpopo, North-West and Kwa-Zulu-Natal Provinces, and Northern Cape (Malago, 2017). Ncube and Schutte (2005). assessed occurrence of dental fluorosis in the Free State, North-West, KwaZulu-Natal, and Western Cape Provinces (Fig 2.2), Where they reported percentage morbidity of dental fluorosis of 97% in the North West province. A study was done by Odiyo and Makungo (2018) in Siloam village, Limpopo province stated that 85% of people who use groundwater have dental fluorosis (mottled teeth), and 50% of those are pupils between the ages of 11 to 14 years.

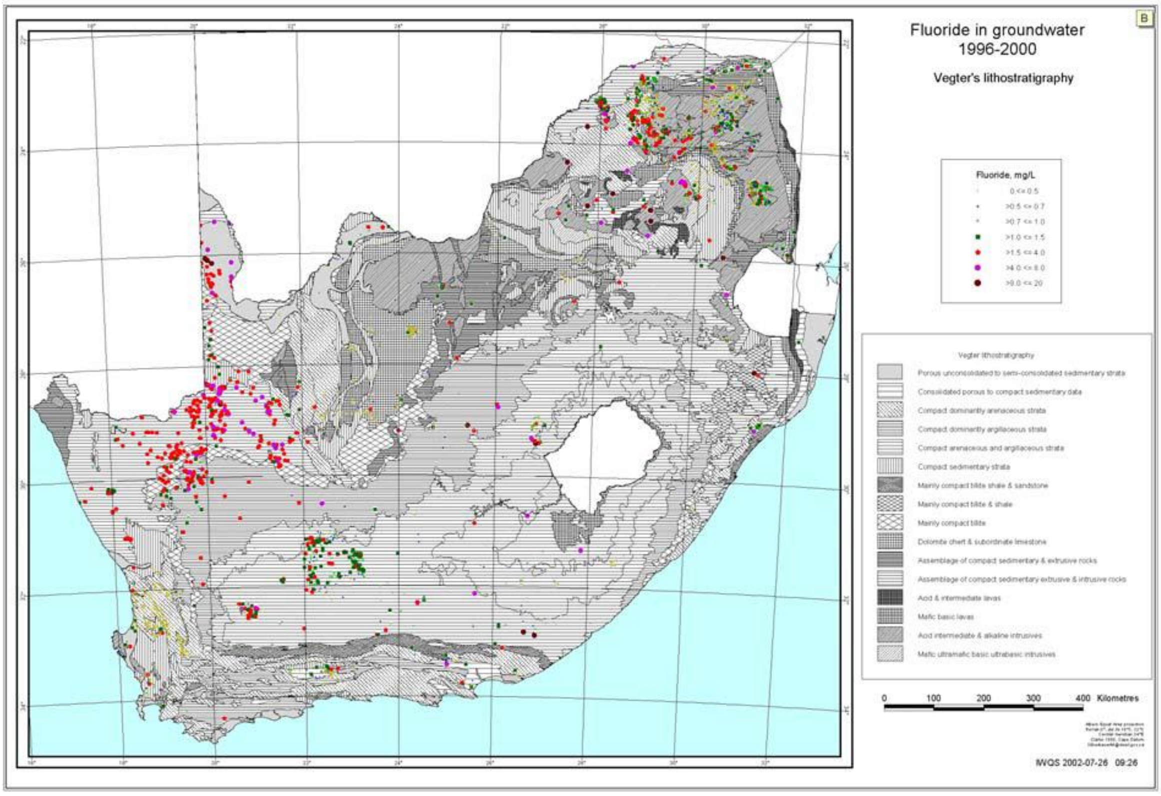

Figure 2.2: Fluoride in South African groundwater (Ncube and Schutte, 2005).

2.2.4. Arsenic

Arsenic is one of the geogenic contaminants, which is associated with the mineralization of rocks (Muñoz et al., 2016). However, it enters the environment from natural processes, industrial activities, pesticides, industrial waste, smelting of copper, lead, and zinc ore and ends up reaching the aquifer thus contaminating groundwater (Abiye et al., 2018).

Arsenic contaminated drinking water can lead to serious skin problems in the form of Melanosis and Keratosis at the initial stage and if left untreated it leads to skin cancer at the advanced stage (Thakur et al. 2013; Mudzielwana et al., 2020) and it can cause problems in the reproductive system, birth defects and harm the nervous system (Ahmad et al., 2021). To minimise the effects of arsenic in human health, the world health organisation (WHO) has set a standard of 10 u/L of arsenic in drinking water which was also adopted by the South African government (SANS241, 2015)

An estimated 130 to 150 million people around the world are directly affected by Arsenic contamination in groundwater (Abiye and Bhattacharya., 2019). High Arsenic concentration in groundwater reported in Mexico, Northern Vermont, USA, China, Chile, Bangladesh, Taiwan, Argentina, Poland, Canada, Hungary, Japan, Ghana, India (Yadav et al., 2021), and also in South Arica where is much higher in Limpopo and Western Cape (Abiye and Bhattacharya, 2019; Mudzielwana et al., 2020) (Figure 2.3). In Limpopo province, the Arsenic concentration of up to 172.53 μg/L was observed in Klein Letaba under the Greater Giyani Municipality (Mudzielwana et al., 2020).

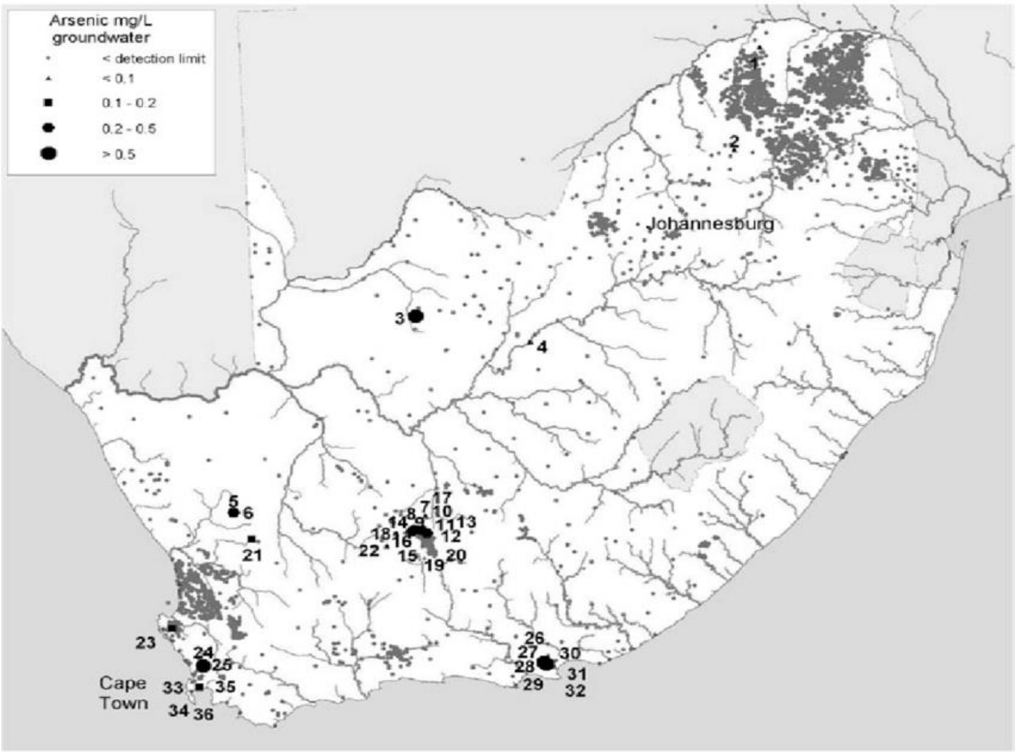

Figure 2.3: Arsenic in South African groundwater (Kempster et al., 2007).

2.2.5. Nitrate

The sources of nitrate (NO_3^-) in groundwater include decaying organic matter, legume plants, sewage, nitrate fertilizers, and nitrates in soil (Yu et al., 2020). High levels of nitrate in groundwater are usually indicative of contamination from anthropogenic activities (Abudaya et al., 2014). Ward et al., (2018) reported that high nitrates in drinking water can cause diseases such as thyroid cancer, ovary infections, and kidney failure. The World Health Organization set a limit for nitrate of 50 mg/L. Figure 2.4 shows the Southern Africa region with high nitrate levels, which include Botswana, Namibia, and South Africa. Ntshangashe (2019) reported that Chaneng village, in the North West province has high nitrate levels of up to 186 mg/L.

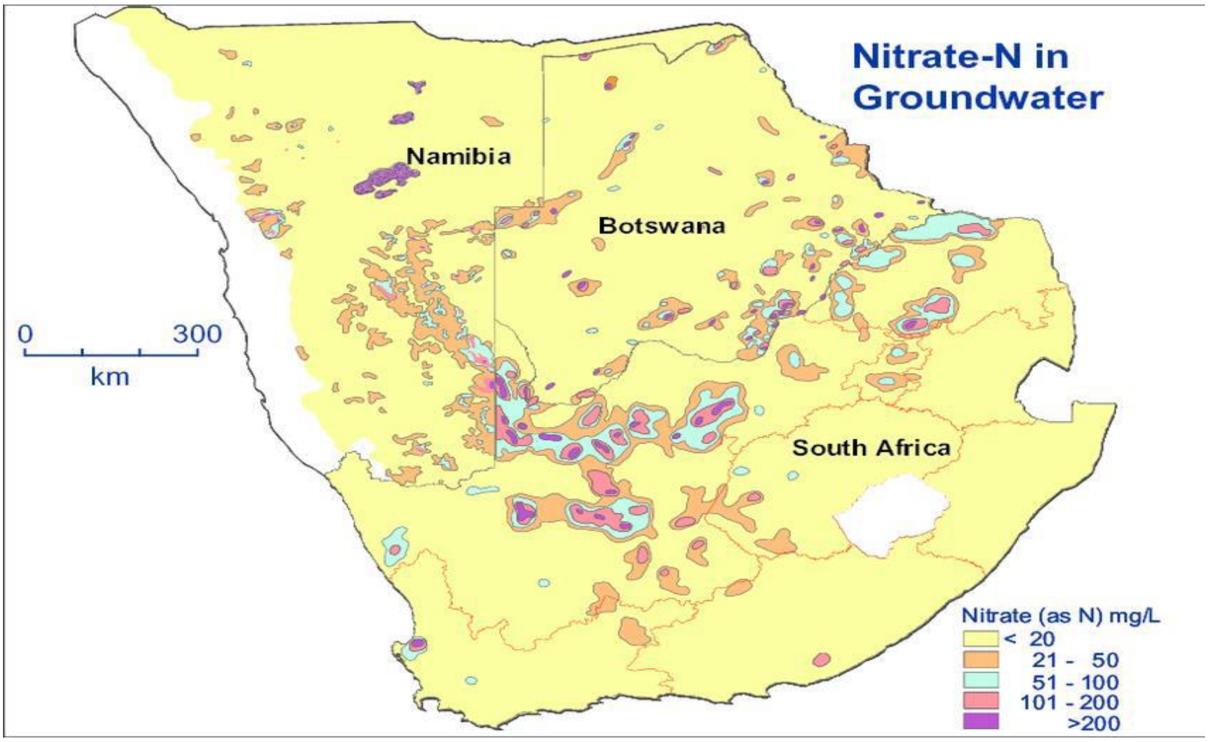

Figure 2.4: Nitrate distribution map of Southern Africa (Tredoux et al., 2022).

2.2.6. Other trace elements

Trace elements occur naturally in the environment, and their presence in groundwater is generally not desired as many have toxic effects even at low concentrations. Even though trace metals are found in the earth’s crust, contamination in groundwater could be an outcome of natural and/or anthropogenic sources (Brindha et al., 2020). The aquifer type, minerals weathering, precipitation frequency, and residence time are the natural factors that control the presence of trace elements in groundwater (Chandrasekar and Lakshmanan, 2017). Anthropogenic sources are due to wastes from industrial activities, soil contamination, underground storage tanks, landfills, mine tailings, urban sewage, and fertilizers (Brindha et al., 2020). Trace elements such as Fe, Mn, Cu, Zn, Co, and Ni are micronutrients for a living system, their shortage can lead to several disorders in the human body. However, some such as Cd, Pb, and Cr can be toxic to human health even at low concentrations (Durowoju et al., 2020). There is increasing public health concern in recent years over contamination of the water by trace elements.

Munyangane et al. (2017) conducted a study on trace elements in the Greater Giyani Municipality, Limpopo Province in South Africa where they reported Pb, Cr, and Se to be the elements exceeding the South African national drinking water standards of 10, 50, and 10 ug/L, respectively.

2.3. Hydrogeochemical Facies

Hydro-chemical properties of the groundwater are attributed to the resident time, lithology, geology, and water regional flow pattern (Alsuhaimi et al., 2019). The nature and distribution of hydrogeochemical facies can provide insights into how groundwater quality changes within and between aquifers (Sivasubramanian et al., 2013). The use of general water quality diagrams is a convenient method to describe the water types according to the ionic composition of the groundwater in question (Adimalla and Venkatayogi, 2018).

2.3.1. Piper (1994) diagram

The Piper diagram shows the general distribution of the anions and cations in the groundwater. Yidina et al., (2018) described the piper plot as a cluster that groups variables based on similarities and dissimilarities in the variation of the data set. Figure 2.5 shows a blank Piper diagram that is used to classify groundwater types. This diagram consists of triangle 1. the Cation which consists of the calcium, magnesium, and sodium water types, and triangle 2. the anion which contains bicarbonate, sulfate, and chloride water type, and a diamond shape in the middle which groups samples into Ca-HCO_3^-, Ca-Mg-HCO_3^-, Ca-Cl, Na-HCO_3^-, Na-Cl, and Ca-Na-HCO_3^- water types. Dissolution of calcite, dolomite, gypsum, and halite will give rise to Ca-HCO_3^-, Ca-Mg-HCO_3^-, and Na-Cl type of groundwater respectively. Na-HCO_3^-, Ca-Cl, and Ca-Na-HCO_3^- may result from cation exchange processes and reverse exchange processes (Ahmad et al., 2020).

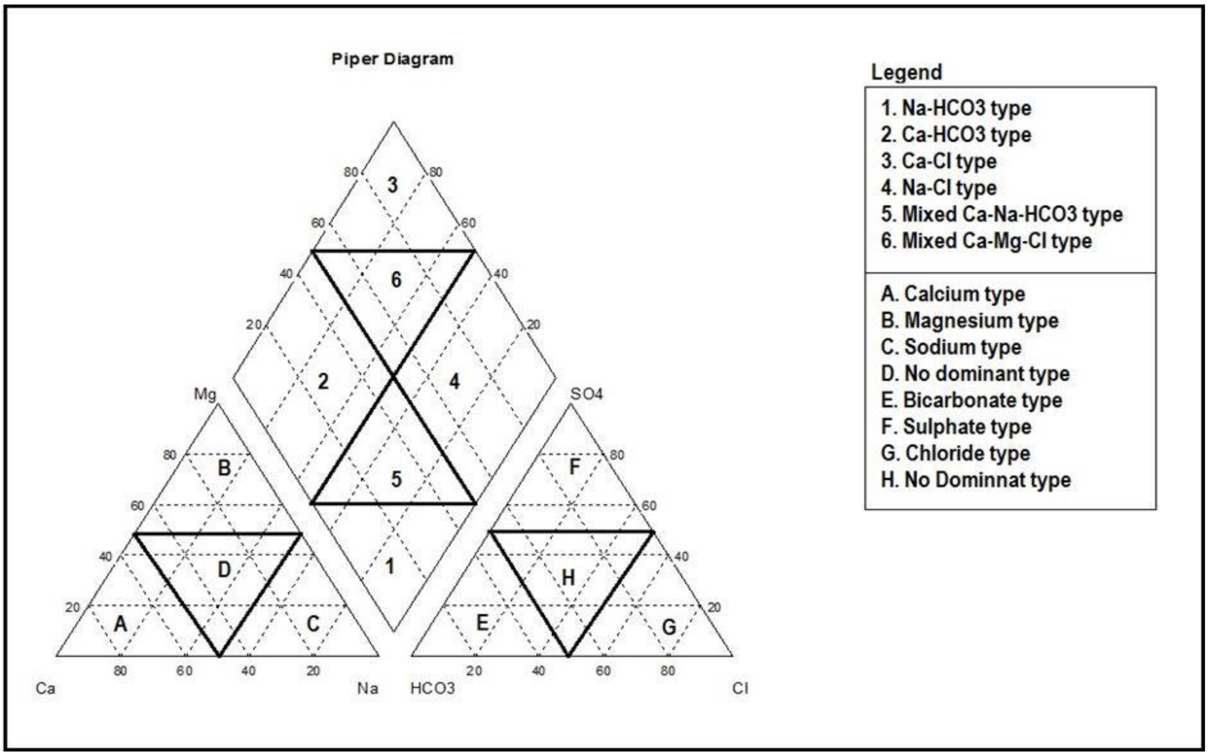

Figure 2.5: Typical Piper plot diagram showing different water type/hydro-chemical facies (Ravikumar et al., 2011)

2.3.2. Gibb's diagram

The Gibbs diagram is useful for analysing major natural factors influencing groundwater formation mechanisms (Figure 2.6). The diagram consists of plots of the ratios of cations and anions against their corresponding TDS. According to the Gibbs diagrams, groundwater formation mechanisms include three types: rock dominance, precipitation dominance, and evaporation dominance (Gibbs 1970).

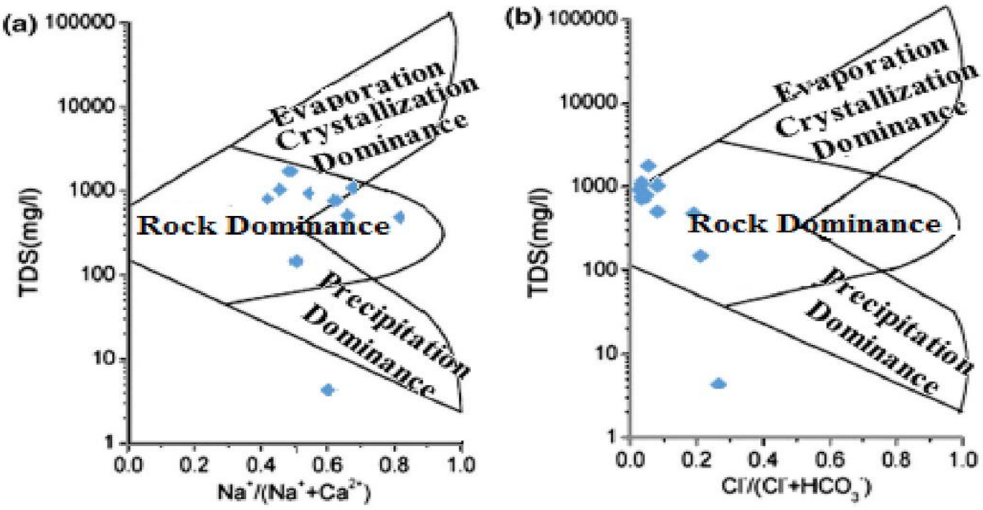

Figure 2.6: Gibb’s plot for groundwater collected in Greater Giyani Municipality (Mudzielwana et al., 2020)

2.4. Water treatment methods

Due to the lack of a clean water supply system, the WHO has recommended the installation of household water treatment systems in communities where water contains higher levels of contaminants (WHO, 2017). The household water treatment systems must be cost-effective, use available materials, and be simple to use (Nde-tchoupe et al., 2015; WHO, 2017).

Available water treatment methods include precipitation (Onyango & Matsuda., 2006), Ion-exchange (Meenakshi & Viswanathan., 2007), adsorption (Gitari et al., 2013); coagulation (Sandoval et al., 2014), Nano-filtration membrane process (Pervov et al., 2000; Waghmare and Arfin., 2015) and reverse osmosis (Trikha & Sharma., 2014).

Other traditional methods used to remove microbial contaminants include boiling (Rose et al, 2010) and household-based chlorination (Mohamed., et al., 2016; Li & Dong, 2017), silver nanoparticles (Tshishonga & Gumbo, 2017; Barkat, et al., 2018). Table 2.1 shows a summary of the pros and cons of some of the water treatment methods.

Table 2.1: Advantages of different chemical treatment methods

Methods	Process/ Materials used	Advantages	Disadvantages	References
Coagulation-	The process involves uptake of the pollutants and separates the products formed	Process simplicity Cost-effective Anti-microbial characteristic	Requires non-reusable chemicals Generates high sludge volume Low removal of arsenic	(Gupta et al. 2012)
Precipitation	Involve precipitation of chemicals dissolved in water into a solid phase	Simple to operate Can be used in high pollutant loads Not metal selective	Consume a lot of chemicals Needs pH monitoring Produce a lot of sludge Ineffective for removal of low metal ion concentrations	(grégorio and Lichtfouse, 2018)
Ion exchange	The method focuses on changing ions through processes such as de-alkalization, deionization, and disinfection.	Easy to use Produce a high-quality treated effluent Efficient for the recovery of valuable metals	Expensive Requires pre-treatment Not effective for pathogen removal	grégorio and Lichtfouse, 2018)
Reverse osmosis	The method uses pressure to separate pollutants from water	No chemicals required Simple, rapid, and efficient to use Low solid waste generation	High energy requirements High maintenance and operation costs Needs skills to operate	(grégorio and Lichtfouse, 2018)

Adsorption	Bentonite clay	High surface area High cation exchange capacity Low cost	Needs modification for adsorption of anions	(Gitari et al., 2013)
	Diatomaceous earth (DE)	High pore size Non-Organic Cannot undergo degradation in water Readily available	Needs modification by hydroxides/oxides for adsorption of ions	(Izuagie et al. 2015)
	Activated alumina	High surface area Much effective on defluoridation	High cost Periodic regeneration Skilled personnel for plant operation	(Waghmare and Arfin, 2015)
	Ag-MgO Nanocomposite	High anti-microbial effectiveness		(Ayinde et al. 2018)
	Bone char	Local available in abundance	May impart taste and odor Achieved by high alkalinity	(Alkurdi et al., 2019)

2.5. Point of use water treatment technologies

While the bulk water supply infrastructure is still not available in most rural areas, a temporary solution needs to be used for water treatment systems at a household level (Dlamini., 2014). This point of use water treatment has the potential to fill the gaps where piped water systems are not possible, where groundwater is highly contaminated resulting in enormous positive impacts in development. The strategy of providing rural communities with these technologies is to meet the Millennium Development Goals and the Sustainable Development Goals (SDGs).

Point of use water treatment technologies are widely used mostly in developed and developing countries, they consist of a range of options that enable communities to remove contaminants in drinking water. (Henry et al., 2013). Point of use technology must be simple to use, less expensive, have low maintenance, and should require locally available materials (Bitton., 2014; Edokpayi et al., 2015). There are several types of point of use water treatment technologies designed to treat various contaminates, - that has been reported worldwide and a few are discussed below;

2.5.1. Chlorination

Chlorination is a process of mixing chlorine into the water to kill bacteria (Figure 2.7). POU treatment of water with chlorine (usually in the liquid form of sodium or calcium hypochlorite) is quite simple; first, you add a measured dose of chlorine to untreated water; then shake or stir the water to ensure adequate distribution. Let the water sit for a measured amount of time to allow the chlorine to act before using it. This method is very effective in eliminating viruses, bacteria, and protozoans, however, doesn’t remove chemical contaminants such as fluoride, arsenic, sodium, copper, chromium, magnesium, potassium, and nitrate (Patil et al., 2020).

Figure 2.7: Chlorination water treatment method (https://sswm.info/affordable-water-supply/chlorination)

Advantages

- Up to 99.99% effective on pathogen removal
- Easily available
- Cost-effective

Disadvantages

- A large amount of chlorine is harmful and poisonous
- When water is turbid, chlorine may be ineffective
- Water may taste metallic, bitter, or like bleach

2.5.2. Boiling

Boiling water is one of the oldest and most common household methods used in the developing world to treat water (Figure 2.8). When used properly, boiling is also one of the most effective ways to disinfect water. Although the boiling point of water at sea level is typically 100 degrees Celsius (depending on impurities in the water, which can affect the boiling temperature), studies have noted a reduction of bacteria and parasites even when the water has been heated to only 70 degrees Celsius (Odwori, 2019).

Figure 2.8: Boiling water method (https://boiling water for drinking)

Advantages

- It is the cheapest and safest method of water purification.
- Easy to kill the microorganisms in the household system
- People are already familiar with the concept of boiling to treat water which makes it the simplest method.

Disadvantages

- High heat while boiling leads to destroying water-soluble vitamins such as B &C
- Requires affordable and sufficient fuel to boil water for daily drinking purposes.
- Boiling may cause burn injuries if proper precautions are not taken
- Water tastes flat after boiling
- Does not remove chemicals (like arsenic and fluoride) or turbidity from the water

2.5.3. Solar water disinfection system (SODIS)

SODIS (Figure 2.9) is a type of water purification system that uses solar energy. It works by exposing contaminated water in a transparent container to sunlight for not less than 6-8 hours (Moreno-SanSegundo et al., 2021). The principle underlying solar disinfection is that microorganisms are vulnerable to light and heat. It has been proven that as soon as the water temperature reaches 50 °C, the inactivation process is accelerated which usually leads to complete bacteriological disinfection (Parsa et al., 2020).

Figure 2.9: Experimental set-up of the solar disinfection tests (Vivar et al 2015)

Advantages

- A safe and easy method of water purification.
- Economical method compared with other methods of water purification as it relies on locally available resources, plastic bottles, and sunlight.
- Environment flexibility.

Disadvantages

- It is not applicable for large volumes of water.
- This method calls for relatively clear water.
- This method is very dependent on favourable climate and weather conditions.

2.5.4. Ceramic water filters

A ceramic point-of-use water filter (Figure 2.10) is a simple and effective way to purify water. This filter works by mixing various materials such as clay, water, silver, and combustible material. The is clay impregnated by silver nanoparticles which are specifically for pathogen removal (Edokpayi et al., 2017). Higher quality ceramic filters treated with bacteriostatic silver have been shown effective in the lab at reducing waterborne protozoa by more than 99.9% and bacteria by more than 99.9999%. The ceramic pot is placed in a larger covered container (usually plastic) that has a spigot. The process of filtering the water is simple: one pours the water into the top of the pot and waits for it to filter through the ceramic and collect at the bottom of the plastic container (Shepard et al., 2020)

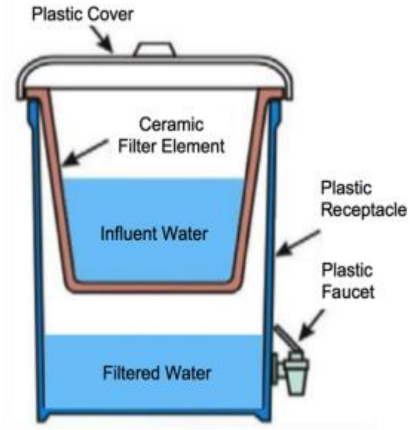

Figure 2.10: Ceramic water filter schematic (Farrow et al., 2018)

Advantages

- It's simple to install, operate and maintain
- Very cost-effective solution to remove turbidity and pathogens
- Provides safe storage to prevent re-contamination
- Does not require any energy supply to filter water

Disadvantages

- Not effective against viruses
- The rate of filtration through ceramic pot is very slow
- Flow rate decreases with time due to clogging by suspended particles in the feed water
- Needs to be cleaned regularly to avoid clogging
- Can break very easily, if dropped accidentally.
- Not effective on chemical contaminants

2.5.5. Biosand filter

A biosand filter (BSF) (Figure 2.11), was introduced by a Canadian researcher with an important design change that allowed the system to operate with only intermittent water flow, unlike the continuous water flow needed with previous slow sand filters (Clasen et al., 2009, Clasen et al., 2007). Water is poured into a concrete or plastic chamber filled with locally available sand; the water filters through the sand and gravel layers and drains to the bottom of the container; there it reaches the outlet pipe (Duran Romero et al., 2020).

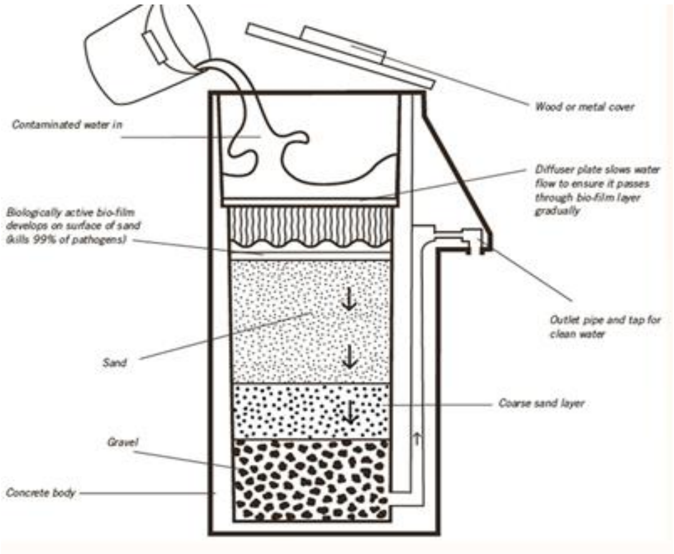

Figure 2.11: A biosand filter illustration (https://palisades-rotary.org/about-biosand-water-filters)

Advantages

- Up to 99 % removal efficiency on microorganisms
- Effective and long-lasting method of household water treatment
- It can be used with any water source such as rainwater, well, bore well, rivers, lakes, or other surface water.
- Easy to use
- As the filter works by gravity, no electricity/ fuel is required

Disadvantages

- Biosand filter cannot remove dissolved contaminants or chemicals, such as salt, arsenic, or fluoride, etc.
- Needs regular maintenance
- Skilled labour is required for the construction and maintenance

2.6. Groundwater quality in South Africa

In South Africa, there is a high demand for potable water due to limited surface water resources and unpredictable climatic conditions. In most South African, rural communities in areas such as Limpopo, Northern Cape, and Northwest Provinces groundwater is the main source of water. Several studies have been done in South Africa to assess and monitor the quality of groundwater (Nyika and Onyari, 2019).

Ligavha-Mbelengwa and Gomo (2020) investigated factors influencing groundwater quality in a typical Karoo aquifer of Beaufort West town of South Africa. The study revealed that hydrogeochemical facies dominating the study area were Ca-HCO3, Na-SO4, and mixed water types. Principal component analysis suggests that there is a potential influence of anthropogenic activities on the groundwater causing mineralisation of the groundwater to result in saline water. In some parts of the study area (higher elevation) groundwater was found suitable for both domestic and irrigation use.

Mpenyana-Monyatsi (2012) conducted a study in the North west province of South Africa with the main aim of assessing the quality of the groundwater currently supplied to the rural communities of the North West. The main findings of this study revealed that some groundwater in the area was not complying with the WHO drinking water standard regarding total coliforms, Faecal coliform, nitrates, fluoride, magnesium, TDS, and calcium. The study further recommended government intervention to provide protection of groundwater sources and drinking water treatment barriers to ensure the safe distribution of potable water.

The quality of groundwater was assessed in Luvuvhu catchment, Limpopo, South Africa. The study reported that Ca–Mg–Cl and Ca–HCO_3^- are the major hydrogeochemical facies and that groundwater is suitable for drinking without any restrictions. Irrigation suitability assessment suggested that groundwater is suitable for all types of crops and soils (Elumalai et al., 2020).

In a study done by Molekoa et al. (2019) fluoride was the only contaminant found to be above the WHO drinking threshold amongst other parameters in the Mokopane area. The study further revealed that Na-HCO_3^- is the most abundant water type and that rock-water interaction is the prime factor responsible for fluoride enrichment in water. The limitation of this study was the limited number of borehole samples for investigation. Hence, the authors recommended a detailed examination of water quality along with soil samples on a larger spatio-temporal scale.

2.7. Residents’ perceptions on water quality and quantity

Studies on rural community members' views about water quality and quantity have been done worldwide. Olawade et al., (2020) evaluated water supply difficulties in selected rural communities in Osun State, Nigeria. The results from this study showed that people from Osun State face water supply challenges due to the absence of water supply systems or the lack of maintenance of available water facilities.

The majority of rural areas in South Africa are experiencing the challenges of accessing water services due to water scarcity, municipality supply challenges, and affordability. A study was done by Mothetha et al., (2013) stated that rural municipalities are struggling to provide services to communities, due to lack of maintenance, broken facilities, and lack of funds.

Mahlasela et al. (2020)conducted a study assessing the household’s thoughts given the efficiency of the water supply offered by the Johannesburg Municipality, South Africa. The study concluded that residents receive sufficient water supply, however, there is limited knowledge amongst participants about water. The study reveals that the major challenges in this urban area are that they do not save water and some pipe leaks spend more time before being repaired resulting in up to 1580 million cubic litres lost per annum. As a limitation, the study did not assess the quality of water supplied in this municipality.

Perceptions on water quality in rural areas under the Luvuvhu-Letaba Water catchment area were studied by Thikolomo, (2012). The study interviewed community members using a structured questionnaire. The results showed that people in this catchment area do not have sufficient water supply for household/domestic use. The study revealed that half (50.1%) of households obtained water from street taps. People in the study area get water from rivers, wells, boreholes, or truck delivery as part of community coping strategies to get water for those living far from the street taps.

2.8. Summary

Groundwater has been reported to be the main source of water in most parts of the world and the majority of people around the world now depend on it as a result of a shortage of surface water. People believe groundwater is free from contaminants, but that’s not always the case. In some parts of the world (China, Thailand, Nigeria, South

Africa), groundwater can be contaminated by fluoride, nitrate, pathogens, arsenic, manganese, and other different contaminants from various sources either anthropogenic or natural which cause diseases and/or disorders (diarrhea, cholera, fluorosis). Hydrogeochemical studies have been done all over the world to get a clear understanding of the chemical characteristics of groundwater and its relation to regional geology. These hydrogeochemical facies are determined using models such as Gibbs and Piper plots.

To minimise the health effects of contaminated groundwater in rural areas, WHO has recommended the use of POU water treatment systems. With that being said, various techniques have been developed to treat water for domestic use. This includes biosand filters, boiling, ceramic water filters, chlorination, etc. A proper POU water treatment technology must be simple to use and maintain, affordable, and have high removal efficiency. Some of the reported techniques are limited to use in a rural-based environment due to lack of maintenance skills, require fuel/energy, and are not cost-effective. Several studies on groundwater assessment have been conducted in South Africa however there is still a need for monitoring of these resources.

People’s views and preferences on this water aspect depend on location, social status, and affordability. Although studies have been reported concerning water supply in South Africa, few studies have been done on perceptions of people regarding water quality. And none have been done in Lephalale Municipality, Limpopo province of South Africa, - this is a gap that needs to be explored.

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Chapter 3: Evaluation of hydrogeochemical and microbial constituents of groundwater Lephalale Municipality, Limpopo province, South Africa: assessing its suitability for domestic and agricultural uses.

3.0. Abstract

This chapter aimed to assess the hydrogeochemical characteristics of groundwater water in Lephalale Municipality, South Africa and further assess its suitability for use in domestic and irrigation purposes. A total of 25 borehole samples were collected from 15 villages within the Lephalale Municipality in April, July, October 2019, and October 2020). Samples were analysed for their physicochemical composition using standard field and laboratory techniques. Microbial analysis was done using spread plate technique and filter membrane method. Hydrogeochemical characteristics of the groundwater samples were determined by plotting piper, Gibb's, USSL and Wilcox diagrams using Grapher 2021 version. 18.1.334 software and Diagrammes 2020 version 6.7. Salinity hazard, Sodium Percent, Sodium Adsorption Ratio, Kelly's ratio, Magnesium Adsorption Ratio, and Permeability Index were computed to evaluate groundwater suitability for irrigation. The physical parameters such pH, EC, TDS, and alkalinity were found to be ranging from 6.69 to 7.87, 620.30 to1937.00 µS/cm, 330.35 to1035.50 mg/Land 50.00-390.00 mg/L, respectively. The mean values of major cations and anions were found to be in the order of Na^+>Ca^{2+}>Mg^{2+}>K^+ and HCO_3^- >Cl^->NO_3^->SO_4^{2-}>F^-, respectively. Of note the concentration of F^- in 36 % of the tested groundwater samples was found to be beyond the WHO permissible limit for drinking water purposes of 1.5 mg/L. This may pose a risk of being exposed to dental and skeletal fluorosis to people living in Lephalale Municipality. The results also indicated that 27 and 41% of the boreholes did not comply with the limits set by the national guidelines (SANS 241) in terms of TC (0-10 CFU/100 mL) and FC (0 CFU/100 mL), respectively. The hydrogeochemical facies determined using piper diagram revealed the dominance mixed CaMgCl and $CaHCO_3$ water type. The Gibbs plot analysis revealed that the main composition controlling processes in the study area is rock-water interaction. Estimated irrigation parameters revealed average values in meq/L for %Na (46.68), SAR (16.25), MAR (42.66), KR (1.06), and PI (53.09). %Na, PI, MAR, and KR values showed that the groundwater in the study area was suitable for irrigation. The analysis further indicated that the groundwater had a high salinity hazard. The findings of this study showed convincing evidence that some groundwater samples in rural areas of Lephalale Municipality pose a serious health risk to consumers and an intervention is required to minimize such effects.

Keywords: Hydrogeochemical characteristics, fluorosis, microbial analysis, irrigation indices, rock-water interaction, sodium adsorption hazard.

3.1. Introduction

Groundwater is the main source of water for drinking, irrigation, and industrial purposes in areas where surface water is scarce mostly in developing countries (Sunkari., et al, 2019). Rao et al, (2019) reported that groundwater has become a primary source of water for more than 1.5 billion people in the world. However, its quality varies from one rock type to another, aquifers, and from catchment to catchment, which is influenced by geology and anthropogenic sources (Rao et al 2019 and Amiri et al 2021). In some cases, groundwater is found to be contaminated by chemical species such as F^-, Arsenic and other trace elements as well as pathogens (Raju et al., 2011; Dhanasekarapandian et al., 2016).

When pollutants are deposited in the land surfaces are washed away into the saturated zone through soils that are porous and permeable which tend to transmit water and certain types of contaminants into the aquifer (Cuystodro., 2014; Talabi and Kayode., 2019). Also, water flowing through soils picks up naturally occurring minerals, salts, and organic compounds which increases as the water migrates downwards till it reaches the aquifer. Consumption of contaminated water particularly by fluoride, arsenic and pathogen can cause sicknesses such as dental and skeletal fluorosis, skin cancer, diarrhoea, fever and cholera in human being (Potgieter., 2007; Henry et al., 2013; Thakur et al., 2013; Abiye et al., 2018).

Lephalale Municipality in Limpopo Province is an arid region with a water scarcity problem (Tukakgomo., 2017). As a result of insufficient surface water supply, all 38 villages under this municipality depend on groundwater for household use (Lephalale draft integrated development plan, 2018/19). Like in any rural area, agricultural activities are recognized as one of the most important economic activities of residents, and therefore, there is a need to assess groundwater for irrigation in Lephalale municipality (Amiri et al., 2021). Department of Water Affairs reported that the groundwater quality in Lephalale is poor and is found to be contaminated by various chemical species such as fluoride and Nitrate (Sonnekus et al., 2015). Apart from chemical species, the presence of E-coli has been reported within the area with Total colony-forming units of 6 counts per 100 mL (Veltman & Botha., 2010; DWS., 2014). Due to the poor quality of groundwater in this area, and the fact that the water is supplied without any pre-treatment there is a need for continuous monitoring to sustain good water quality and improve human health.

The hygrogeochemistry of an area is altered by processes such as evaporation, geological structures, ion exchange, mineral precipitaion, dissolution, and rock water interaction (Abanyie et al., 2020). Research studies related to hydrogeochemical Charecteristics of groundwater in Limpopo have been done (Durowoju et al., 2015; Malaza, 2017; Molekoa et al., 2019; Mudzielwana et al., 2020). These studies involve an in-depth evaluation of the chemical composition of groundwater about geology and hence offer a better understanding of possible changes in groundwater quality (Zakaria, 2020). Conducting these techniques is vital for understanding the quality of groundwater since they discriminate hydro-chemical facies, determine pollution sources, and characterize groundwater evolution, and help regulate its suitability for various uses (Xu et al., 2019).

The focus of this chapter was to evaluate mechanisms of groundwater chemistry and determine the quality of groundwater in 15 villages of Lephalale municipality for domestic and irrigation use. Hydrogeochemical statuses and processes controlling the chemical composition of groundwater resources have also been investigated. This study will help local decision makers have insights into the overall quality of groundwater and thus assist them to better manage the groundwater resource.

3.2. Description of Study Area

The study was conducted in Lephalale municipality in the Waterberg district, Limpopo province, south Africa which is located between the latitudes of 23º30' and 24º00' south and longitudes of 27º30' and 28º00' east (Figure 3.1). Lephalale Municipality is situated in the north western part of south Africa in Limpopo province covering an area of 13 794 km^2 (Lephalale IDP., 2018/19). The total population is approximately of 140 240 with about 43 002 households. Approximately 65% of the population living in rural areas (StatsSA, 2016).

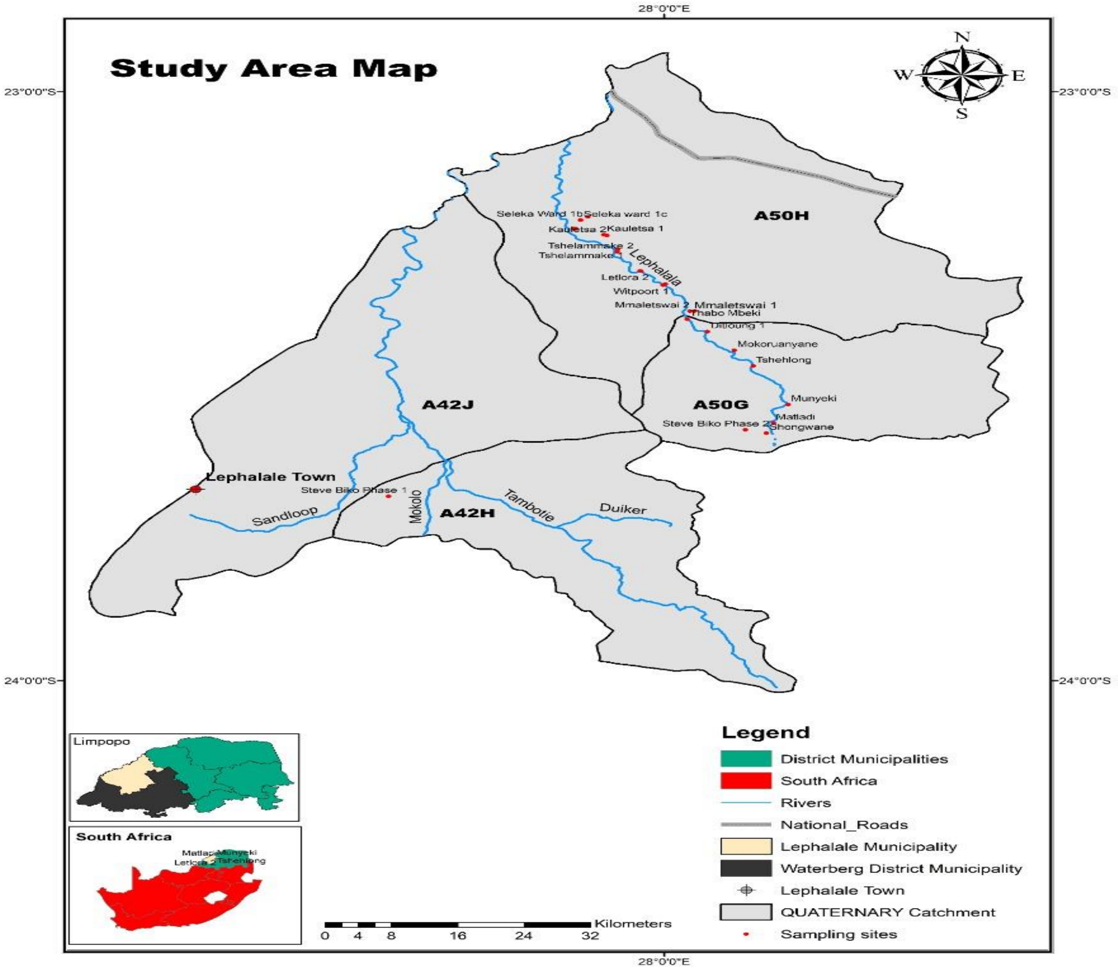


Figure 3.12: A map showing the location of a study area and sampling points

3.2.1. Climatic conditions

The climatic regime of the study area is characterised by hot, moist summers and mild, dry winters. The long-term annual average rainfall is 485 mm, of which 420 mm (86,5%) falls between October and March (Lephalale IDP., 2018/19). The area experiences high daily temperatures of up to 42℃, especially in the summer months. The annual evaporation in the area is approximately 2 281 mm (Matimba, 2006).

3.2.2. Hydrology

The study area falls within the Palala/Lephalala River Catchment, which drains into the Limpopo River. The Lephalala River catchment covers an area of 4 868 km^2. The river originates in the Waterberg mountains and grows in stature as it drops through a steep valley before merging with the Klip, Melkrivier, Blocklandspruit and Daggakraal tributaries on the southern boundary of the Lephalala Wilderness Area (Bruyns and Scholes, 2016). Below the Waterberg range, the river continues in a northern direction up to its convergence with the Limpopo River (Oberholster et al., 2010). The topography of the area is flat, and the drainage system is poorly developed. The river now only flows seasonally, and it has changed from perennial to non-perennial due to Due to high water demand, evaporation, and loss of connectivity (Seaman et al., 2013).

3.2.3. Geology

The Lephalale Municipality lies within the Beit Bridge Complex. The underlying sediments on the Elisras basin include several Formations with coal layers. The underlying Formations from youngest (Top) to oldest (down) are the Clarens, Lisbon, Greenwich, Eendragtpan, Grootegeluc, Swartrant, Willington, and Waterkloof Formation (Bambford, 2014). The Clarens formation consisting of sandstone of 5-10 m depth which is the most dominant and is underlain by red mudrock, coal with an average depth of 60 m and siltstone (Titus & Rossouw, 2008). The sandstones in this area are mainly feldspathic wackes and quartz. The mud-rock consists of mudstone and carbonaceous shale (Johnson et al., 2006). The other part of Lephalale also falls within the Waterberg basin which is dominated by iron-rich, quartzites, and conglomerates and contains a percentage of appetite and sandstone which gives rise to fluorspar mineralisation (Johnson et al., 2006).

Leaching of the fluorspar minerals into the aquifer results in the introduction of fluoride in Lephalale groundwater (Onipe et al., 2019). In addition, the coal richness in the area can lead to groundwater pollution by Arsenic (Abiye et al., 2018b). Moreover, the hydrogeological properties of an aquifer mostly result from post-depositional activities constrained by weathering, faulting, fracturing processes, and the influence of the intrusive rocks (Toit et al., 2011).

3.3. Materials and methods

3.3.1. Sample collection and preservation

A total of 24 borehole water samples were collected in April, July, October 2019, and October 2020 from 15 villages within the Lephalale Municipality. The periodic sampling was to take care of the dynamic nature of groundwater as average values were used for consequent evaluation. Borehole coordinates were recorded using a hand-held Garmin GPS (Etrex 10). Water samples were collected and stored in HDPE bottles which were prewashed before going to the field and rinsed with deionized water. Prior to groundwater sampling, water was pumped for few minutes to eliminate the influence of static water (Ahmad et al, 2020). Physical parameters such as temperature, pH, total dissolved solids (TDS), electrical conductivity (EC) were measured in the field immediately after sampling using a pH/conductivity meter (Jenway, 430). An electrode probe of the multi-meter was calibrated using pH standard buffer solutions of pH 4.00, pH 7.00, and pH 10.00. The samples were collected in triplicates, one for anions, one for cations and the other one for microbial analysis. Samples for cations/metals analysis were acidified with 3 drops of 3 M nitric acid to prevent colloid formation while the samples for anions analysis were unacidified (Mudzielwana et al., 2020). After sampling, the groundwater samples were labelled, stored in a cooler box with ice cubes and transported to the laboratory at the University of Venda. Microbial samples were collected in 110 mL Whirl-pak sterile sampling bags, stored in a separate cooler box with ice cubes and the analysis was done within 24 hours after sample collection.

3.3.2. Laboratory analysis

The cations (K^+ + Na^+, $Ca^{2+,}$ and Mg^{2+}) and anions (HCO_3^-, SO_4^{2-}, Cl^-, and F^-) were analysed in the laboratory. Anion's constituents were analysed in the laboratory using Ion chromatography (professional IC, 850, metrohm). The cations were determined using Inductively coupled plasma mass spectrometry (ICP-MS) (Thermo ICap 6200 ICP-AES, 7900 ICP-MS) at the central analytical laboratory, Stellenbosch University. Alkalinity was determined using titration method. A volume of 0.20N of Sulfuric acid was titrated into 50 mL volume of sample to a pH of 4.5 to get the value of alkalinity in $CaCO_3$. For quality assurance, samples analysis was done in duplicates and blanks were established as control.

3.3.3. Microbial analysis

The microbial content of groundwater was assessed using total coliforms (TC) and faecal coliforms *(E. coli*) bacterial indicators. The two parameters were determined using filtration method, and serial dilution method was employed for samples which were highly contaminated. In the method, 100 mL of the sample was filtered through a membrane filter of 47 mm diameter and 0.45 µm pore size that does not allow bacteria filtration. The membrane filter was placed in a culture media, ready plate 55 CCA (Merk & Co. Germany) and incubated for 24 hours at 37°C. Blue and pink colonies were inspected, pink colonies were counted as positive colonies for total coliform bacteria, while blue colonies were counted as faecal coliform bacteria. The plate showing <300cfu/100ml was counted and those with greater than 300 CFU were referred to as TMTC (Too much to count). The colony forming unit was calculated using Eq.2.

$$CFU\ per\ 100mL = \frac{number\ of\ colonies * dilution\ factor}{volume\ of\ culture} \qquad (3.1)$$

3.4. Hydrogeochemical analysis of groundwater

Acquired physicochemical data were graphically analysed using Piper and Gibbs diagrams that were plotted using Grapher 2021 version. 18.1.334 software. The Piper diagram modified consists of two separate triangular representations of cations and anions and a diamond shape of combined ions that are used to explain hydrogeochemical faces of water samples (Sunkari et al., 2020). The Gibbs diagram consists of plots of the ratios of cations and anions against their corresponding TDS. The plot is divided into three fields; precipitation, rock-water interaction and evaporation and is used to interpret the mechanisms controlling groundwater geochemistry (Nyika and Onyari, 2019).

The Rock Source Deduction calculations are done to understand the possible origin of the water sample. The results are a general overview based on ion ratios found in a sample which are compared to ratios of the respective ions in reactive minerals. This is done acquired by using Equation 3 and 4 (Adewumi et al., 2018).

$$\frac{Na^{+}+K^{+}-Cl^{-}}{Na^{+}+K^{+}-Cl^{-}+Ca^{2+}}\ (Mg/L) \qquad (3.2)$$

$$\frac{Na^{+}}{Na^{+}+Cl^{-}}\ (Mg/L) \qquad (3.3)$$

3.5. Irrigation Water Quality

The chemical composition of irrigation water directly effects plants and agricultural soils, and leads to less productivity (Khanoranga and Khalid, 2019). Therefore, a water quality assessment for irrigation is very important for effective agricultural production in Lephalale Municipality. The Wilcox (1955) and United States Salinity Laboratory (USSL) (1954) diagrams were used to assess the suitability of groundwater for irrigation. The Wilcox diagram was generated using by plotting the sodium hazard values against their corresponding EC values using Diagrammes software V6.7. The groundwater quality for irrigation purposes was also determined using several indices including; percent sodium (Wilcox, 1955), sodium adsorption ratio (Richards, 1954), Magnesium adsorption ratio (Raghumath, 1987), Kelley's ratio (Kelley, 1963) and Permeability Index (Doneen, 1964). These indicators were obtained using the following equations:

Soluble sodium percentage (Na%) defined by Doneen (1964) as:

$$\%\,Na=\frac{(Na^{+})\times 100}{Ca^{2+}+Mg^{2+}+Na^{+}+K^{+}} \qquad (3.4)$$

The sodium adsorption ratio (SAR) by Richards (1954) is defined as:

$$SAR=\frac{Na^{+}}{\sqrt{(Ca^{2+}+Mg^{2+})/2}} \qquad (3.5)$$

The magnesium Ratio (MAR) by Raghumath (1987)

$$MAR=\frac{Mg^{2+}\times 100}{Ca^{2+}+Mg^{2+}} \qquad (3.6)$$

The Kelley's ratio (KR) by Kelley (1963)

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}} \qquad (3.7)$$

Permeability index (PI) by Doneen (1964):

$$PI = \frac{(Na^{+}\sqrt{HCO_{3}^{-}})\times 100}{Ca^{2+} + Mg^{2+} + Na^{+}} \qquad (3.8)$$

With all concentrations expressed in meq/L

3.6. Results and discussion

3.6.1. Physicochemical characteristics

The statistical summary of physicochemical parameters of groundwater samples from Lephalale municipality collected during April, July, October 2019, and October 2020 are shown in Table 3.1.

Table 3.1: Physicochemical parameters

Parameters	SI unit	Min	Max	Average	WHO/SANS standard
pH		7.2	7.9	7.6	5-9.7
EC	µs/cm	655.0	1967.7	1309.0	1500
TDS	mg/L	338.8	1035.5	694.0	1000
Temperature	℃	24.7	32.9	27.6	
Alkalinity as $CaCo_3$	mg/L	82.0	307.5	171.7	200
HCO_3^-	mg/L	100.0	375.2	209.5	500
CL^-	mg/L	30.4	259.6	120.0	250
NO_3^-	mg/L	6.3	172.2	78.9	45
SO_4^{2-}	mg/L	28.0	99.1	57.0	250
F^-	mg/L	0.3	7.4	1.8	1.5
Na^+	mg/L	60.8	331.0	136.5	200
Ca^{2+}	mg/L	40.5	213.9	89.4	150
Mg^{2+}	mg/L	25.0	120.3	65.1	70
K^+	mg/L	0.2	11.8	6.4	50
Si	mg/L	13.7	49.1	36.6	
B	ug/L	0.1	370.1	158.1	2400
Al	ug/L	0.0	37.0	6.4	100
V	ug/L	0.0	47.8	16.6	200
Cr	ug/L	0.0	1.3	0.4	50
Mn	ug/L	0.0	552.2	29.4	50
Fe	ug/L	0.5	95.7	7.8	100
Co	ug/L	0.0	1.5	0.1	500
Ni	ug/L	0.0	4.5	0.6	70
Cu	ug/L	0.0	82.1	7.0	2000
Zn	ug/L	0.0	190.4	34.6	5000
As	ug/L	0.0	5.1	0.8	10
Se	ug/L	0.0	3.0	1.2	40
Sr	ug/L	0.2	1122.4	422.7	
Mo	ug/L	0.0	8.2	1.9	
Cd	ug/L	0.0	0.4	0.1	
Ba	ug/L	0.0	325.7	73.9	700
Pb	ug/L	0.0	2.0	0.2	10

The pH of Groundwater samples was found to be ranging from 7.2 to 7.9 with the mean of 7.6. this indicates that the groundwater in Lephalale has near neutral to slight alkaline pH level. The pH values for all the samples lies within the WHO and SANS-241 guidelines for drinking water (SANS-241, 2015; WHO, 2017). The EC and TDS were found to be ranging from 655.0 to 1967.7 µS/cm and 338.8 mg/L to 1035.5 mg/L with the mean values of 1309.0 µS/cm and 694.0 mg/L, respectively (Table 1). TDS less than 1 000 mg/L is classified as freshwater, between 1 000 – 10 000 mg/L is blackish water and greater than 10 000mg/L is saline water (Rao et al 2019). Amongst the samples, 86% are classified as freshwater, 12% had TDS above the 1000 mg/L and are classified as blackish water. Ahmad et al, (2020) classified EC into 3 types: Type 1 as low saline (<1500 µS/cm), type 2 as medium saline (between 1500 and 3000 µS/cm) and type 3 high saline (>3000 µS/cm). Groundwater in Lephalale Municipality shows that 72% falls under type 1 which was reported by Rao et al., (2019) to be due to soil-rock-water interaction. 28% had EC beyond the WHO, (2017) recommended limit of 1500 µS/cm and is classified under medium salt enrichment. High salinity hazard which can be measured by TDS or EC leads to the incapability of plant roots to absorb water with high salt concentrations (Amiri et al, 2021). Alkalinity as $CaCO_3$ ranged between 82–307.5 mg/L and a mean of 171.7 mg/L with the highest value detected in Munyeki village.

The average concentration of cations decreased in the following order $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ (Figure 3.2). Na^+ is the most abundant cation in the Lephalale municipality and the concentration ranges from 60.8 to 331.05 mg/L with an average of 136.5 mg/L. It is important to note that two (SANS241) out of twenty-four (25) boreholes were observed to have Na^+ concentration above the WHO, (2017) and SANS 241, (2015) guidelines of 200 mg/L. Na^+ can be attributed to a contribution from geogenic activities such as the weathering of ferromagnesian minerals like feldspars which is mainly found on the sandstones in Lephalale (Johnson et al., 2006). There is no indication of adverse health effects associated with high Na^+ levels in drinking water, although such water may not be suitable for bottle-fed infants because of its faintly salty taste (WHO, 2017). High Na^+ concentration is known to cause soil structure deterioration, thus reducing soil drainage and permeability (Amiri et al., 2021).

The concentration of Ca^{2+} ranged from 40.5 mg/L to 213.9 mg/L with the mean of 83.4 mg/L whereas Mg^{2+} ranged from 25.0 mg/L – 120.3 mg/L with the mean of 65.1mg/L. According to Olubukola et al. (2018), Mg^{2+} occurs in natural water, but its concentration is always lower than that of Ca^{2+}, which seems to be the case in the study area. The high concentration of Ca^{2+} and Mg^{2+} in Lephalale may be due to dolomitic geology which is mainly composed of calcium magnesium carbonate ($CaMg(CO_3)_2$) and also from minerals such as feldspar (Johnson et al., 2006, Srinivas et al., 2017). Mg^{2+} has no health implications but causes the water to taste bitter and may have a laxative effect on people not familiar with the water (WHO, 2007). High concentrations of Ca^{2+} impair the lathering of soap (DWAF, 1996; WHO, 2017).

The values recorded for K^+ ranged from 0.2 to 11.8 mg/L with a mean of 6.4 mg/L. The highest K^+ concentration was observed at Tshelammake 2. All the groundwater samples were within the K^+ recommended standard of 200 mg/L in drinking water (WHO, 2017). The dissolution processes of salts stored in the soil profile are probably the reason behind the lower concentration of K^+ than other cations in groundwater, which may be due to the relatively lower abundance of this k^+ element in the bearing rocks of the groundwater (Abboud et al., 2018).

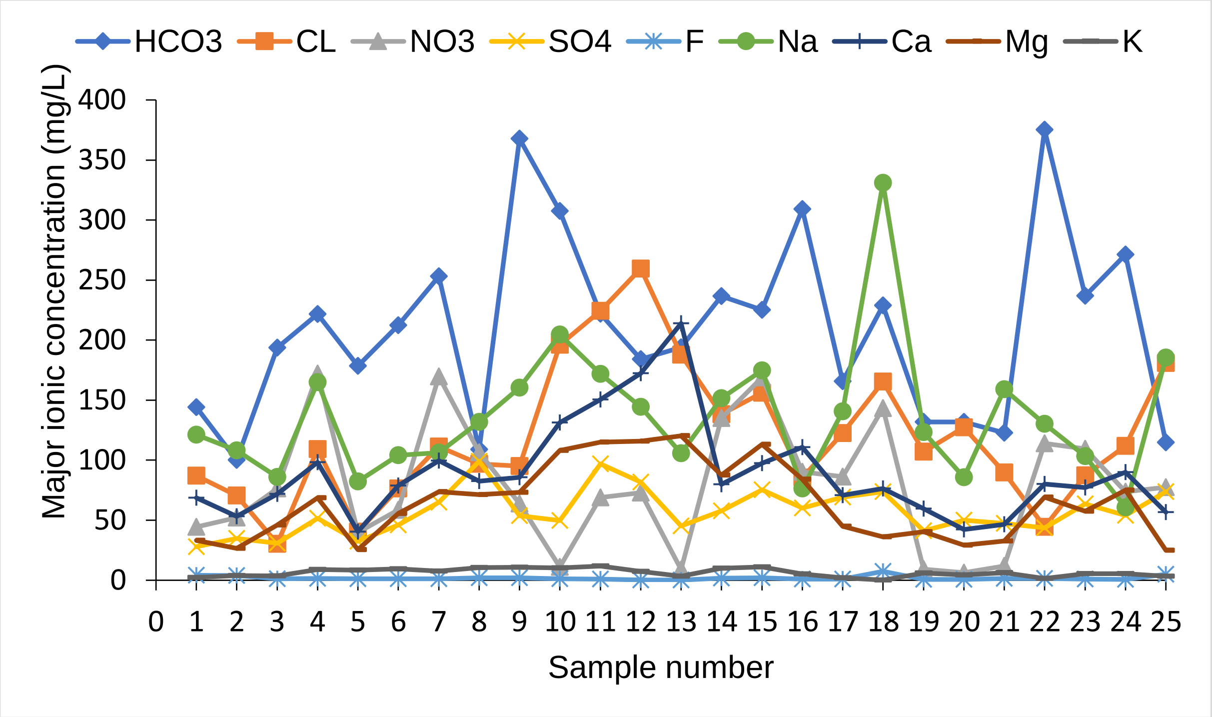


Figure 3.13: Major ionic concentration of groundwater in mg/L

The average concentration of anions of Lephalale groundwater decreased as follows, $HCO_3^- > Cl^- > NO_3^- > SO_4^{2-} > F^-$ (Figure 3.2). HCO_3^- is the most abundant anion in Lephalale and it ranged from 100 mg/L to 375.2 mg/L with an average of 220.0 mg/L. All the boreholes were observed to have HCO_3^- less than the drinking water standard of 500 mg/L (WHO, 2017). HCO_3^- in groundwater is reported to be caused by the presence of carbonaceous sandstones in the aquifer and carbonate minerals weathering (Yetis et al., 2020). The HCO_3^- levels in water are directly related to the alkalinity of the water and the high levels of HCO_3^- indicate that the groundwater is alkaline (Eljamassi and Elamassi, 2015). Abboud et al., (2018) reported that $HCO3^-$ concentration of more than 300 mg/l in the drinking water can leads to the formation of kidney stones.

Cl^- concentrations in the water samples ranged from 30.4 to 259.6 mg/L with a mean of 120.0 mg/L. Few villages were noticed to have Cl^- which is higher than the recommended drinking water limit of 250 mg/L (WHO, 2017). The presence of Cl^- in groundwater results from the weathering of sedimentary rock materials, industrial effluents, chemical fertilizers and domestic effluents (Srinivas et al., 2017, Adimalla and Taloor, 2020). High concentration of Cl^- is not toxic to humans, however it causes salty tastes in water (Yetiş et al., 2019).

NO_3^- ranged between 6.3 – 172.2. mg/L with an average of 78.9 mg/L. Where 18 (72%) boreholes were detected to be above the drinking water standard of 45 mg/L with the highest observed at Seleka ward 2b. Agricultural activities are one of the main dependents on the groundwater resources in Lephalale municipality which might be the cause of high NO_3^- concentration in some boreholes as a result of seepage of irrigation waters from agricultural fields where chemical fertilizers are being used (Zakaria et al., 2020). High NO_3^- concentrations can cause methaemoglobinaemia (blue-baby syndrome) in bottle-fed infants and could result in the occurrence of mucous membrane irritation in adults (Mpenyana-Monyatsi and Momba, 2012).

SO_4^{2-} ranged between 22.2- 66.2 mg/L with an average of 45.9 mg/L, all boreholes were observed to be within the permissible limit of 250 mg/L and 200 mg/L by WHO, (2017) and SANS 241 (2014) respectively. Dissolution of pyrite, in coal beds, might be the source of SO_4^{2-} in Lephalale area (Ovens and Thornton, 2017)

The concentration of F^- ranged from 0.3 mg/L to 7.40 mg/L with a mean of 1.8 mg/L, where Nitne (9) villages including Lerupurupung, Kauletsa 1 & 2, Steve Biko phase 1 & 2, Matladi, Shongwane, and two boreholes in Mmaletwai were observed to be above the WHO, (2017) and SANS 241, (2015) limit of 1.5 mg/L. The highest level of F^- was observed at Matladi. The concentration of F^- in Lephalale might be due to the dominated appetite and sandstone which gives rise to fluorspar mineralisation that leaches into the aquifer and introduces F^- in the groundwater (Johnson et al., 2006). High F^- concentration in Limpopo was reported by Ncube and Schutte (2005) and was also reported in Lephalale by the DWA (2010). F^- concentration of more than 1.5 mg/L in drinking water can cause skeletal and dental fluorosis.

The concentration of trace elements such as Al, V, Cr, Fe, Co, Ni, Cu, Zn, As, Se, Be, Ba, Pb and Mn were analysed. All the boreholes were found to be within the recommended limit for those trace elements except for Mn. Mn concentration ranged between 0.0 - 552.2 µg/L with an average of 29.4 µg/L. Only two (2) borerholes were found to be higher than the WHO recommended limit of 50 µg/L. The Transvaal supergroup which forms part of the water berg belt might be the reason for the richness of Mn in the Waterberg district. The high concentration of Mn has no health effects on humans; however, it gives the drinking water an undesirable taste (Nyirenda et al., 2016).

3.6.2. Microbial analysis

The Analyses of the coliform counts obtained from Lephalale municipality groundwater are shown in table 3.2. The results show that FC and TC ranged between 0-71 with an average of 0.56 CFU/100mL and between 0-360.5 with the average of 30.81 CFU/100mL, respectively. The highest FC (71 CFU/100mL) and TC (360.5 CFU/100mL) were recorded at Tshehlong village. Nine 9 samples (41%) had detectable *E coli* colony forming units which was above the 0 CFU/100 mL recommendations by SANS and that points to the presence of disease-causing organisms in the groundwater. A study by Wanda et al (2015) in groundwater of Northwest province, South Africa, detected *E coli* and attributed it to the presence of pathogens that rendered it harmful for consumption. Faecal coliform could be an indication of sewage and leachate contamination in groundwater in this case from poor pit latrines, and animal dumping (Mpenyana-Monyatsi and Momba, 2012, Odiyo and Mkungo, 2018).

Total coliforms were detected in most of the boreholes, but their levels were found to be beyond SANS241 limit of <10 CFU/100 mL in 9 (41%) boreholes. This observation could be due to leachate of bacterial pollutants in groundwater and could indicate the presence of *Escherichia, Citrobacter, Klebsiella and Enterobacter*. High Total coliforms in water could cause diseases such as gastroenteritis, dysentery, cholera, typhoid fever, and salmonellosis to consumers (Nyika et al., 2019)

Table 3.2: Microbial count of samples boreholes in Lephalale Municipality.

Village name	TC (CFU/100 mL)	FC (CFU/100 mL)
Shongwane	1	0
Seleka Ward 2a	0	2.5
Seleka Ward 2b	12	0.5
Seleka Ward 1a	0	0
Seleka ward 1b	0	0
Kauletsi 2	1	1
Kauletsi 1	10.5	0.5
Tshelammake 1	0	0
Tshelammake 2	31.5	20
Letlora 1	6.5	0.5
Letlora 2	0	0
Mmaletwai 1	1	0
Mmaletwai 2	58.5	40
Ditloung 1	0	0
Tshetlong	360.5	71
Matladi	8	0
Witpoort	0	0
Lerupurupung	186.5	0
Munyeki	0	7
Thabo Mbeki	0.5	0
Mokoruanyane	0.5	0
Seleka Ward 1c	0	0
Min	0	0
Max	360.5	71
Average	30.81	0.56
Standard (SANS 241, 2015)	10	0

3.6.3. Hydrogeochemical processes controlling the water quality

Groundwater hydro-geochemistry is affected by many factors such as the rock type, residing time in the host rock, original composition of groundwater, and other characteristics of the water flow path (Tóth, 1999, Abdalla and Al-Abri, 2014). Gibb's plot and Piper diagram was plotted using the Rockwork, 2004 (V. 4.8.19) to understand the mechanism and classification of groundwater.

3.6.3.1. Hydrogeochemical faeces

Hydrogeochemical facies is applied to analyse the chemical composition of groundwater and illustrate the origin and chemical water types (Ahmand et al., 2020). The Piper trilinear diagram (Piper 1944) (Figure: 3.3) was used for the interpretation of the inorganic constituents in the study area. On the cation ternary diagram, most of the sample's plot on the no- dominant field indicating that the groundwaters are mostly of mixed type. Few of the samples however, plot on the $Na^+ + K^+$ water type field. On the anion diagram, the samples scatter on the no-dominant type, Cl^- type, and bicarbonate fields. The central diamond-shaped diagram shows that 60% of the groundwater samples plot in the field of CaMgCl water type, 16% of CaCl water type, 12% for NaCl, and $CaHCO_3^-$ water type respectively. Most the samples plot in sub-division where the alkaline earth elements (Ca+Mg) exceed the alkali metals (Na+K). In addition, most of the samples also plot in subdivision where strong acidic anions (SO_4^{2-} $+Cl^-$) exceed weak acidic anions (HCO_3^-). The groundwater samples are dominated by CaMgCl water type followed by CaCl water type which indicate that the original chemical quality of groundwater is mainly controlled by mixed water type due to gradual influences of anthropogenic activities on the aquifer system, and by carbonate hardness (fresh water) type which is influenced by soil–rock–water interactions through dissolution of minerals in the underlying rocks (Molekoa et al., 2019; Rao et al., 2019; Sunkuari et al., 2019).

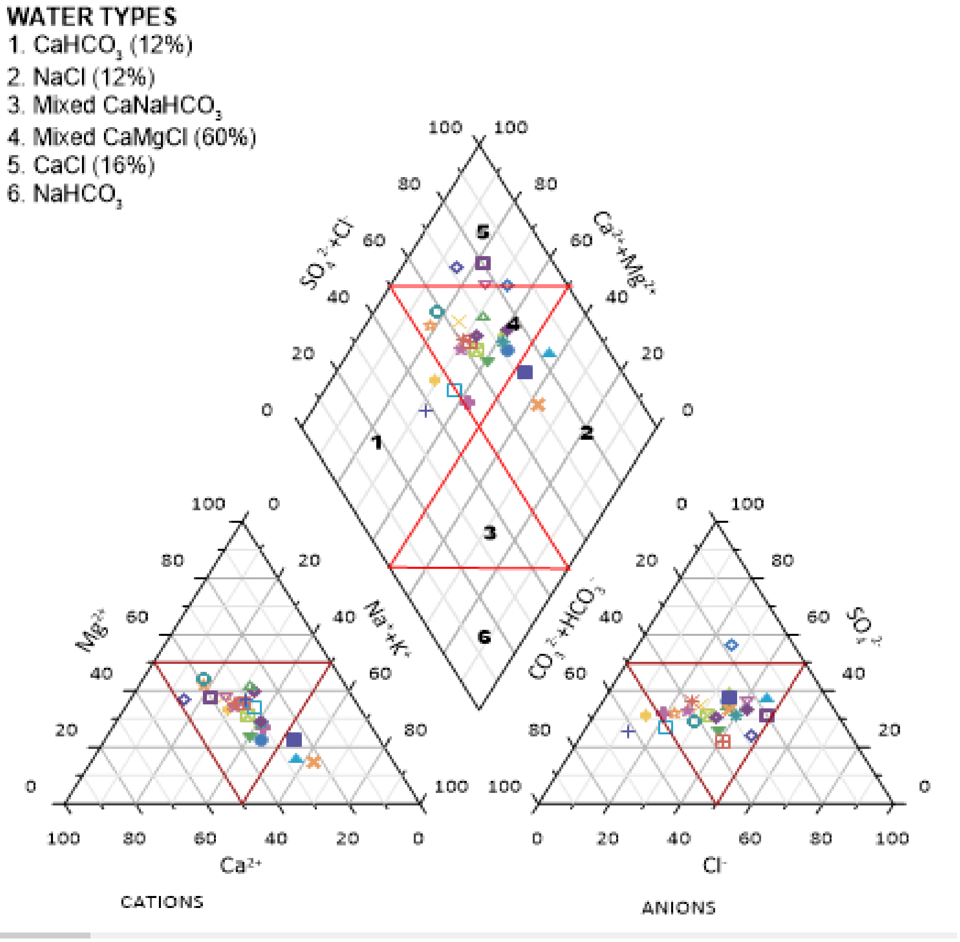


Figure 3.14: Piper diagram of Lephalale groundwater.

3.6.3.2. Mechanism controlling groundwater chemistry

To distinguish the influences of rainfall (precipitation), lithology (rock–water interactions) and climate (evaporation) processes as mechanisms controlling the chemistry of groundwater, the cation ratio (Na^+/Na^++Ca^{2+}) were plotted against TDS in Gibbs diagrams (Gibbs 1970). The Gibb's plot (Figure.3.4) indicates that all the groundwater samples fall under the rock-water interaction zone. This implies that the chemistry of groundwater in Lephalale is due to the dissolution of the rock that makes up the aquifer in which the groundwater is stored (Mudzielwana et al., 2020).

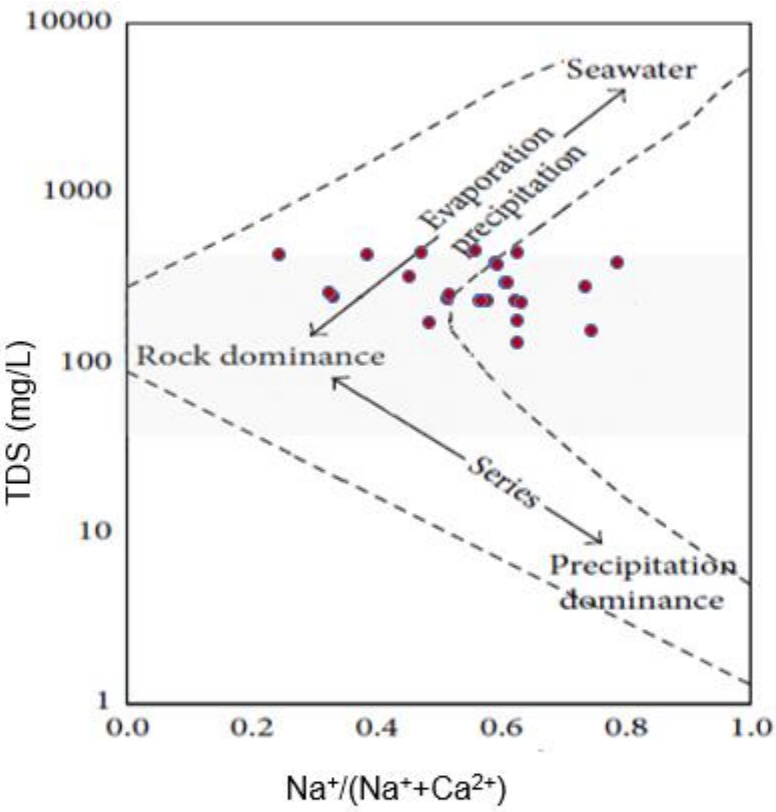


Figure 3.15:Gibb’s Plot of Lephalale groundwater.

3.7.4. Rock source deduction

Figures 3.5 and 3.6 present the silicate and plagioclase weathering chats respectively which are plotted to understand the source of the ions in groundwater the rocks from which they dissolved from. There are three factors considered to determine the rock source that contributes to the ionic components of the groundwater (Adewumi et al., 2018).

Firstly, if the value of TDS is greater than 500 mg/L indicates that carbonate rock is a possible source rock but if it is less than 500 mg/L it indicates that silicate bearing rock is a possible source rock. In the study area, 4 samples (16%) have TDS<500 mg/L and 21 samples (84%) have TDS>500 mg/L which is indicative of carbonate weathering (Figure. 3.5). Carbonate weathering was the dominant hydrogeochemical process that modified the chemistry of groundwater in the study area (Xu et al., 2019).

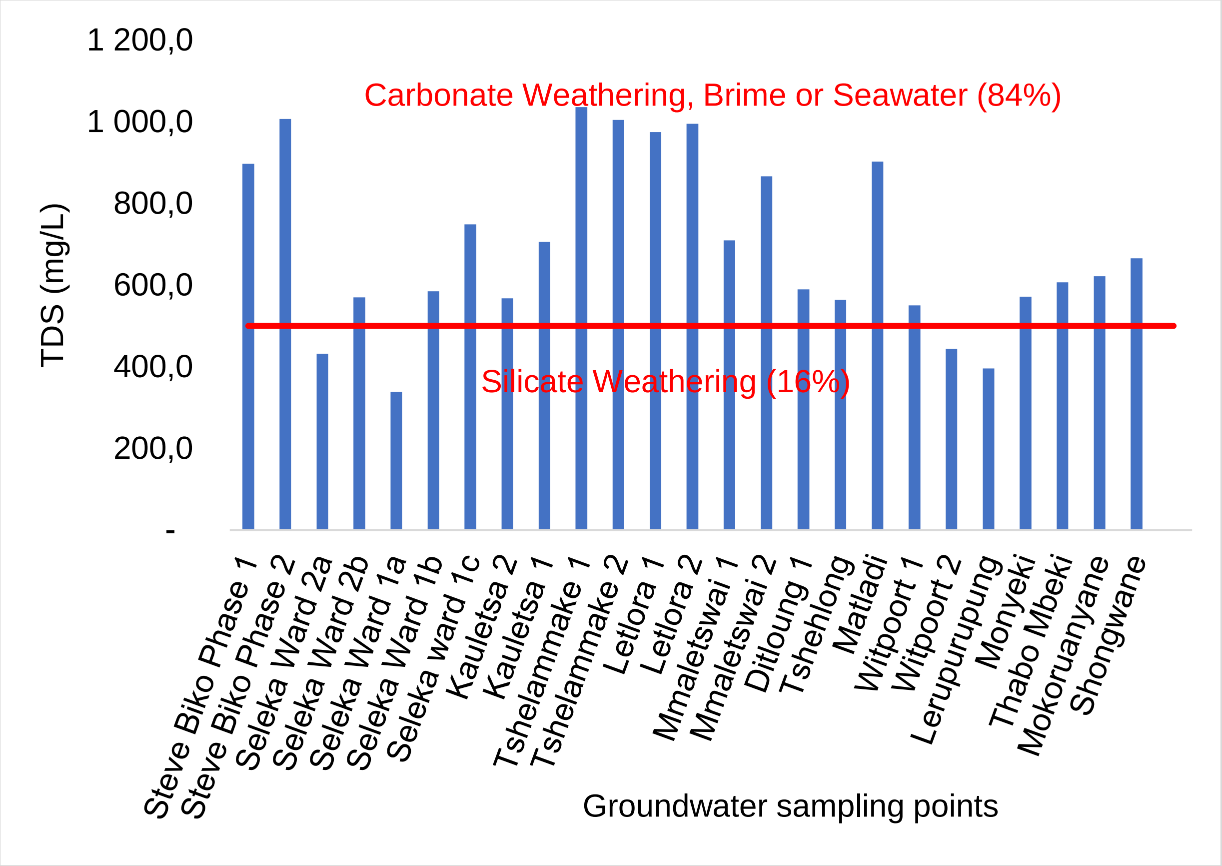


Figure 3.16**:** Silicate weathering chart.

Ionic ratios below (equations 3.6 and 3.7) are used to interpret a plagioclase weathering and sodium/halite solution source rock respectively.

$$\frac{Na^{+}+K^{+}-Cl^{-}}{Na^{+}+K^{+}-Cl^{-}+Ca^{2+}}\ (Mg/L) \tag{3.9}$$

$$\frac{Na^{+}}{Na^{+}+Cl^{-}}\ (Mg/L) \tag{3.10}$$

Secondly, if the value of equation 3.9 is between > 0.2 and < 0.8, the possibility of plagioclase weathering is inferred, but if equation 3.9 is less <0.2 or >0.8 then plagioclase weathering is unlikely.

Thirdly, if equation 3.10 ratio is >0.5 a sodium source other than halite, albite, and ionic exchange can be deduced. If it is <0.5 with a TDS value >500 mg/L, then a reverse softening can be inferred. If equation 3.10 = 0.5 halite solution is likely to occur. If equation 3.10 is <0.5 with a TDS value less than 50, then rainwater can be inferred. And when equation 3.10 is <0.5 with a TDS value <500 mg/L an analysis error might have occurred (Adewumi et al., 2018).

In this study, based on equation 3.10, 16 samples (64%) of the groundwater samples have undergone plagioclase weathering while plagioclase weathering was unlikely in 9 samples (36%) of the samples (figure 3.6). Eleven (44%) samples fell into the category in which equation 3.10 is > 0.5 indicating that the groundwater samples had ion source input into the groundwater of the area from sodium source with the possible ionic exchange process. Halite solution was inferred in nine samples (36%). In addition, nine (36%) samples were involved in reverse softening as equation 3.10 was <0.5 with TDS value >500 mg/L.

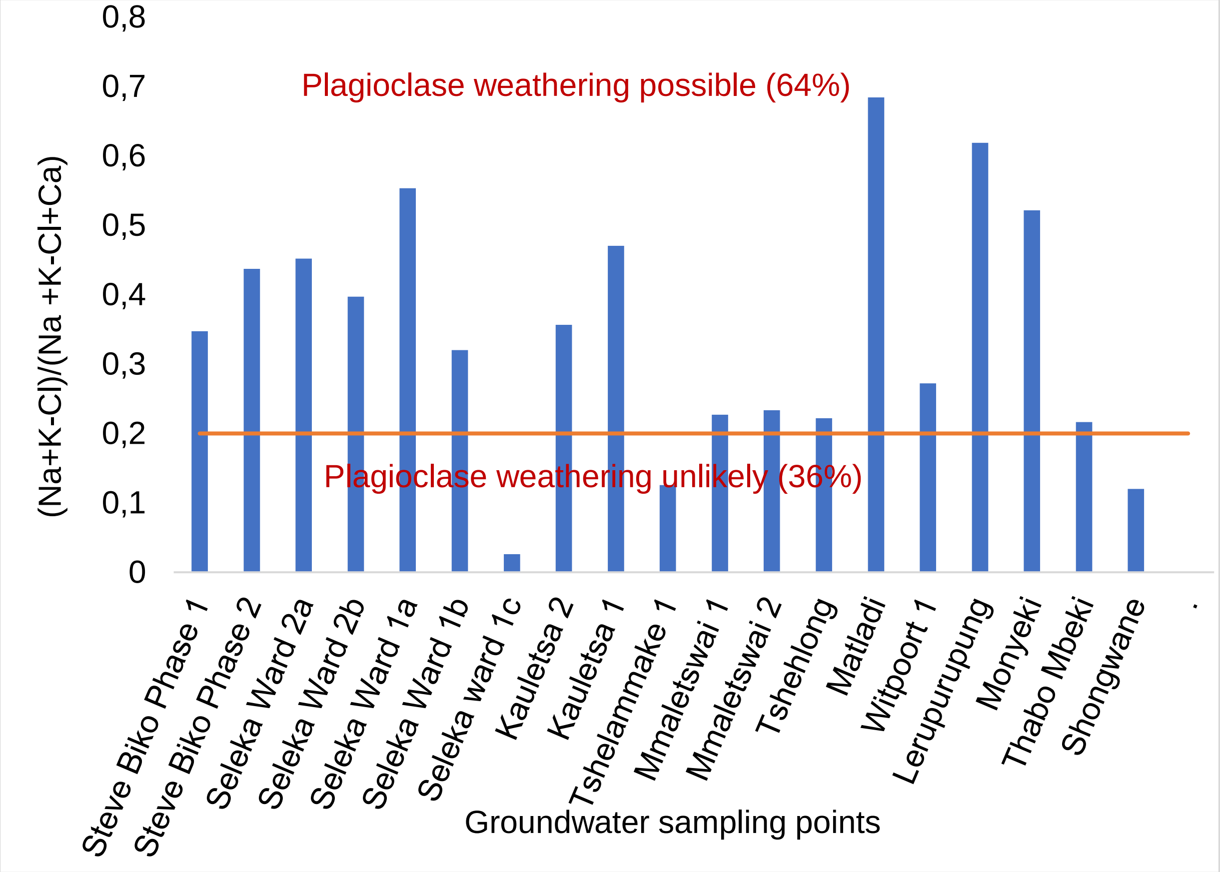
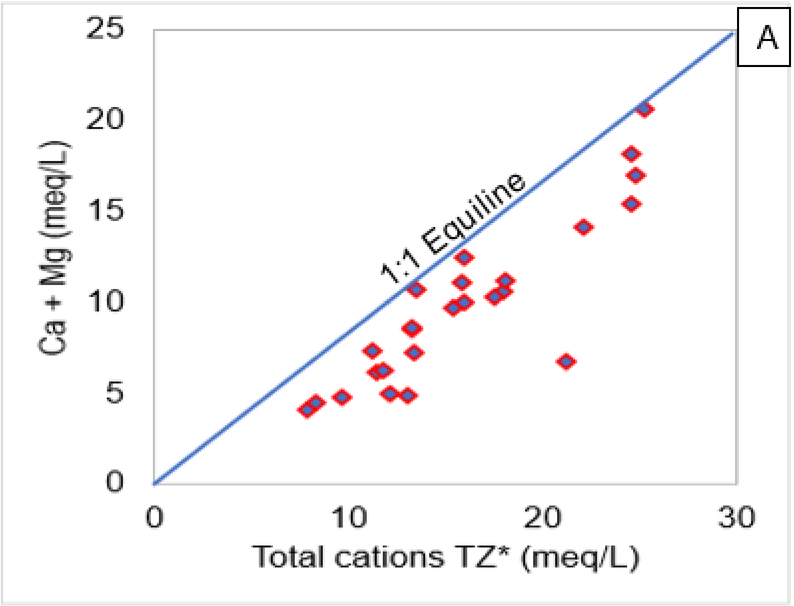


Figure 3.17**:** Plagioclase weathering chart.

3.7.5. Weathering and Dissolution

Scatter diagrams of (Ca+Mg) versus total cations (TZ+) and (Na+K) versus total cations (TZ+) (Figure 3.7) are designed in this study to best comprehend the contribution of silicate weathering to cation concentration of the groundwater (Kumar et al., 2007). The TZ^+ versus (Ca^{2+} + Mg^{2+}) scatter plot (Fig 3.7a) shows that all the groundwater samples are below the 1:1 equiline indicating that Ca and Ma have originated from Ca2+ and Mg2+ rich rocks as a result of silicate weathering (Wisitthammasri et al., 2020).

The plot of (TZ$^+$) versus (Na$^+$ + K$^+$) (Fig. 3.7b), has 22 samples (88%) plotted below the 1:1 equiline, while 3 samples (12%) were above the line. Majority of the sample's points plot near the 1:1 equiline suggesting that weathering of intensive silicate (alkali feldspar) minerals is the source of major cations in the geochemical evolution of groundwater in the study area (Stallard and Edmond, 1983).



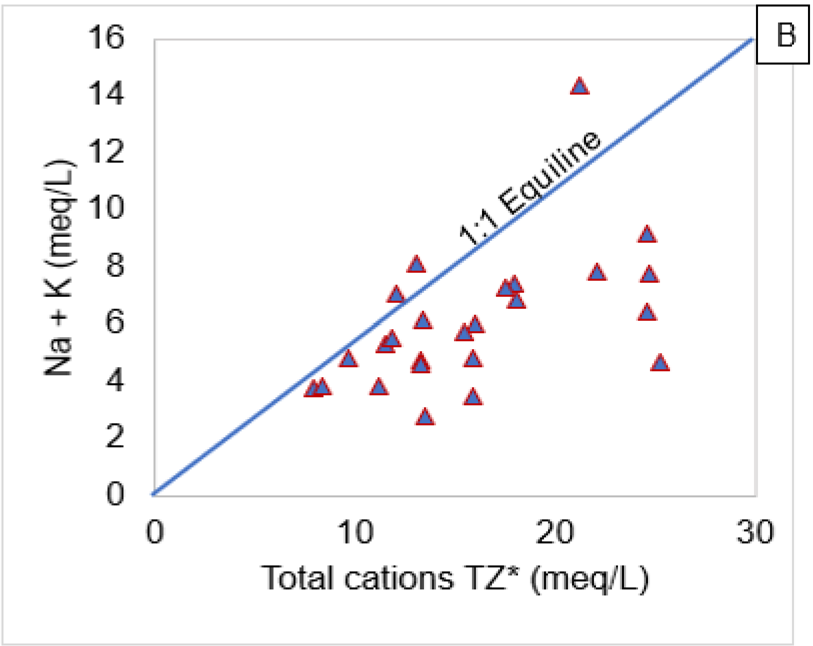


Figure 3.18: Scatter diagrams of (a) (Ca+Mg) versus total cations (TZ^+) and (b) (Na+K) versus total cations (TZ^+).

3.8. Evaluation of water quality for irrigation

The quality of water used for irrigation has effects on both soil and plants, irrigation water with excess salt can alter the physical and chemical structure of soil and affect plants growth (Sunkuari et al., 2020). Several indices are used to assess the suitability of water for irrigation, this includes total salt concentration measured by EC (salinity hazard) and the relative proportion of sodium which indicates the sodium hazard (Sodium percent, Sodium absorption ratio, Kelly's ratio, Permeability index, and Magnesium ratio).

3.8.1. Salinity Hazard

Classification of the groundwater for salinity hazards according to the US salinity diagram is shown in figure 3.8. majority (80%) of the groundwater samples in the study area fall in the high salinity hazard (class C3S1), meaning they are unsuitable for irrigation purposes. Following by 16% and 4% which falls under C2S1 and C2S1, respectively. Normally, irrigation water with an EC of < 700 µS/cm causes little or no threat to most crops while EC > 3000 µS/cm may limit their growth (Tijani, 1994). Thus, groundwater in the high salinity hazard category cannot be used as irrigation water because such water may have detrimental effects on salt-sensitive crops, and in certain cases; it may adversely affect many plants (Islam et al., 2017). Irrigation in such an area requires careful management practices. The high salinity hazard in the groundwater samples could probably have resulted from soluble mineral materials along the flow path of groundwater and dissolution of the chemical fertilizers by irrigation water and municipal waste disposal (Asante-Annor, 2018).

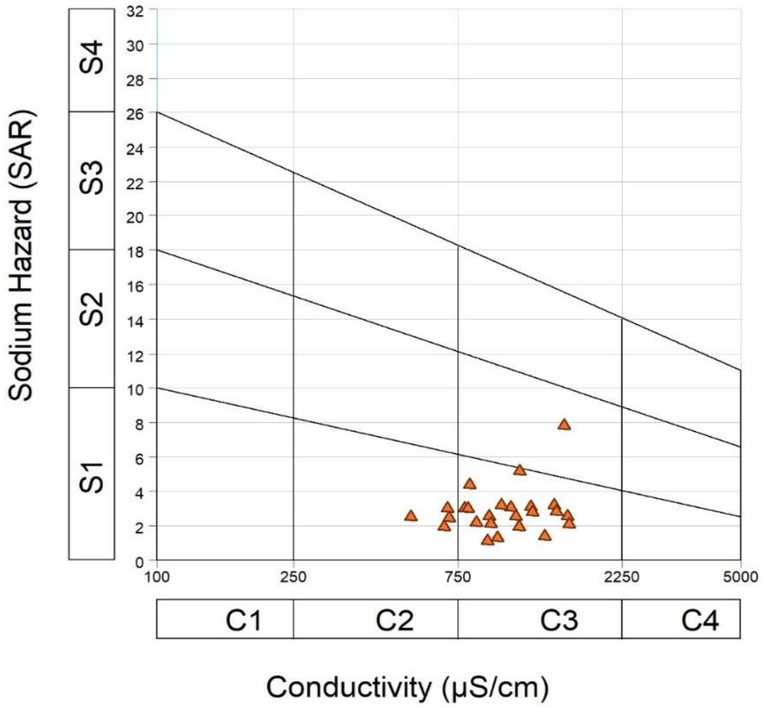


Figure 3.19: Salinity diagram for the classification of irrigation waters (Richards, 1954)

However, Alam (2018) reported, Sodium Hazard can be judged by the amount of EC in water. The main lethal effect of a high EC in water is the failure of plants to compete with ions in the soil results in a physiological condition like drought (Khanoranga and Khalid, 2019). Table 3.3. below shows the classification of water-based on EC (Chandrasekar et al., 2014). According to this classification 21 (84%), groundwater samples are permissible for irrigation, and 4 (16%) are good for irrigation when it comes to salinity hazard.

Table 3.3: Classification of water based on EC.

Salinity Hazard	EC (mS/m)	Sample No:	Percentage (%)
Excellent	<250	-	-
Good	250 – 750	4	16
Permissible	750 – 2000	21	84
Doubtful	2000 – 3000	-	-
Unsuitable	>3000	-	-

3.8.2. Sodium Hazard

The sodium hazard results from the accumulation of sodium in an excessive amount which causes the physical structure of the soil to breakdown. When calcium and magnesium are replaced by sodium adsorbed on clays it destroys the soil structure and causes soil particles to disperse (Shammi et al., 2016). Therefore, the soil becomes hard and compact when dry and impermeable resulting in plant roots not being able to absorb enough water (Hiscock, 2005). For this reason, Na^+ is an important parameter when determining the suitability of the water for irrigation. The summary of the estimated irrigation parameters of groundwater from the study area is presented in Table 3.4.

Table 3.4: Estimated Irrigation parameters in the study area

Parameters	Min	Max	Mean	Stdev
% Na	23.83	76.07	46.68	12.73
SAR	7.54	46.87	16.25	8.05
MAR	32.48	60.52	42.66	6.58
KR	0.32	3.18	1.06	0.63
PI	26.88	79.34	53.09	13.49

3.8.2.1. The sodium adsorption ratio

Assessment of groundwater potential to induce sodic soil conditions was analysed by computing the SAR values (Table 3.5). The minimum and maximum values of SAR for groundwater samples in the area were 7.54 – 46.87 respectively with an average value of 16.25 and standard dev. value is 8.05 (Table 3.4). Based on SAR (Bouwer, 1978), the groundwater in the study area was not suitable for irrigation as 21 (84%) of the samples have excess Na^+. The more Na^+ than Ca^{2+} and Mg^{2+}, resulting in a high capacity of the water to cause soil sodicity and therefore unsuitable for irrigation. Only 4 samples (16%) of the groundwater had SAR<10 and are excellent for irrigation purposes, which indicates that the capacity of the water to induce sodic conditions in the soil is low and are suitable for irrigation (Mandel, 1991, Zango et al., 2019).

Table 3.5: Groundwater classification based on Sodium Adsorption Ratio.

Groundwater class	Range	Sample no	In %
No problem	< 6	-	-
Increasing problem	6 to 9	4	16
Severe problem	>9	21	84

3.8.2.2. Sodium Percentage

Sodium percentage is widely used for assessing the suitability of water for irrigation purposes (Xu et al., 2019). Based on table 3.4, Sodium percentage ranged between 23.83 and 76.07 with a mean of 46.68 and a standard deviation of 12.73. When classifying groundwater based on the %Na (Laboratory, 1954), 24% of the samples are classified as good and 64% can be classified as permissible while 12% of the groundwater samples fall into the doubtful class (Table 3.6).

Table 3.6: Groundwater classification based on Sodium percentage (%Na),

Groundwater classes	%Na range	No of samples	Percentage
Excellent	<20	-	-
Good	20 - 40	6	24
Permissible	40 - 60	16	64
Doubtful	60 - 80	3	12
Unsuitable	>80	-	-

Wilcox’s diagram (Wilcox, 1955) is especially implemented to classify groundwater quality for irrigation, wherein the %Na is plotted against EC of water. Figure 3.9. shows that only 4 groundwater samples (16%) were in the excellent water category, 2 groundwater samples (8%) fell in the permissible class while the remaining 19 groundwater samples (72%) are within the good water category. The results demonstrate poor groundwater quality regarding irrigation and that only salt tolerant plants may grow well in this area (Sunkuari et al., 2019).

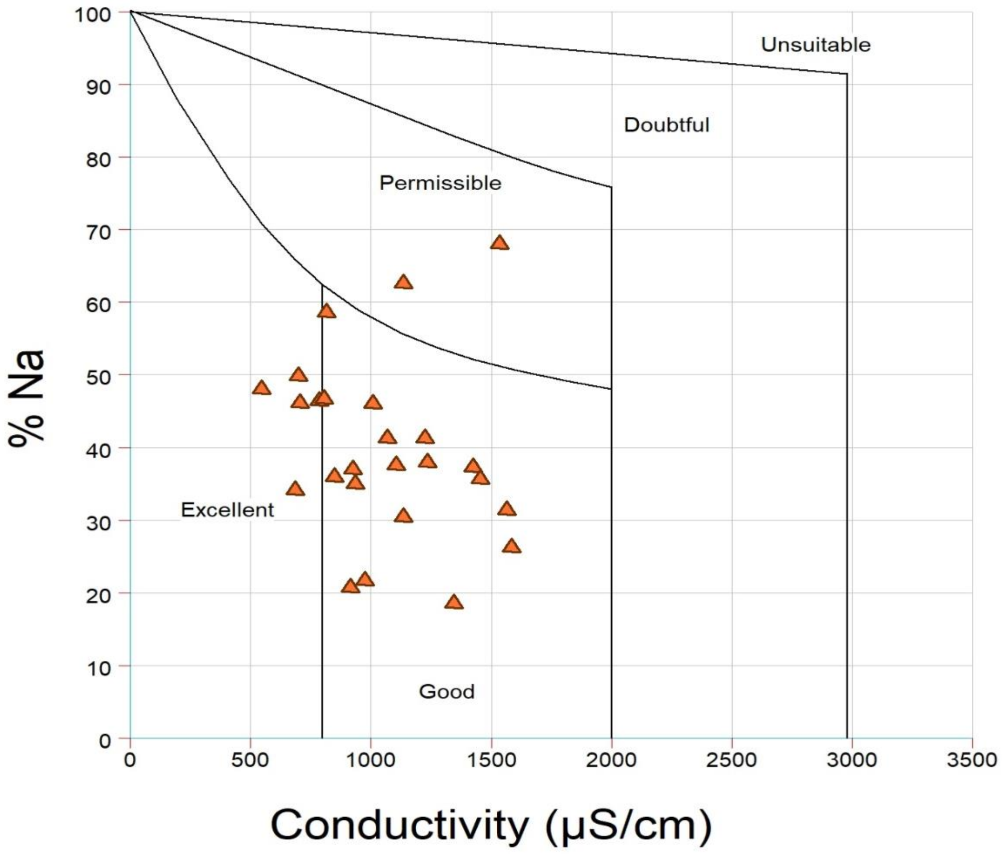


Figure 3.20: Plot of Na% and electrical conductivity for the classification of groundwater for irrigation uses.

3.8.2.3. Kelly's Ratio

The suitability of groundwater irrigation can also be assessed based on Kelly's Ratio (Xu et al., 2019). Kelly's ratio assesses irrigation water quality based on the level of Na+ against Ca^{2+} and Mg^{2+} (Table 3.7). The KR ranged from 0.32 to 3.18 with a mean of 1.06 (Table 3.4). The KR value of the investigated groundwater has about 56% of it samples suitable for the irrigation while 44% were found to be unsuitable for irrigation purpose.

Table 3.7: Kelley's Ratio

Groundwater classification	KR range	No of samples	Percentage (%)
Suitable	<1	14	56
Unsuitable	>2	11	44

3.8.2.4. Permeability Index

The quality of irrigation water can affect the permeability of the soil after long term use; this can be measured by computing the Permeability index (PI). PI is influenced by total soluble salt, sodium, calcium, magnesium, and bicarbonate contents of the water. PI of 75% or above max permeability indicates that the groundwater is suitable for irrigation (class I and class II), while a PI of 25% or below max permeability is regarded as unsuitable for irrigation (class III) (Doneen, 1964).

PI values computed for the groundwater samples for the study area ranged from 26.88% to 79.34% with a mean value of 53.09% (Stdev. 13.49) Table 3.4. According to the classification by Doneen (Table 3.8), the 17 (68%) samples were classified as class I and class II indicating that they are suitable for irrigation and 8 (32%) samples fall under class III, indicating that they are unsuitable for irrigation. High PI values are related to high levels of Na^+ and HCO_3^- which may be due to the cation exchange and carbonate dissolution (Xu et al., 2019).

Table 3.8: Permeability index

PI class	Classification	No. of samples	Percentage (%)
Class I and II	Suitable for irrigation	17	68
Class III	Unsuitable for irrigation	8	32

3.8.2.5. Magnesium Adsorption Ratio

MAR indicates the degree of damage to the soil structure caused by Mg^{2+} in irrigation water (Xu et al., 2019). The use of water with high Mg^{2+} content for irrigation may pose a threat to crop yield as it may cause an alkaline condition in the soil which decreases the crop yield (Kumar et al., 2007). The computed MAR values for the study area ranges between 32.48% to 60.52% with an average of 42.66% (Table 3.4). The results in table 3.9 show that 22 (88%) of the samples from the study area are suitable for irrigation and 3 (12%) samples are unsuitable for irrigation concerning MAR. This indicates that only 12% of the groundwater samples have the potential to cause alkaline soil which is known to have low infiltration capacity (Islam et al., 2017).

Table 3.9: Magnesium hazard

Groundwater classification	KR range	No of samples	Percentage (%)
Suitable	<50	22	88
Unsuitable	>50	3	12

3.9. Summary

This chapter aimed to evaluate the quality of groundwater in Lephalale Local Municipality and to determine the suitability of the water for drinking and irrigation purposes. To achieve this, the DWAF (1996), WHO (2011), and SANS 241 (2014) water guidelines were used as the basis of evaluating the groundwater for drinking purposes. For irrigation, EC (salinity hazard), Sodium percent (Na%), Sodium adsorption ratio, Kelly's ratio (KR), Permeability Index (PI), and Magnesium ratio (MR) were used.

The results revealed that most of the samples are within the permissible range for the WHO (2017) and SANS 241, (2014) water guidelines. However, F^- exceeded 1.5 mg/L approved WHO (2011) and SANS241 (2014) standard for drinking water in 32% of the groundwater samples requiring monitoring to prevent break out of dental caries and fluorosis disease in the sampling localities. The groundwater was found to be generally low in salt enrichment, and fresh with an average of EC<1500 µS/cm and TDS<1000 mg/L in nature. The dominance of major ions in the area is $Na^+>Ca^{2+}>Mg^{2+}>K^+$ cations and $HCO_3^->Cl^->NO_3^->SO_4^{2-}>F^-$ anions. The study proved the presence of FC and TC in the groundwater supplied in Lephalale local municipality and recommend the use of point of use water disinfection system.

Classical hydrogeochemical methods showed the existence of five hydrogeochemical facies/water types in the area, 60% CaMgCl water type, 12% $CaHCO_3$ water, 12%

NaCl water, and 16% CaCl water type. Gibb’s plot indicated rock-water interaction as the main process controlling groundwater chemistry in the area.

According to the irrigation indexes Na%, SAR, PI, KR, and MAR, approximately 88%, 84%, 68%, 56%, and 88% of groundwater sources were suitable for irrigation in the Lephalale, respectively. Similarly, 12%, 16%, 32%, 44%, and 12% of Lephalale municipality groundwater samples are unsuitable for irrigation, respectively. Moreover, salinity hazard showed that 80% of the groundwater samples fell under the C3S1 class and were classified as not suitable for irrigation.

The results of a comprehensive consideration of these indicators show that the average level of Lephalale municipality groundwater samples (76.8%) are suitable for irrigation purposes. Land irrigated with such water will not be exposed to alkali hazard but will suffer from Salinity Hazard, which is more dominant in the Lephalale. The groundwater of the study area is moderately suitable for irrigation. Therefore, when using local groundwater to irrigate farmland, proper adaptation strategies must be taken to control the salt content in the water and to prevent the accumulation of soil salt.

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Chapter 4: Assessing the challenges and community's perceptions on water quality and supply: A case study of Mmatladi Village, Lephalale Local Municipality, South Africa.

4.0. Abstract

The previous chapter revealed that groundwater in Lephalale contains high levels of physicochemical parameters such as EC, Cl^-, NO_3^-, F^-, Na^+, $Ca^{2+,}$ and Mg^{2+}; and microbial contaminates. Therefore, the following chapter will be developing an intervention to address the water quality challenges identified in chapter 3. The aim is to evaluate the perspectives of community members of Mmatladi Village within Lephalale local Municipality with regard to water quality and supply. A total of 103 questioners were administered from randomly selected households within the village. The obtained data were captured and analysed using Microsoft excel and Statistical Package for the Social Sciences (SPSS). The results illustrated that groundwater is the main source of water in Mmatladi community. About 19% of respondents indicated that they sometimes spend over a month without water in their taps. To cope with that challenge, most of the villagers buy water (51%) from retail stores, and neighbours with private boreholes. Most respondents in this area do not have any background knowledge when it comes to water quality (78%), groundwater contamination (84%), fluoride in groundwater (87%), and effects of groundwater contamination (74%). The participants' perspectives with regard to water quality were that it is poor (59%) due to its saltiness. About 28%, 6% and 2% of the households have reported cases of fluorosis, diarrhoea, and cholera, respectively. Even though people still use unimproved water sources, they still do not treat water (79%) before consumption, only 21% does. Of those who do treat their water before use (n=21), majority of them said they use boiling method because it is simple and affordable. About 78% of the household representatives are willing to have an intervention on water treatment module. Due to a lack of knowledge amongst the participants concerning water quality, there is a need for public awareness. Moreover, a need for a water treatment system to minimise waterborne diseases and promote the use of clean potable water.

Keywords: Lephalale municipality, Perspectives, Mmtladi village, water quality, and supply.

4.1. Introduction

Access to adequate supplies of water is a fundamental human need and a basic human right (Abdulsalam and Olawale, 2020). However, majority of people living in developing countries lack access to safe and improved water supplies (Tshikolomo, 2012, Domínguez et al., 2019). In 2017, the World health organisation estimated that 2.1 billion people do not have access to safely managed drinking water resources. Of these people, 263 million spend more than 30 min. per trip to collect water, 844 million do not have basic drinking water, while 159 million drink water directly from surface water sources, such as streams or lakes (WHO, 2017). In South Africa, the department of water and sanitation (DWS) reported that 36% of South African households do not have access to reliable water services (DWS, 2018).

Lephalale Municipality is an arid region situated in the north-western part of the Waterberg District in the Limpopo Province. Due to high temperature, low rainfall, high evaporation, development, population growth, there has been a lack of surface water. Because of the water scarcity problem in the area, the municipality has intervened by installing total of 138 boreholes across the villages within the municipality (Lephalale IDP, 2018). In the previous chapter, it was found that groundwater from some of these boreholes have higher electrical conductivity and alkalinity and further contains higher concentrations of Cl^-, NO_3^-, F^-, Na^+, Ca^{2+} and Mg^{2+}. The findings also showed water has higher total coliforms and feacal coliforms in 41% and 27% of the boreholes respectively (SANS241, 2015). Higher fluoride and presence of coliforms in drinking water can lead to dental fluorosis, skeletal fluorosis, Diarrhea, and other waterborne diseases to people living in Lephalale Local Municipality.

Although boreholes were installed in Lephalale municipality, there are still challenges that can lead to water scarcity problems. Lephalale IDP, (2020/21) reported that dry boreholes due to lack of rain, old infrastructure in some rural areas, Insufficient budget for operations and maintenance of water infrastructure in rural villages and poor quality of groundwater in rural areas are challenges faced by rural communities in Lephalale leading to an inadequate water supply.

Mangani et al. (2020) conducted a study on socio-economic benefits stemming from bush clearing and restoration projects in D'Nyala Nature Reserve and Shongoane Village, Lephalale municipality. The objectives of this study were achieved by conducting a purposive interview on D’Nyala employees and Shongoane residents in order to understand their perspectives on how bush cleaning and restoration projects affects their socio-economic values.

Understanding the community’s perceptive regarding water quality and supply becomes imperative for policymakers and drinking water service providers since it informs them of the community’s experience with water services and the improvements needed when it comes to formulation of water quality standards and water treatment guidelines (Achore et al., 2020, Mahlasela, 2020).Therefore, this chapter aims at evaluating challenges faced by Lephalale community members regarding water quality and supply as well as their perspectives on water quality and supply.

4.2. Methodology

4.2.1. Description of the study area

The study was conducted in Mmatladi Village within Lephalale Local Municipality in Limpopo Province (Figure 4.1). The village lies within the geographical location of longitudes 23°33'26" and 23º34'11"S and latitudes 28º06'47" and 28°07'48"E. Mmatladi Village is a rural area with an estimated population of 2460 individuals and households’ number of 672 (Lephalale, 2018/19). In terms of language diversity, Sepedi and Setswana are the main languages spoken in this rural area. The rural community of Mmatladi is situated alongside the Palala River. The community depends mainly on groundwater as the major source of water for household and domestic use. The water supplied in this village was reported in the previous objective to have the highest concentration of fluoride of up to 7.4 mg/L hence it was selected for the social study.

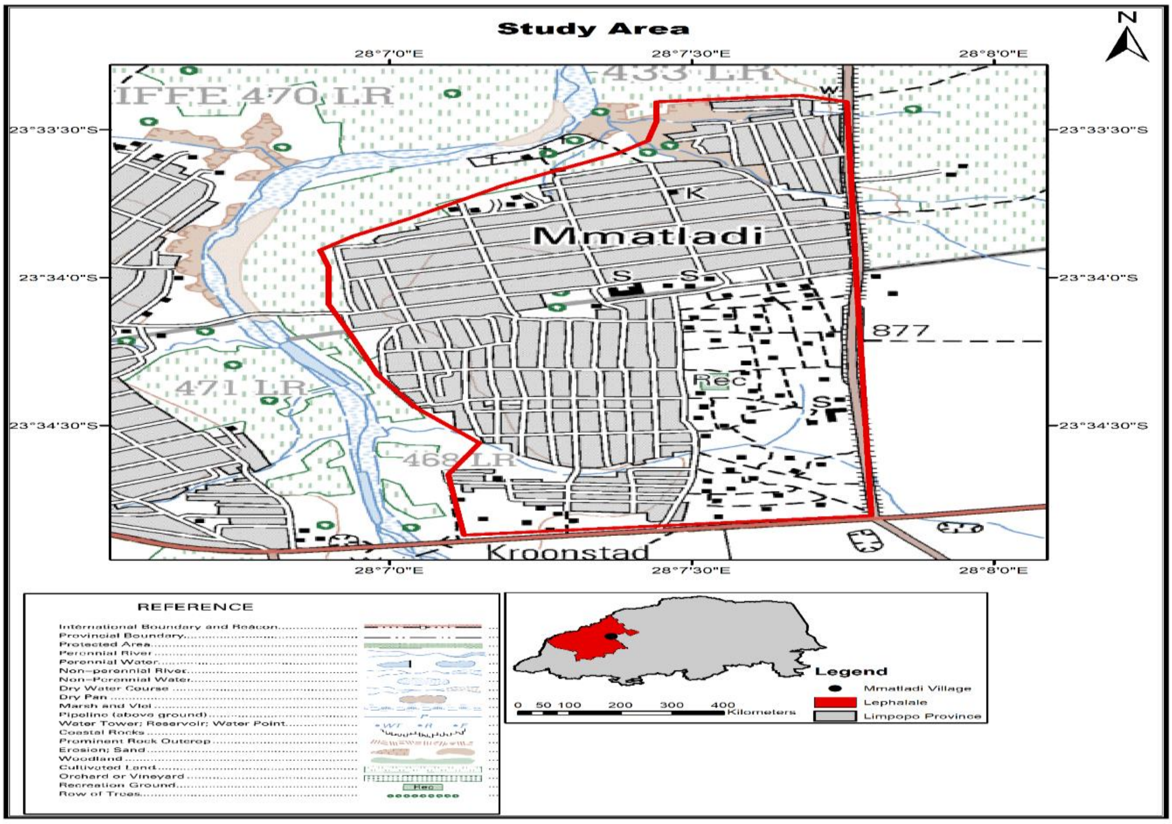

Figure 4.21: Location of Mmatladi Village in Lephalale Local Municipality.

4.2.2. Data collection

The sample size of this study was determined using Raosoft online sample size calculator with a margin of error of 5%, a confidence level of 73%, a sample size of 657 households, and a response distribution of 50%. The recommended sample size was 103 with a margin of error of 5.31%.

Data was collected from 103 households in Mmatladi village through interviews which were conducted using a structured questionnaire. The questionnaire consisted of both open-ended (24%) and closed-ended (76%) questions which included household socio-economic questions as well as those on water supply and demand (Appendix A). Systematic sampling (Kothari, 2004) was used to select households, to give each household an equal chance to be selected.

4.2.3. Data analysis

Statistical tools which include Microsoft Excel and Statistical Package for the Social Scientists (SPSS) (version 27) were used to analyse the data. SPSS is a data management software and statistical analysis tool which has the capability of processing and analysing data.

4.2.4. Ethical considerations

Ethical clearance for this study was obtained from the ethics committee of the University of Venda, Thohoyandou, South Africa. Sample collection, permission was requested from the Lephalale municipality as well as the village leaders.

Consent was requested from volunteering households' participants, and they were informed about the research purpose, advantages, and disadvantages of being a participant, and how collected data is to be used and shared.

4.3. Results and Discussions

4.3.1. Demographic profile of the respondents

The demographics of the respondents from Mmatladi Village are summarized in Table 4.1. A total of 77% of respondents were females while 23% were male. The dominance of females over males was expected, given the national sex-ratio statistics of 97 males per 100 females (StatsSA, 2019). In terms of age, 40% of the respondents were aged between 18-35 years old while the other 22%, 21%, and 17% of respondents were aged 50-60, 36-50, and >60 years old, respectively. Amongst the respondents, 10% had no formal education, 19% had primary education, 58% had high school education and 14% had post-secondary qualifications. About 70% of the respondents were unemployed and depend on child support grants from the government as the main source of income. The high unemployment rate in the community might be due to a lack of jobs, considering that majority of respondents are youthful (Age 18-35). About 53% of the households were getting an income of over R2000, while 25% were earning R1000 to R2000. People earning R500 to R1000 were 17% and only 5% of the households were earning less than R500. According to StatsSA (2019), households with monthly incomes of R0-1000 are all categorised as poor with some of those with a monthly income of R1000-R2000 or >R2000 depending on the number of people in a household which generally indicate that they cannot afford to pay for basic services including water (Mathapo, 2019).

Table 4.10: Demographic characteristics of participants

Variables	No. of participants (n)	percentage (%)
Gender	103	
Female	79	77
male	24	23
Age	103	
18-35	42	40
36-50	21	21
50-60	23	22
>60	17	17
Educational level	102	
No formal education	10	10
Primary education	19	19
Secondary education	59	58
Tertiary education	14	14
Occupation	103	
Unemployed	72	70
Employed	19	18
Self Employed	11	11
Other	1	1

Variables	No. of participants (n)	percentage (%)
Households' monthly income	95	
<500	5	5
500-1000	16	17
1000-2000	24	25
>2000	50	53
Source of income	91	
Salary	7	8
Social grant	64	70
Wedges	5	5,5
Dependent	3	3
Piece jobs	5	5,5
Pension Funds	7	8

4.3.2. Water supply

The main water sources used in households of Mmatladi village are presented in Figure 4.2(a). Survey showed that 79% of the respondents depend on use borehole water (79%) while 21% of the respondents indicated that they depend on tap water. Water that comes from the street taps is connected to the boreholes installed by the municipality. This implies that groundwater is the sole source of water in the Village. However, throughout the fieldwork period in Lephalale municipality, it was observed that existing boreholes are unable to meet the demand due to low yield, others were not working to do breakage of equipment and poor maintenance of infrastructure. In some cases, operators are not available at the time the infrastructure is broken, thus it takes longer to fix and have it working on time, often leading to an inconsistent water supply. Malima (2020) conducted a study in Vhembe district municipality where they reported that the problem with water supply facilities was due to systems that were not maintained and therefore falls into disuse. To add to that, none of the respondents indicated surface water as their main water source.

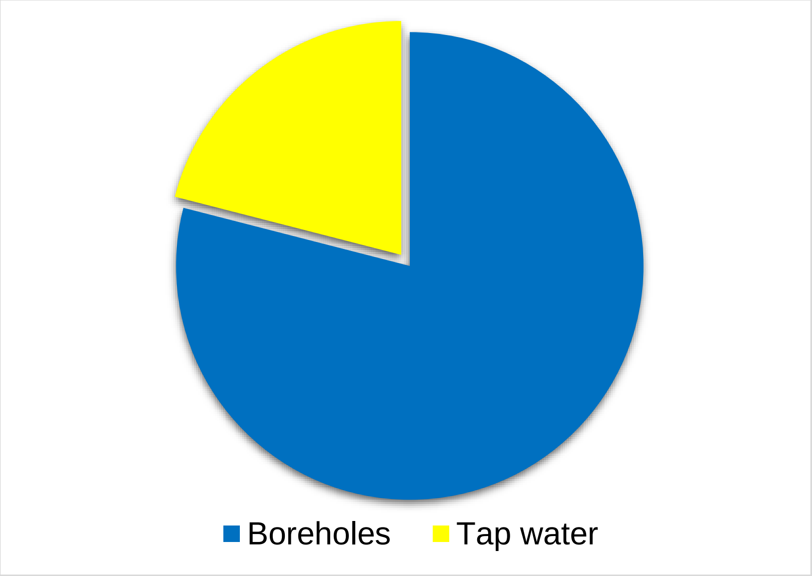

Figure 4.22: Main source of water in Mmatladi village.

The water demand in Mmatladi village is summarized in Figure 4.3. Based on the findings showed that 43% of the respondents uses in their households 100 and 200 L of water per day (43%) while those who use <100 L, 200-300 L, and >500 L constitute 24%, 21%, and 13%, respectively. The amount of water used in a household depend mainly on the availability of water, proximity to the water source, together with the number of people in a household (Fan et al., 2013, Ramulongo et al., 2017). In this case, the majority of households having more than 5 members use >200L per day (Figure 4.4). The average daily consumption in a household was computed using equation 4.1 (Ramulongo et al., 2017). Based on the findings from the survey, 29% of the households do not have sufficient potable water of 25 L per day per capita as reported by WRC (2016).

$$Average\ daily\ water\ consumption\ per\ person = \frac{daily\ water\ consumtion}{No\text{: } of\ people\ in\ a\ household} \qquad (4.1)$$

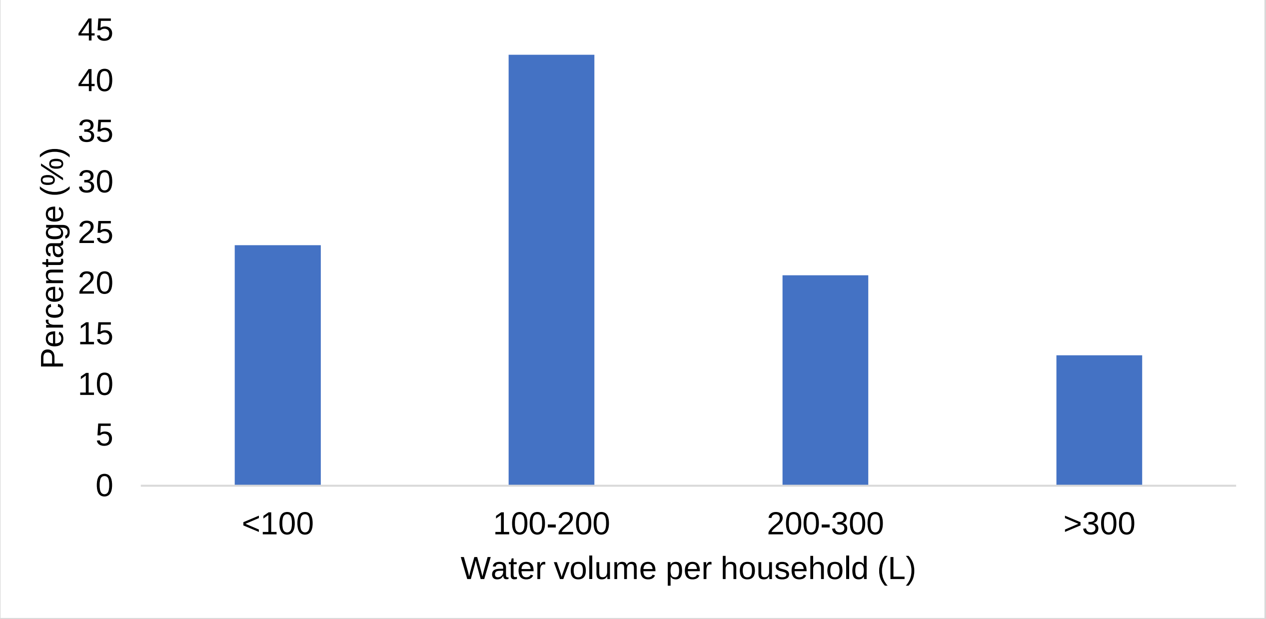

Figure 4.23: Percentage on estimated amount of water used in a household in Mmatladi community.

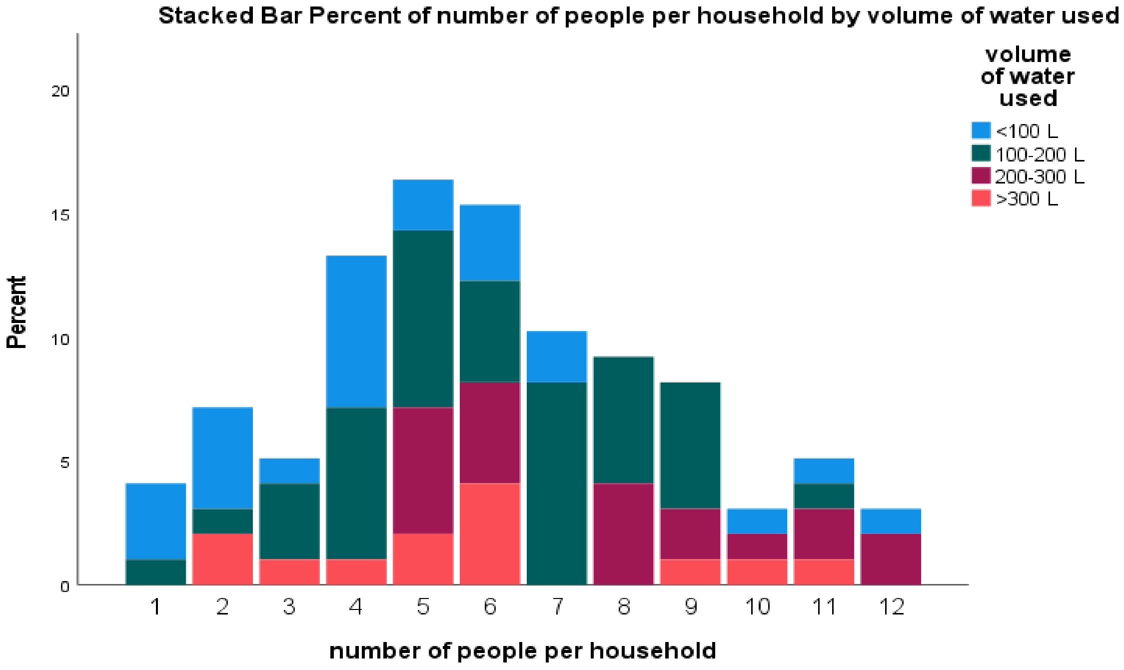

Figure 4.24: Relationship between the number of household members and volume of water needed per household in Mmatladi community.

The time taken by the community members to access the water supplied by the municipality is summarized in Figure 4.5. About 68% of the respondents have a yard connection which consist of those with private boreholes and those with municipality piped water in their household. The remaining 32% of the respondents travel distance when collecting water from the street taps, of that, only 6 % (n= 3) spend more than 15 min per trip. Based on the responses, the community in Mmatladi Village travels less than 30 min. to collect water for domestic use. This is in line with the recommendation of the WHO which indicates that people should not travel more than 30 minutes walking distance to and from the water source (WHO, 2017).

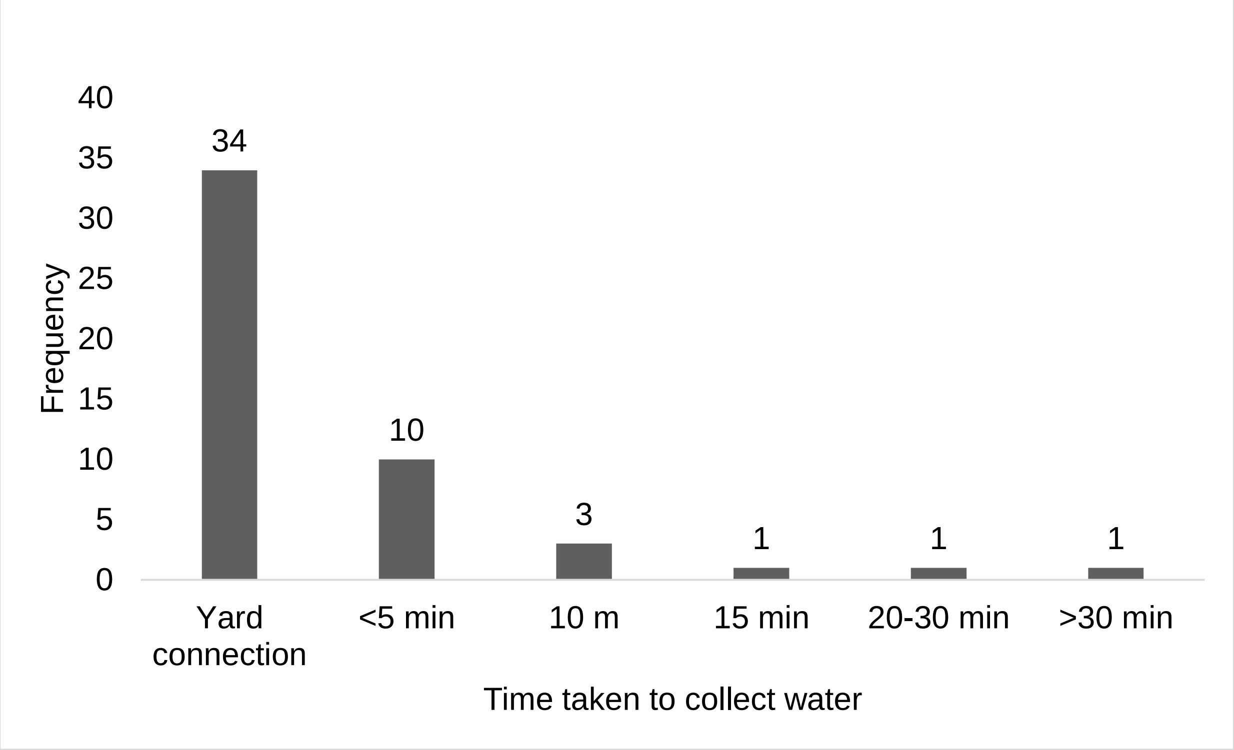

Figure 4.25: Time spent by Mmatladi community members to fetch water from community standpipes.

4.3.3. Perception of Water Supply and coping strategies

Figure 4.6 illustrated the response on water supply and copping strategies. Based on the municipal water supply, respondents (n=103) indicated that they spend 2-3 weeks without water (49%), and 32% indicated that they spend 1 week while about 19% indicated that they sometimes spend up to a month. According to the South African National Standards report, household water supply must be interrupted by less than 48 hours at any time with a cumulative interruption time of less than 15 days per year SANS241 (2015). Based on this finding, 93% of respondents showed that water may be interrupted for more than 48 hours which implies that the water supplied by the Municipality is insufficient and irregular.

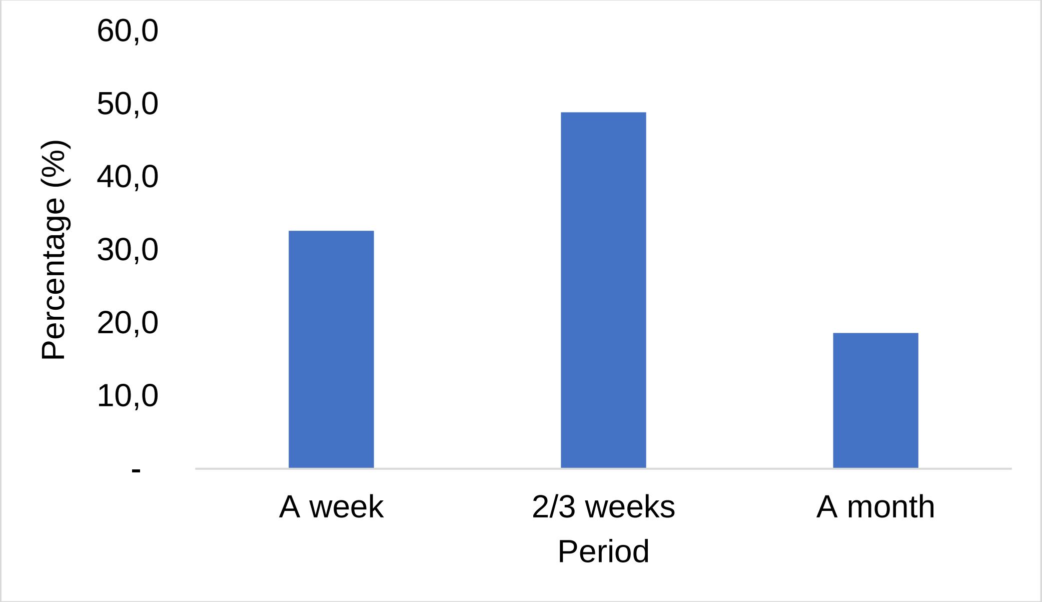

Figure 4.26: Time spent by Mmatladi dwellers without running water.

Majuru et al. (2016) reported that villagers who do not have adequate water to meet their needs often resort to alternative coping strategies. The alternative sources of water to community members in Mmatladi village with no boreholes in their households are summarized in Figure 4.7. About 51% of the respondents showed that they buy water either from community members with boreholes or from the retail stores main mainly the drinking water. Unfortunately, even though majority of people depend on government grants they still buy water for basic household use which affects their socio-economic values too. To support that, *participant 94 (male, 50-60 years) said that there is a shortage of water in the area and community members spend a lot of money buying water*. The other community members indicated that they ask for water from neighbours who have boreholes (25%), collect from the river (11%), and others indicated that they store water from municipal supply systems in tanks (2%).

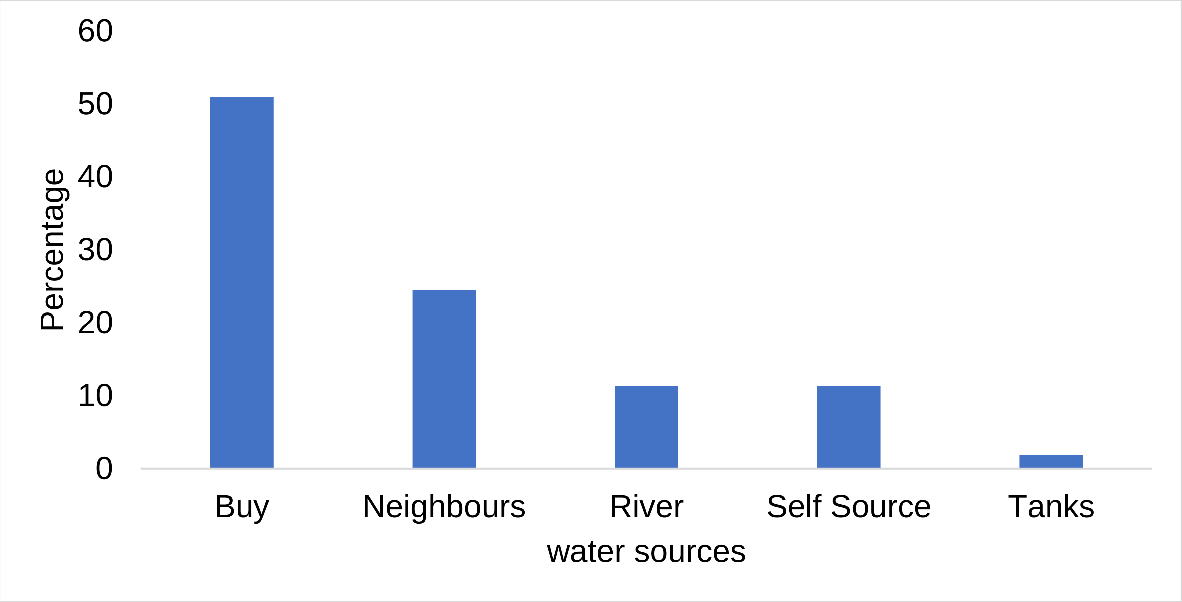

Figure 4.27: Alternative sources of water for community in Mmatladi Village.

4.3.4. Perceptions of water quality

In order to understand the perceptions of Mmatladi Villagers with respect to water quality questions were asked to gauge their knowledge about water quality, groundwater contaminants, fluoride in groundwater and if they know of any health effects of water contaminants. Figure 4.8 summarizes the response of the community members with respect to their general knowledge of water quality and contaminants. Majority of the respondents do not have knowledge with respect to water quality (78%), groundwater contaminants (84%), fluoride in groundwater (87%), and the effect of groundwater contamination (74%). The fact that community members of this area do not know much of either water quality, groundwater contamination, fluoride in groundwater, or effects of groundwater contamination raise a concern that there is still a gap with regard to public awareness. This is in line with the fact that most people in this area are not much educated. However, there is a need to raise awareness on these factors so that people can know the quality of the water they are using on a daily basis (Mnisi, 2011). As participant 45 mentioned; *"I think it will be good to have a treatment module because of the lack of knowledge about water contamination"*.

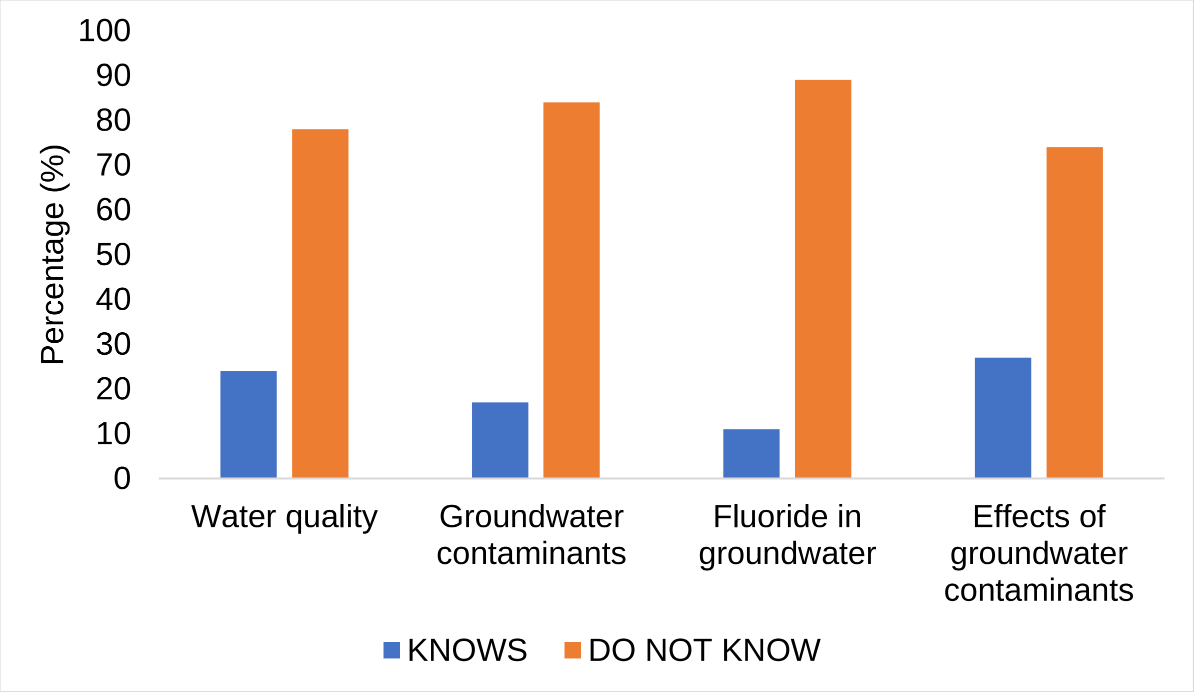

Figure 4.28: Mmatladi community members' knowledge on water quality.

The perceptions of Mmatladi villagers concerning water quality are summarized in Table 4.2. The community members were asked if they think the water they are using is of good or poor quality. About 59% of the respondents indicated that the water they are using is of poor quality while the remaining 41% said the quality is good. Morales et al. (2020) reported that perception of water quality in rural areas is based on specific parameters such as smell, colour, and flavour of water, as well as judgements about its purity. Amongst the respondents, 82% indicated that the water is salty/odour which supports that their water quality judgement was based on the organoleptic characteristics. *P22 (female, 50-60 years) commented that the water has poor quality and salty taste*. Drinking water with a high salinity level has been linked to risk of gestational hypertension, which is a risk factor for overall mortality, cardiovascular diseases, myocardial infarction, heart failure, stroke, renal disease as well as stroke (Nahian et al., 2018, Shammi et al., 2019). Pregnant women are particularly at risk of high blood pressure, preeclampsia, and post-partum infant morbidity and mortality due to consumption of salty water (Chakraborty et al., 2019).

Table 4.11: Perception of Mmatladi household members on water quality and taste/odour

Variables	No. of participants (n)	Percentage (%)
water quality	102	
Good	42	41
Poor	60	59
Taste/Odour	103	
Yes	84	82
No	19	18

4.3.5. Water-related illnesses

As indicated in Fig 4.9, about 74% of the respondents indicated that they do not know of any effects of water contaminants on human health with only 27% indicating that they know concerning the effects of drinking contaminated water. Following the findings that the groundwater in the area contains a higher level of fluoride and is also contaminated by coliforms. A question was set to find out if any of the household members suffer from fluorosis, cholera, or diarrhoea which are diseases associated with fluoride and coliforms (Table 4.3). About 28% of the respondents indicated that they have a household member who suffers from fluorosis respectively, which is linked to consumption of fluoride-rich water. Community members indicated that they do not know that mottled teeth are a result of water they are drinking rather the effect of not washing the teeth regularly leading to “chocolate teeth”. Unfortunately, the study did not go into detail to find out how many people suffering from these diseases and at what age. Moreover, 2% of participants indicated that they have a family member who has suffered from cholera. Although most people were not treating water before use, there has not been an outbreak of cholera recently in this area. The last cholera outbreak in Lephalale was reported in 2009, it was severe to a point that even the Medupi power station ended up being closed for few days (Bruyn, 2009). In addition, about 6% of the respondents indicated that one of their family members experiences diarrhoea. Drinking water with high number of total coliforms and *E. coli* is the reason behind people suffering from diarrhoea and cholera (Edokpayi et al., 2018).

Table 4.12: Health status of Mmatladi household members

Diseases	Total number of participants	Number of respondents	% Of respondents
Fluorosis	99	28	28
Diarrhoea	100	6	6
Cholera	100	2	2

4.3.6. Perception of Water treatment

The perception of the community members regarding the treatment of water before use was assessed. This was done to understand if household members treat their water to address water quality issues and minimise diseases associated with groundwater contamination as mentioned above. The observation in Figure 4.9a revealed that 79% of the respondents do not treat their water before use and only 21 % of the households treat their water before consumption. Therefore, it can be deduced that the respondents who know about the water quality are the ones who treat water before consumption since only 24% indicated that they know about the water quality. Amongst the 21% (n=21) who indicated that they treat water, 54% use boiling as it's the cheapest method while 38% uses chlorination and 10% uses filter membranes to treat water before consumption (Figure 4.9b).

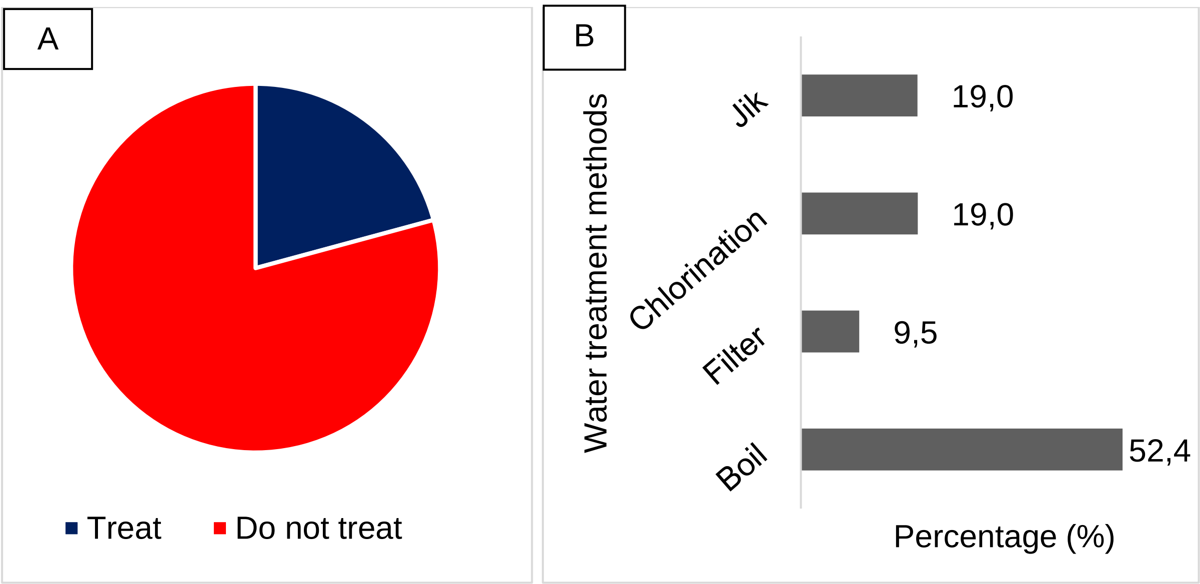

Figure 4.29: The use of water treatment methods (a) and the type of treatment used (b).

Following the question on water treatment, the respondents were further asked if they would like any intervention such as the development of water treatment devices. The results in Table 4.4 show that the majority of respondents (78%) are willing to have a water treatment intervention. The long-term objective of this study is to develop a household water treatment device that can be used for fluoride and pathogen removal from groundwater. We further asked if participants are willing to taste the water treatment devices in their household. About 81% responded that they are willing to try and use the point of use water treatment system in their homes. This was also emphasised by a lot of members in their comment section whereby 30% of those comments were related to seeking the household water treatment to reduce the saltiness of water. Participant no: 79 commented that *there should be an intervention when it comes to water purification, especially to reduce the salt content in the water*. Another comment was from respondent no: 80 who said… *she hopes the developed water treatment module will be able to remove the salt content in the water*. Of importance, the respondents were weary of the amount spent to buy water.

Table 13.4: Community perception in water treatment interventions

	No. of participants	Percentage (%)
Willingness to have water treatment intervention		
Yes	80	78
No	22	22
Willingness to use the water treatment system		
Yes	83	81
No	19	19

4.4. Summary

This study assessed the perspectives of the community member of Mmatladi Village within Lephalale Municipality regarding the water quality and supply. Lephalale local municipality intervened and initiated a water supply strategy by installing boreholes in their villages for community use. The community standpipes are close by, this was confirmed by the results which shows that majority of the community members who travel distance to collect water (30%) in this village travel less than 30 min. per trip. However, the findings show that 29% of the households do not have enough access to the minimum 25L per day per capita which is recommended by WRC. The water supply by the municipality was said to be cut for up to a month (19%), leading people to find alternative ways such as buying (51%), asking from neighbours (25%) with private boreholes, and accessing water from unreliable sources such rivers (11%).

There was a huge knowledge gap among the respondents whereby 78%, 84%, 87% and 74% indicated that they do not know anything about water quality, groundwater contamination, fluoride in groundwater and groundwater contamination, respectively. About 28% of the households have people suffering from fluorosis, 6% and 2% members who have suffered from diarrhoea and cholera. The study did not go into details with regard to age and the number of people suffering from these diseases together with other waterborne diseases. The exposure to such diseases was not surprising since 79% of the respondents said that they do not treat water before use. Of the 21% who does, they prefer the boiling (54%) method because it is cheap and does not require skills however boiling alone does not eliminate chemical species such as Fluoride which is causing people to suffer from fluorosis. There is hope in people living in this area since up to 71% of them are agreeing to have an intervention and 81% are willing to be part of that intervention by using and testing the water treatment module.

Based on the key findings, the study recommends the initiation of campaigns to raise awareness and educate household members about water quality and quantity. A well-detailed study on finding the number of people with fluorosis per age, and the money spent to buy water for basic household use.

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Chapter 5: Developing Al/Fe oxide modified Diatomaceous Earth-based household water treatment system

5.0. Abstract

The preceding chapters presented the groundwater quality and perspectives of community members in selected villages of Lephalale Municipality regarding water quality and supply. The results concerning water quality showed that groundwater in Lephalale contains up to 7 mg/L of fluoride. Fluorosis was found to be a concern in this area whereby 28 % (n=99) of the households have family members with dental fluorosis. The participants' perspectives regarding water quality stated that the water is poor (59%) due to the salty taste. The use of suitable point of use water treatment system was recommended and supported by community members who sought an intervention on reduction of fluoride (saltiness) in the water. This part of the work aimed at developing Al/Fe metal oxide modified diatomaceous earth-based water treatment system for use at household level. The developed water treatment system could treat 1.68 L in 2 hours using 30g of Al/Fe oxide DE. The system also showed efficiency in reduction of other contaminants such as Na^{+}, Mg^{2+}, and TDS. The results obtained from this part of the work showed that the bucket water system is a suitable defluoridation technology that can be adopted for water treatment at a household level in rural communities.

Keywords: Al/Fe oxide Diatomaceous Earth, two-Bucket water treatment, defluoridation, point of use.

5.1. Introduction

The community in Lephalale relies on groundwater as source of water for drinking purposes. Chapter 3 of this study revealed that groundwater in Lephalale is contaminated by fluoride with about 32% boreholes containing fluoride concentrations above 1.5 mg/L recommended by World Health Organization. This is a major concern from the health point of view. From chapter 4, about 28% (n = 28/99) reported that at least one family member in their household suffers from fluorosis. This is linked to higher fluoride concentrations reported in the area, and stresses for development of household water treatment system in order to reduce health effect.

Izuagie et al. (2016) developed Al/Fe metal oxide modified DE for groundwater defluoridation and reported maximum fluoride adsorption capacity of 7.63 mg/g using batch adsorption experiments. Owing to higher adsorption capacity of Al/Fe metal oxide modified DE, this study attempts to test the efficiency of the material using a two-bucket water treatment system to simulate the household water treatment system. This was done with the aim of proposing simple household water treatment system to use at rural households of Lephalale Municipality.

5.2. Methods and materials

To achieve the aim of this objective the following materials and chemicals were used; Diatomaceous earth (DE), 10 L bucket containers, sodium hydroxide (NaOH), iron (III) sulphate hydrate [$Fe_2(SO_4)_3.H_2O$], aluminum sulfate octadecahydrate [$Al_2(SO_4)_3.18H_2O$], sodium fluoride and total ionic strength adjustment buffer (TISAB III). All the chemicals used for the preparation of required solutions were of analytical grade. Chemicals were produced by Sigma-Aldrich, Germany and supplied by Rochelle Chemicals, South Africa

5.2.1. Synthesis of Al/Fe Diatomaceous Earth

Al/Fe metal oxide modified DE was synthesized following the procedure developed by Izuagie et al, (2016). Figure 5.1 summarizes the flow chat of synthesis steps. Solutions containing 0.25 M of Al^{3+} and 0.25 M Fe^{3+} were prepared by dissolving 8.33304g of $Al_2(SO_4)_3.18H_2O$ and 4.9985g of $Fe_2(SO_4)_3.H_2O$ in respective 100 mL volumetric flasks. In a 1 L plastic bottle, 15 g of raw DE was dispersed into the solution and agitated at 200 rpm for 20 min. Thereafter, $Al_2(OH)_3$ and $Fe_2(OH)_3$ were allowed to co-precipitate on the surface of DE by adjusting the pH of the solution to 8.2 with rapid stirring using 2 M of NaOH. The mixture was shaken using a reciprocating shaker at 100 rpm speed for 50 min. The solids were left exposed to air for 10 h for oxidation of Fe^{2+} to Fe^{3+} and Al^{2+} to Al^{3+} to take place. The content was then centrifuged to remove excess NaOH while washing with deionized water. The solids were scooped out of the centrifuge tubes and dried in an oven at 110℃ for 8 h, cooled and stored in a container for future use.

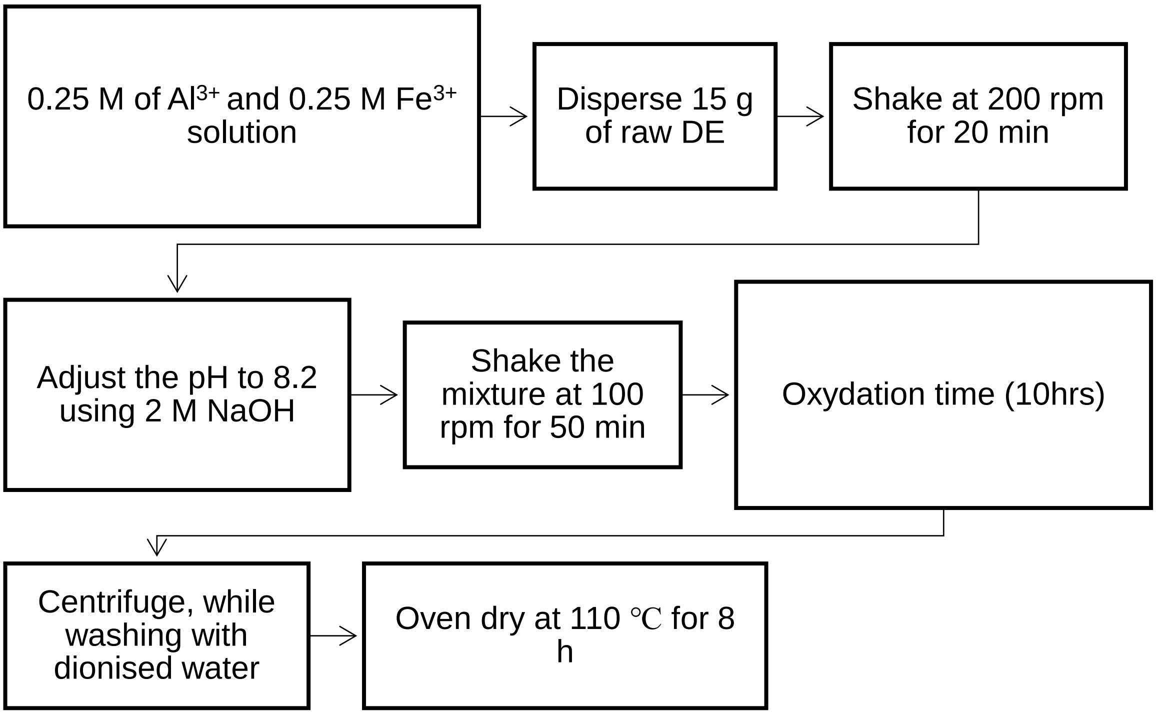

Figure 5.30: Flow diagram for modification of DE with Al/Fe metal oxides

5.2.2. Material characterization

The X-ray fluorescence (XRF) (Bruker SI Titan/Tracer Handheld XRF) was used to determine the chemical composition of the raw DE, and Al/Fe metal oxides modified DE. Mineralogical assemblage and crystallinity of the raw and Al/Fe modified DE was determined using X-ray diffraction (XRD). Surface microstructure and elemental composition were determined using scanning electron microscopy (SEM) equipped with energy dispersive X-ray (EDX). The surface area was determined by the Brunauer–Emmett–Teller (BET) method and the surface functional groups were determined using Fourier Transform Infra-red spectrophotometer (FTIR) (Bruker Alpha Platinum-ATR)

5.2.3. Design of water purification cartridge

Figure 5.2 shows a schematic diagram of a water purification cartridge developed in the form of a two-bucket container and a ceramic cup with a 4 cm diameter and 9 cm height. The adsorbent was placed inside the commercial cup-shaped ceramic (A) and Whatman No. 41 ash-less filter paper was placed at the bottom of the ceramic cup.

Fluoride-containing synthetic and groundwater were poured on the top bucket and percolated through the ceramic cup with the adsorbent to the bottom bucket. To evaluate the effect of initial fluoride concentration and the adsorbent weight, the Initial fluoride concentration was varied from 3 to 10 mg/L while the adsorbent weight was varied from 15- to 40 g. The treated samples were collected from the exit at different time intervals and measured for the remaining fluoride concentration using the Thermo Scientific Orion A215 ISE/pH meter. Calibrations were done using standard fluoride solutions with fluoride concentrations ranging from 0.1 to 100 mg/L were prepared from a standard stock solution of 1000 mg/L. For decomplexation of complexes and avoiding interference with the electrode performance, TISAB-II solution was added at 1:10 proportion to 10 mL of sample solution. The water treatment experiments were performed at room temperature and no adjustments regarding pH were done.

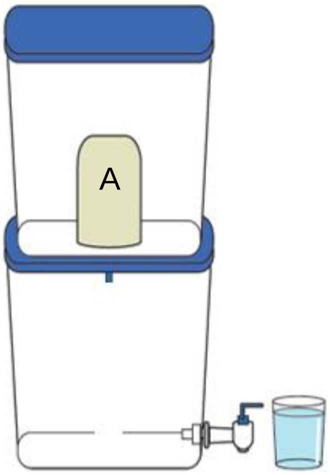

Figure 5.31: Schematic diagram of the household water module

5.2.4. Field water testing

Field water collected from the Mmatladi Local borehole, in Lephalale municipality, Limpopo Province, South Africa was used to test the efficiency of the system at household level. The previous objective revealed that the Mmatladi groundwater contained 7.4 mg/L fluoride concentration hence water from this borehole was selected. The water was treated using the two buckets water system with an adsorbent mass of 30g. Fluoride concentration, electrical conductivity (EC), total dissolved solids (TDS), pH, cations, anions, and microbial contaminants were measured before and after the filtration process.

The quantity of adsorbed fluoride was calculated as in Eq.5.1

$$qe = \frac{C_0 - C_e}{W}\ v \qquad (5.9)$$

where q_e is the adsorption capacity up to the breakthrough point (mg/g), C_0 is the initial concentration of fluoride (mg/L), C_e is the concentration of fluoride at time t (mg/L), W is the mass of adsorbent (g), and V is the volume treated up to the breakthrough point (L).

5.3. Results and discussions

5.3.1. XRF Results

Table 5.1 shows the composition percentage for major oxides and trace elements with regards to raw DE and modified DE. There was an increase in the percent compositions of Al_2O_3 (0.511 to 6.446%) and Fe_2O_3 (0.051 to 5.042%) following the modification by Al/Fe metal oxides. The content of SiO_2 on the other hand decreased (79.374 to 61.335%). The increase in the values of the Al and Fe metal oxides indicates that modification of DE was effective. Moreover, the decrease in SiO_2 content may be due to leaching of silica from the material during treatment and subsequent dilution during the introduction of Al_2O_3 and Fe_2O_3 oxides.

Table 5.14: Elemental composition for Raw DE and Al/Fe ion modified DE

	Composition percentage (%)	
Oxides	Raw DE	Al/Fe oxide modified DE
SiO_2	79.374	61.335
MgO	0.782	0.534
Al_2O_3	0.511	6.446
CaO	0.090	0.105
P_2O_5	0.069	0.078
Fe_2O_3	0.051	5.042
K_2O	0.043	0.046

5.3.2. XRD analysis

The pattern of XRD peaks for raw DE and Al/Fe oxide-modified DE are presented in Figure 5.3. A strong diffraction peak appears at 2Ɵ = 21.75 represents cristobalite, the peaks between 2Ɵ = 28.21 to 2Ɵ = 32.87 are ascribed to quartz. Both quartz and cristobalite are the mineral phase of SiO_2. According to the XRD pattern, the observed peaks on raw DE seem to be decreasing after modification which might be due to the decrease in of silica oxide as observed in XRF results. The decrease in the peak intensity could be credited to exchange of oxides during the process of modification. The peaks alignment shows that the material is crystal in general which is quite the opposite of what was reported in the Izuagie et al., (2016) study. This might be because of the difference in the DE used.

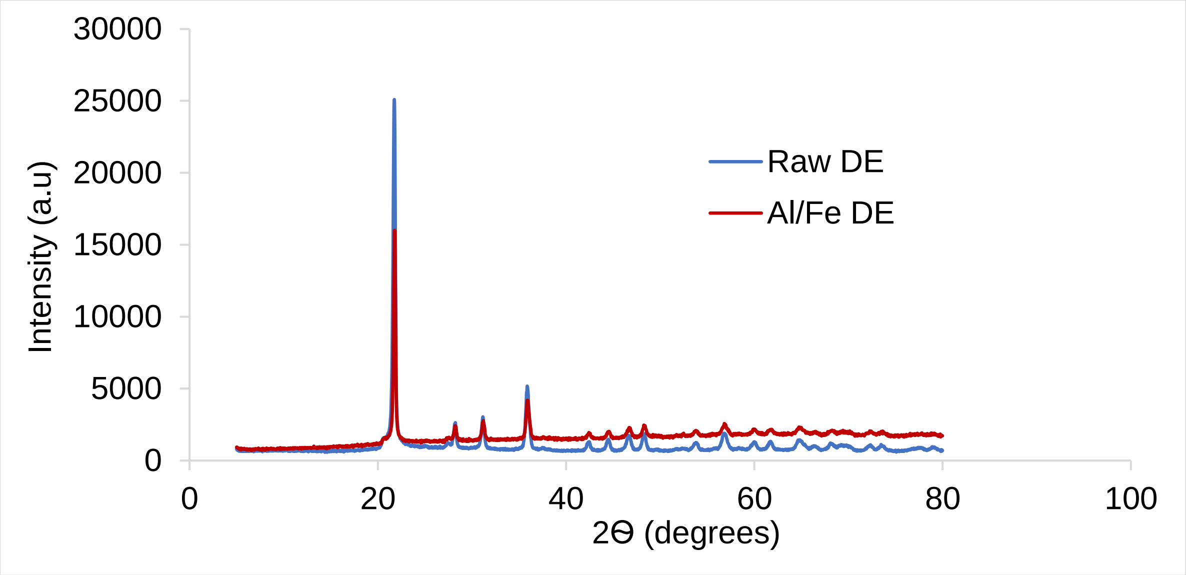

Figure 5.32: XRD plots for raw DE and Al/Fe modified DE

5.3.3. Surface morphology and elemental analysis

Figures 5.4 shows the micrographs of raw and modified DE while Table 5.2 shows the elemental analysis determined by SEM-EDX. The SEM images are showing a regular cylindrical shape, and there is no difference between material structure, however the particle sizes of the modified DE are smaller compared to raw DE. The EDX table show the presence of Na, C, O, and Si in the raw DE. After modification, Al and Fe were observed at 2.5 and 6.8 weight percentage respectively which confirm their introduction into the surface of the DE.

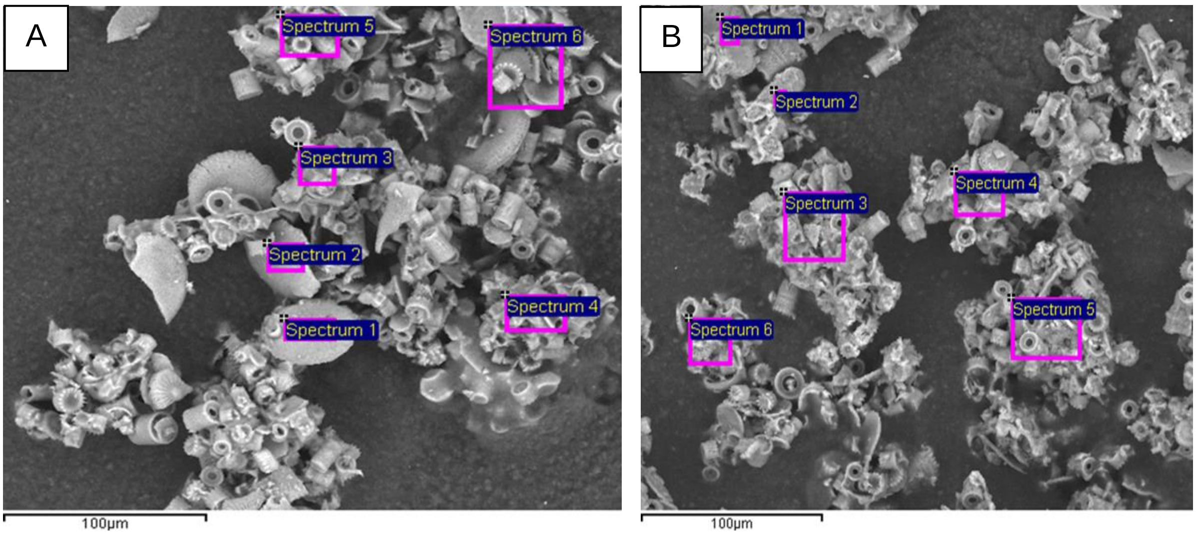

Figure 5.33: SEM images for raw DE (A) and Al/Fe modified DE (B).

Table 5.15: EDX spectrum content for Raw DE and Al/Fe modified DE

	Raw DE (%W)				Al/Fe oxide DE (%W)					
Spectrum	C	O	Na	Si	C	O	Na	Al	Si	Fe
1	17,2	57.8	1.6	23.5	11,8	57,6	1,5	0,5	28,6	0
2	32.5	38.4	0.5	28.6	15,9	47.0	0,7	2,5	26,0	7,9
3	25.3	51.0	0.7	23.1	19,0	51,6	0,8	3,9	17,1	7,7
4	23.4	51.2	1.5	23.9	16,9	50,3	1,2	1,6	27,7	2,3
5	9.0	57.3	1.5	32.3	22,6	48,6	0,8	2	20,2	5,9
6	28.4	50.2	0.9	20.5	24,4	40,7	0,7	4,4	16,4	13,3
Mean	22.6	51.0	1.1	25.3	18,4	49,3	1.0	2,5	22,7	6,18

5.3.4: Porosity and surface area analysis

The surface area, pore diameter, and volume of raw DE and Al/Fe oxide-modified DE are shown in Table 5.3. The results indicate that the BET surface area increased from 0.71 m^2/g in raw DE to 31.99 m^2/g in Al/Fe oxide-modified DE. The increase in surface area might be due to the deposit of Al/Fe oxide. An increase in surface area of adsorbent provides more active adsorption sites (Obijole et al., 2019). The average pore diameter and pore volume increased from 36.69 nm to 47.31 nm and 0.00 to 0.01 cm^3/g respectively after modification. The pore diameter of 2 – 50 nm was reported to categorise the material as mesopores (Abu Bakar et al., 2019). The increase in surface area, pore diameter, and volume after DE modification with Al/Fe metal oxide was also reported by Izuagie et al., (2016).

Table 5.16: surface area, pore diameter, and pore volume of adsorbents

Adsorbent	Surface area (m^2/g)	Average pore diameter (nm)	Pore volume/ porosity (cm^3/g)
Raw DE	0.7087	36.6886	0.000287
Al/Fe DE	31.98860	47.3065	0.01319

5.3.5. Functional group analysis

The FTIR spectroscopic analysis of both Raw DE and Al/Fe modified DE is shown in Figure 5.5. The FTIR spectrum shows the vibration of Si-OH and Si-O bands at 468 cm^{-1} and 1072 cm^{-1} wavelength regions, respectively. The projected peak at 617 cm^{-1} wavelength regions might be because of the vibration of the Fe-O bond. The stretching of the Al-O bond was observed at the 791 cm^{-1} wavelength bend. The band between 3032 and 3577 cm^{-1} in the modified DE is associated with the stretching of the hydroxyl group (Gitari et al., 2020). After DE modification, the bands' intensity on wavelength 468 cm^{-1}, 1072 cm^{-1}, 617 cm^{-1}, and 791 cm^{-1} increased which might be due to the introduction of Al/Fe during modification.

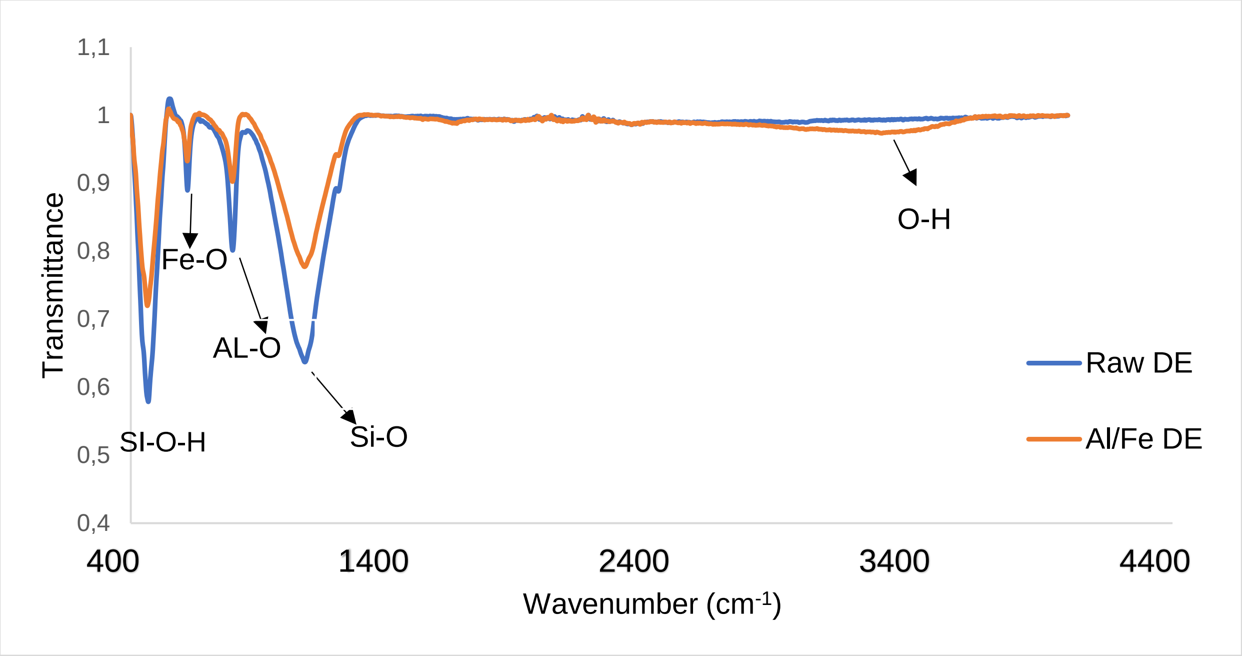

Figure 5.34: FTIR for Raw DE and Al/Fe modified DE

5.3.6. Experimental Breakthrough Curves

Breakthrough curves obtained during the treatment of fluoride rich water by the bucket system at different initial concentration and adsorbent mass are presented in this section. The breakthrough curves were obtained by plotting the fluoride concentration (C_e/C_0) against time (t), where C_e is the concentration of fluoride at equilibrium (mg/L), C_0 is the initial concentration (mg/L). The breakthrough point in this study was taken as 1.5 mg/L, which is the permissible limit for fluoride in drinking water as determined by WHO (2017) and SANS241 (2015).

5.3.6.1. Effects of adsorbent mass

The breakthrough curves for fluoride adsorption on Al/Fe oxide modified DE at the different masses of 15, 30, and 40g are shown in Fig. 5.6. Feed fluoride solution with 5 mg/L concentration was introduced into the adsorption column in order to observe the effect of adsorbent mass on breakthrough curves. The results show that the adsorbent dose of 15g, 30g, and 40g reached the breakthrough point just before the 6th, on the 10th and 12th hour, respectively. The acquired outcomes confirmed that the breakthrough time increases with increasing bed mass. As a result of this, the saturation time as well as the volume of water collected at the breakthrough point increases with increasing bed height. This is attributed to the fact that higher bed height provides more residence time for fluoride solution along with more active sites for fluoride ion resulting to longer breakthrough time and higher volume of water at breakthrough time (Ye et al., 2018). Breakthrough time increased probably due to the larger mass transfer zone available for adsorption with a higher surface area of the adsorbent providing a greater number of binding sites to fluoride ions in solution (Bolshak et al., 2020, Verduzco-Navarro et al., 2020). The adsorption capacities obtained in different bed mass are shown in Table 5.4. It was observed that adsorption capacity decreases with an increase in bed weight, it decreases from 0.69 to 0.53 mg/g when increasing bed weight from 15g to 40g.

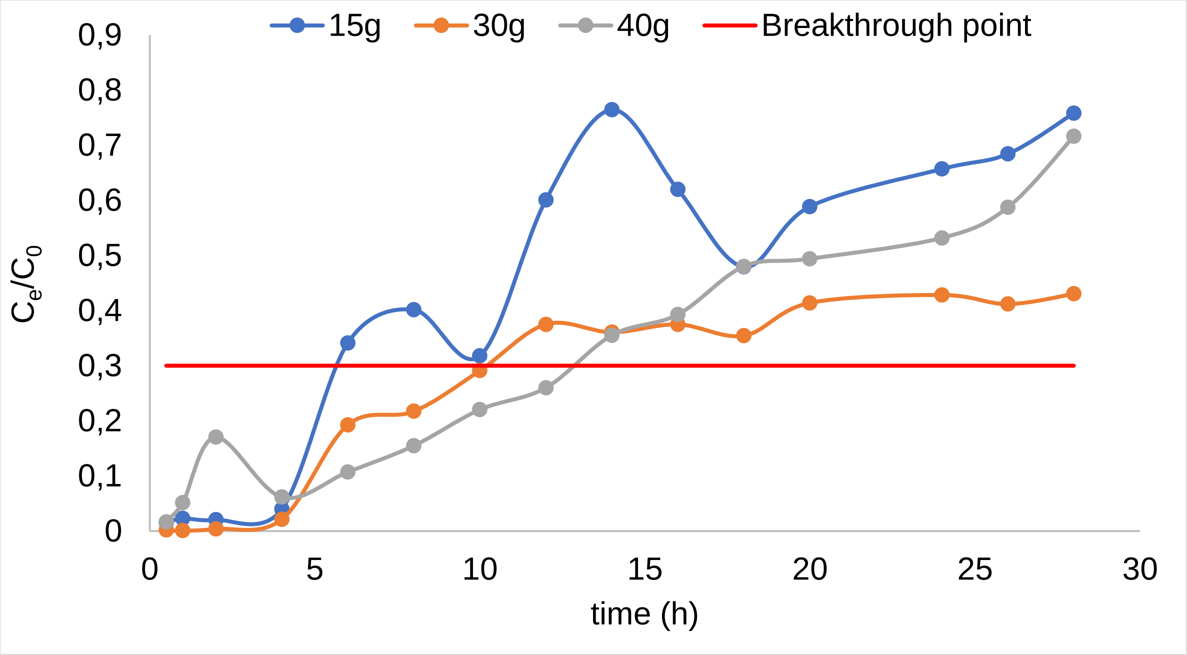

Figure 5.35: Effects of bed weight on breakthrough curve

5.3.6.2. Effect of initial concentration

The relationship between initial fluoride concentration and breakthrough time is shown in Fig. 5.7. Three feed fluoride concentrations were varied from 3 to 10 mg/L to determine the effect of solute concentration on breakthrough performances while adsorbent mass was kept constant at 30 g. The breakthrough times were found to be 20 h, 10h and 2h for 3 mg/L, 5 mg/L, and 10 mg/L feed fluoride concentration, respectively. It is observed that an increase in initial fluoride concentration decreases the breakthrough time and the volumes of water treated. This could be because the mass of adsorbent was constant while there was an increase in the initial concentration of adsorbate resulting in quickly exhaustion of binding sites (Mudzielwana and Gitari, 2021). The higher the initial adsorbate concentration, the greater the driving force for mass transfer, resulting in faster adsorbent saturation and shorter breakthrough early breakthrough (Kumari et al., 2021).

The adsorption capacity of AL/Fe DE at breakpoint point for initial fluoride concentration variation is shown in Table 5.4. The results show an increase in adsorption capacity from 0.5 to 0.66 mg/g, with an increase in fluoride concentration. The increase in inlet fluoride concentration increased the driving force for mass transfer, which in turn decreased the length of the adsorption zone. It was also noticed that a rise in the feed fluoride concentration decreased the volume treated before the bed got exhausted.

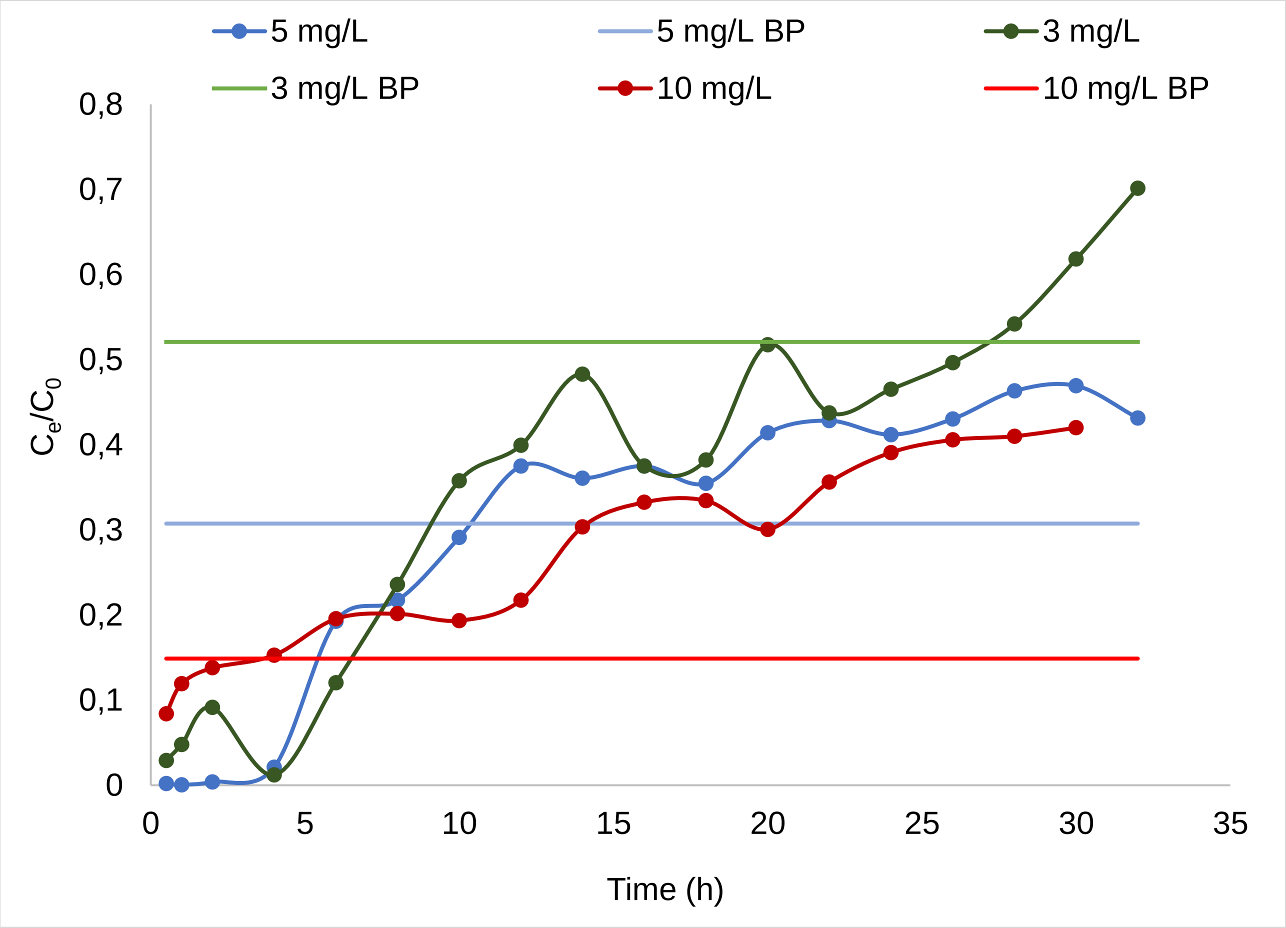

Figure 5.36: Breakthrough curves for 3 mg/L, 5 mg/L and 10 mg/L as initial fluoride concentration. *BP = Breakthrough point.

Table 5.17: fluoride removal capacity at breakthrough point

Initial f concentration (mg/L)	Q_e (mg/g)	Breakthrough time (h)	Volume (L)

3	0.49	20	10.6
5	0.63	10	5.4
10	0.66	4	2.3
Bed weight	Q_e (mg/g)	Breakthrough time (h)	Volume (L)
15	0.69	<6	2.1
30	0.63	10	5.4
40	0.59	12	6.4

5.3.7. Adsorption Exhaustion Rate (AER) as the performance indicator

The AER is an indicator of the column performance efficiency, and it is used to determine how regularly the adsorbent is replaced. The value of the adsorbent exhaustion rate reflects the goodness of the adsorbent bed performance (Mondal et al., 2018). The lower the AER the greater the adsorbent performance. AER is estimated using equation 5.2

$$AER = \frac{M}{V} \qquad \text{Equation 5.10}$$

Where M is the adsorbent mass (g), and V is the volume treated. The calculated values of AER are shown in Table 5.5, and it was observed that the AER values decreased from 7.1 to 5.5 g/L with an increase in bed mass. The AER values were observed to increase with an increase in initial fluoride concentration from 2.8 to 14.1 g/L. The bucket water system is anticipated to work better at lower fluoride concentration and higher adsorbent dosages. The fluoride capacity of Al/Fe adsorbent at the breakthrough point was found to be 0.33 mg/g and 1.68 L of water was treated with 30 g of adsorbent. It can be estimated that 446 g of Al/Fe DE will be required to treat 25 L (minimum required water per household) of water with 7.36 mg/L fluoride daily.

Table 5.18: Adsorption exhaustion rate for Al/Fe oxide DE

Parameter	Adsorbent mass (g)	Initial fluoride concentration (mg/L)

	15	30	40	3	5	10
AER (g/L)	7.1	6.3	5.5	2.8	5.5	14.1

5.3.8. Field water treatment studies

Defluoridation experiments were carried out through a 2-bucket water system using groundwater from Mmatladi village, Waterberg district which was reported to have the highest fluoride concentration (i.e., 7.36 mg/L) in the previous objective. The physicochemical properties of the collected field water were assessed before and at the breakthrough point as illustrated in Table 5.6 and the breakthrough curve plot is observed in Fig. 5.8. The results indicate that the breakthrough point was reached after 2 hours with the initial fluoride concentration of 7.36 mg/L using 30 g adsorbent mass. A total of 1.68 L of water was treated at breakthrough point. Physicochemical parameters such as pH, TDS, Cl^-, NO_3^-, SO_4^{2-}, Fe, Al, Mg^{2+}, and Ca^{2+} were found to be below the WHO, (2017) and SANS 241 (2015) recommendation guideline for drinking water (Table 5.6). EC and Na^+ were found to be above the limit at the breakthrough point. It was also observed that Al and Fe increased from BDL to 20.3 and 8.5 µg/l respectively. This indicates that the ions were leaching from the adsorbent which could be also the reason behind the increase in EC, Na^+, and other parameters which increased after the treatment. The increase in Na may be due to the excess NaOH used for precipitating Fe and AL metal ions during the modification process.

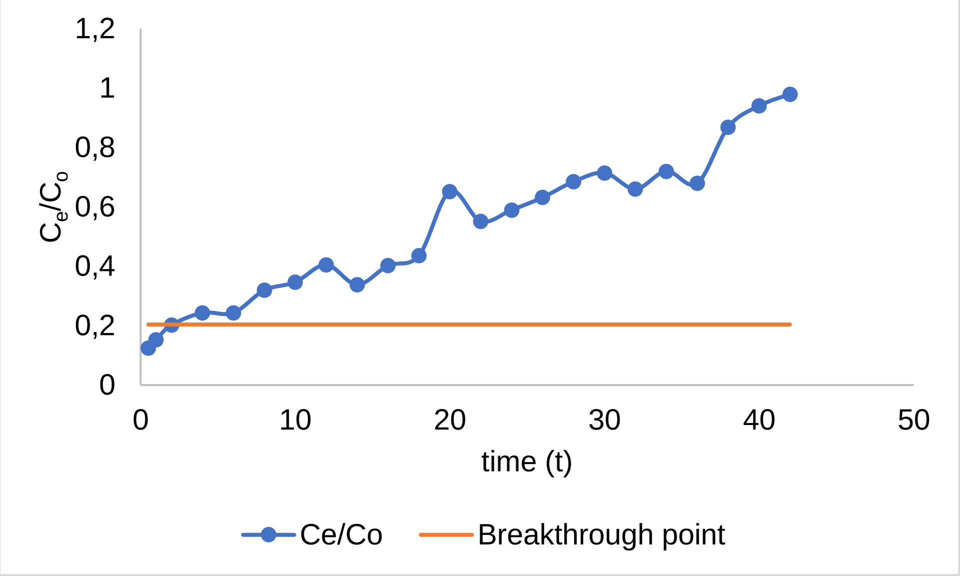

Figure 5.37: Breakthrough curve for groundwater water

Table 5.19: Physicochemical parameters of groundwater at a breakthrough point

Parameters	Before treatment	Breakthrough point	WHO/SANS
pH	7,83	7,48	5 – 9,7
TDS (mg/L)	1014	963	1200
EC (uS/cm)	2068	1176	170
F- (mg/L)	7.36	1.49	1.5
Al (ug/L)	BDL	20,3	100
Fe (ug/L)	BDL	8,5	100
Ca (mg/L)	83,4	68,5	150
Mg (mg/L)	37,5	36,4	70
Na (mg/L)	301,9	298,4	200
CL (mg/L)	85,6	144,22	300
NO3 (mg/L)	7	14,43	50
SO4 (mg/L)	30,2	262,8	500

5.3.9. Comparison of Al/Fe oxide modified DE adsorption capacity with other adsorbents

In order to evaluate how competitive Al/Fe oxide DE prepared is, - the adsorption capacity achieved in this study was compared with the capacities of different adsorbents reported in the literature. Comparison of Al/Fe oxide modified DE with other adsorbents is shown in Table 5.10. The Maximum adsorption capacity obtained from this study was compared with other adsorbents in literature. The results shows that Al/Fe modified DE synthesised in this study is competitive over other adsorbent that have been reported in the literature and has a potential in removing fluoride

Table 5.20: Comparison of adoption capacity of different adsorbents for defluoridation

Adsorbent	Experimental conditions	Adsorption capacity (Qe) (mg/g)	Reference

Bio-F sorbent	Initial concentration = 30 mg/L Bed weight = 10 g pH = 6.7	9.87	(Yadav et al., 2015)
Coconut husk activated carbon	Initial concentration = 10 mg/L Adsorbent dose = 1.4 g/L pH = 6.7	1.3	(Talat et al., 2018)
M-I-HAPa	Initial concentration = 12.6 mg/L Bed mass = 3 kg pH = 8.05	1.09	(Mondal et al., 2018)
Quaternized palm kernel shell	Initial concentration 6 mg/L Bed heigh = 6 cm pH = 3	0.99	(Abu Bakar et al., 2019)
Al/Fe oxide modified DE	Initial concentration = 7.4 Bed weight = 30 g pH = 7.8	0.67	Present study

5.4. Summary

In this chapter, the main purpose was to taste the 2 backet water treatment system at a lab scale for household defluoridation. Breakthrough studies showed an increase in breakthrough points (6-12 hours) with increasing bed weight (15- 40 g). For initial fluoride concentration variation, breakthrough point decreases with an increase in fluoride. The AER results showed that the water defluoridation system performs better at higher bed mass and lower concentration. As observed, in-field water testing studies, the breakthrough point was reached after treating 1.68 L in 2 hours. The physicochemical parameters were within the WHO and SANS241 drinking water guidelines except for EC and Na^+. The adsorbent capacity at the breakthrough point was 0.33 after treating 1.68 L of 7 mg/L fluorides concentrated groundwater in 2 hours. Over and above, the results obtained from this objective showed that the Al/Fe oxide modified DE can be used for defluoridation in a rural-based household. The results also revealed leaching of Al and Fe oxides which calls for future intervention. It is recommended that further studies are done to minimise leaching of the oxide and taste the water treatment system at a household level.

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CHAPTER 6: Conclusions and Recommendations

The first objective aimed to evaluate the quality of groundwater and hydrogeochemical processes controlling groundwater quality in Lephalale Local Municipality and to determine the suitability of the water for drinking and irrigation purposes results revealed that most of the samples are within the permissible range for the WHO (2017) and SANS 241, (2014) water guidelines. However, F^- exceeded 1.5 mg/L approved WHO (2017) and SANS241 (2014) standard for drinking water in 36% of the groundwater samples and the maximum concentration of 7.4 mg/L was observed in Mmatladi village. The dominance of major ions in the area is $Na^+>Ca^{2+}>Mg^{2+}>K^+$ cations and $HCO_3^->Cl^->NO_3^->SO_4^{2-}>F^-$ anions. This study demonstrates the presence of feacal coliform and total coliform in groundwater supplied to the municipality. Classical hydro-chemical methods showed the existence of four hydrogeochemical facies/water types in the area, 60% CaMgCl water type, 16% CaCl water, 12% NaCl water, and 12% CaHCO3 water type. Gibb's plot indicated rock-water interaction as the main process controlling groundwater chemistry in the area. According to the irrigation indexes Na%, SAR, PI, KR, and MAR, approximately 87%, 83%, 67%, 58%, and 87% of groundwater sources were suitable for irrigation in the Lephalale, respectively. Moreover, salinity hazard showed that all samples fell under the C3S1 class and were classified as not suitable for irrigation.

Recommendations:

- Continuous monitoring of boreholes in Lephalale municipality
- Proper adaptation strategies must be taken to control the salt content in the water and to prevent the accumulation of salt by both soil and plants.

The second objective aimed to assess the perspectives of the community member of Mmatladi Village within Lephalale Municipality regarding the water quality and supply. Lephalale local municipality intervened and initiated a water supply strategy by installing boreholes in their villages for community use. The water supply by the municipality was said to be cut for up to a month (19%), leading people to find alternative ways such as buying (51%), asking from neighbors (25%) with private boreholes, and accessing water from unreliable sources such rivers (11%). About 28% of the households have people suffering from fluorosis, 6% and 2% members who have suffered from diarrhea and cholera. The exposure to such diseases was not surprising since 79% of the respondents said that they do not treat water before use. There was a huge knowledge gap among the respondents whereby 78%, 84%, 87% and 74% indicated that they do not know anything about water quality, groundwater contamination, fluoride in groundwater and groundwater contamination, respectively.

Recommendations:

- Initiation of campaigns to raise awareness and educate household members about water quality and quantity.
- A well-detailed study on evaluating the number of people with fluorosis per age, and the amount of money spent to buy water for basic household use.

The third objective focused on assessing the performance of Al/Fe oxide modified Diatomaceous Earth-based water treatment system for household use. The results from XRF showed an increase in the Al_2O_3 and Fe_2O_3 element composition from 0.5 to 6.4% and from 0.05 to 5.0%, respectively. EDS results revealed the presence of Al, Fe, and Na on the surface of the adsorbent which proves that indeed modification was a success. The BET results indicated an increase in pore volume (0.000287-0.01319 cm^3/g), pore diameter (36.69 - 47.3 nm), and surface area (0.71 – 31.99 m^2/g) which indicates high water permeability. Breakthrough studies showed an increase in breakthrough points with increasing bed weight. The performance indicator computations showed that the water system is more effective at high bet weight and lower concentrations In-field water testing studies, the breakthrough point was reached after treating 1.68 L in 2 hours. The physicochemical parameters were within the WHO and SANS241 drinking water guidelines except for EC and Na^+. The results also revealed leaching of Al/Fe ions which calls for future intervention. The adsorbent capacity at the breakthrough point was 0.33 after treating 1.68 L of 7 mg/L fluorides concentrated groundwater in 2 hours. Over and above, the results obtained from this objective showed that the Al/Fe oxide modified DE has the potential to be used as a defluoridation technique in a rural-based household.

Recommendations:

- Enhancement of the Al/Fe adsorbent used in the treatment system to minimise leaching of elements and increase adsorption capacity.

- Distributing and monitoring of the water treatment system in rural area households.

Chapter 7: Appendices

Appendix A: Standard questionnaire

Topic: **Comprehensive Assessment of Groundwater Quality and Community's Experiences in relation to water challenges In Lephalale Municipality, Waterberg District, Limpopo province in South Africa**

SECTION A: DEMOGRAPHIC FACTORS

INSTRUCTION: Please tick and write where necessary

1. Age:

<13 years		20 – 35 years		50 – 60 years	
13 – 19 years		36 – 50 years		>60 years	

2. Gender	Male		Female	

4. Educational level

No formal education		Secondary education	
Primary education		Tertiary education	

5. Marital status

Married		Divorced		Widowed	
Single		Other (specify)			

6. Occupation

Unemployed		Self-employed	
Employed		Others (specify)	

8. Number of people living in your household ………….

9. For how long have you been living in this area?

Less than 5 years		6-10 years		16-25 years	

5 years		11-15 years		More than 25 years	

10. Household income

<500		500-1000		1000-2000		>2000	

11. Source of income……………………………………………………………………

12. Health conditions

Excellent		Good		Poor	

13. Have you/any members of the family ever suffered from	Yes	No
Cholera		
Diarrhoea		
Fluorosis		
Others (specify)		

SECTION B:

INSTRUCTION: Please read the following statements and tick one response that best describe your opinion.

1. What water do you use for domestic use?

Surface water		Groundwater		Tap water	

2. Estimated water volume you use per day

<100 l		100 l -200 l		200 l -300 l		>300 l	

3.	**yes**	**No**
Are you aware of the water quality you use in your household?		
Do you know anything about groundwater contamination?		
Are you aware of the level of fluoride in drinking water		
Do you know the effect of contaminants in groundwater?		

Do you filter/treat water before consumption?		
Are you willing to have an intervention on water treatment?		
Are you willing to participate by using the water treatment module?		

4. How long does it take you to retrieve water for your home?

   ……………………………………………………………………………………………

5. Does your water supply continuous or interrupted?	Yes		No	

If yes, for how long……………………………………………………………………

6. During the interruptions, where do you often get water?

   ………………………………………………………………………………………

7. Do you treat your water in any way to make it safe for drinking?	Yes		No	

If yes, which method do you use? ………………………………………………………

8. How would you describe your drinking water?	Good		Poor	
1. Have you ever noticed any kind of taste /odour in drinking water supply?	Yes		No	

Any comments/suggestions?

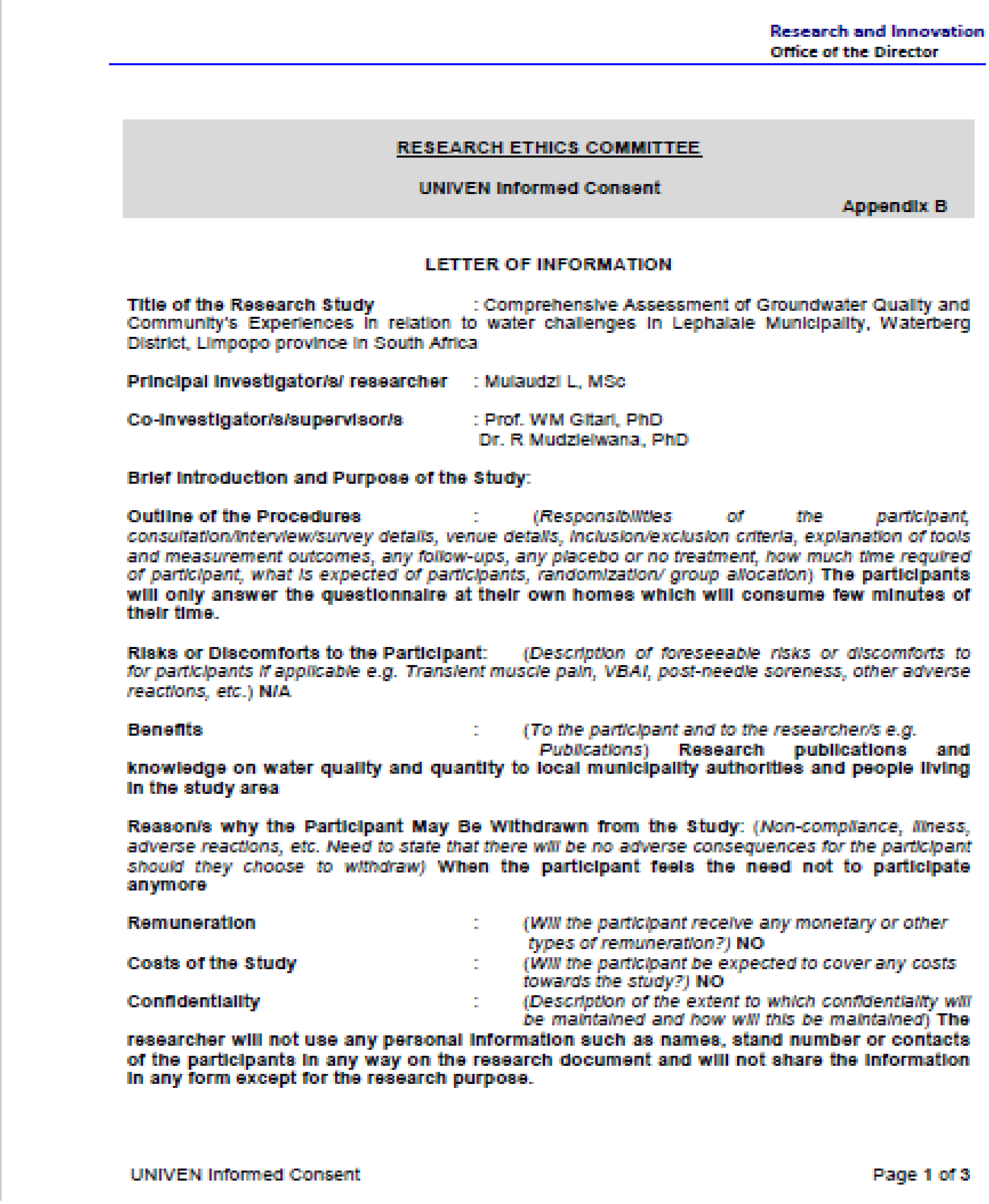
……

……

……

……………………………………………………………………………………

Appendix B: Consent form



Research and Innovation
Office of the Director

RESEARCH ETHICS COMMITTEE

UNIVEN Informed Consent

Appendix B

LETTER OF INFORMATION

Title of the Research Study : Comprehensive Assessment of Groundwater Quality and Community's Experiences in relation to water challenges in Lephalale Municipality, Waterberg District, Limpopo province in South Africa

Principal Investigator/s/ researcher : Mulaudzi L, MSc

Co-Investigator/s/supervisor/s : Prof. WM Gitari, PhD
Dr. R Mudzielwana, PhD

Brief Introduction and Purpose of the Study:

Outline of the Procedures : *(Responsibilities of the participant, consultation/interview/survey details, venue details, inclusion/exclusion criteria, explanation of tools and measurement outcomes, any follow-ups, any placebo or no treatment, how much time required of participant, what is expected of participants, randomization/ group allocation)* **The participants will only answer the questionnaire at their own homes which will consume few minutes of their time.**

Risks or Discomforts to the Participant: *(Description of foreseeable risks or discomforts to for participants if applicable e.g. Transient muscle pain, VBAI, post-needle soreness, other adverse reactions, etc.)* **N/A**

Benefits : *(To the participant and to the researcher/s e.g. Publications)* **Research publications and knowledge on water quality and quantity to local municipality authorities and people living in the study area**

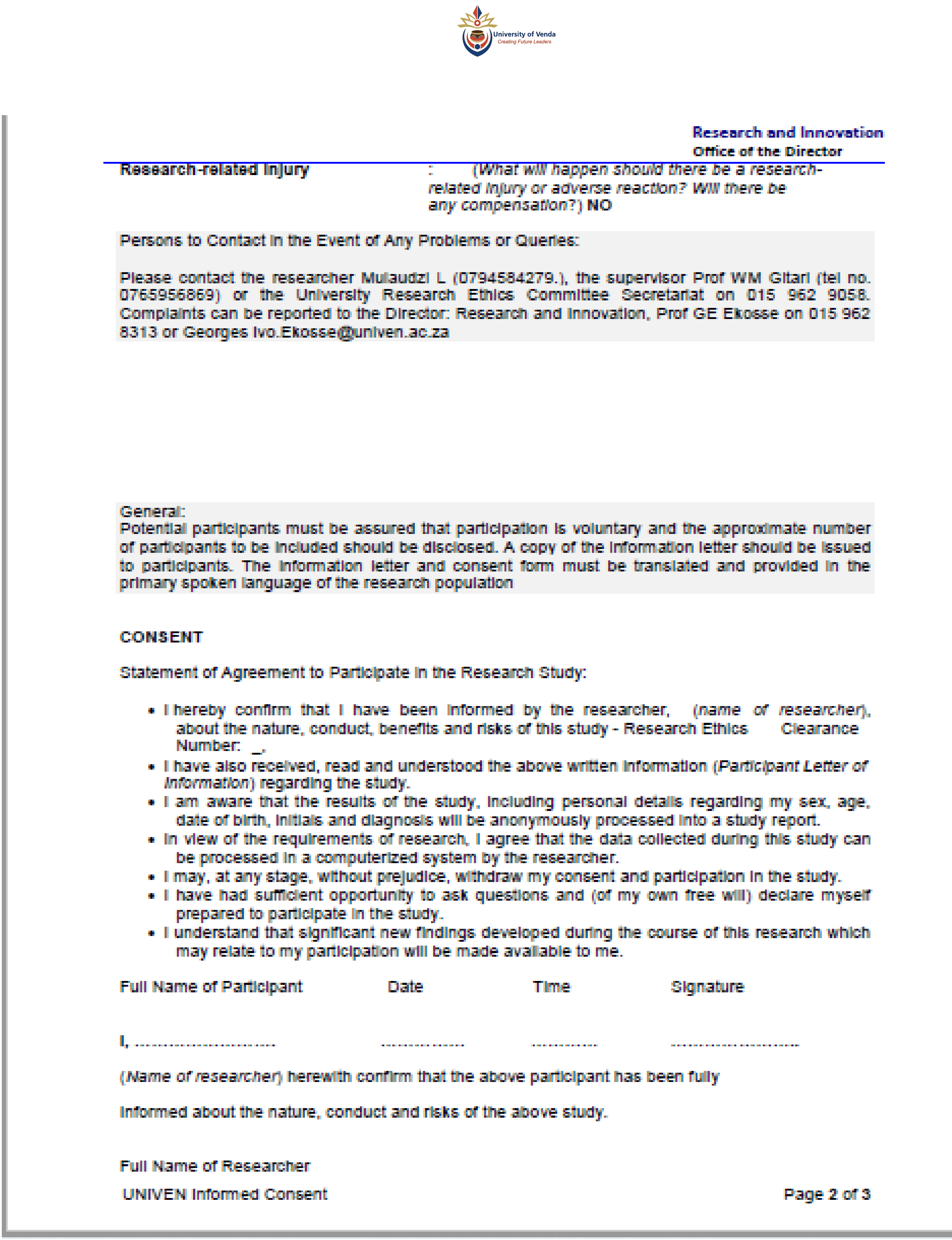
Reason/s why the Participant May Be Withdrawn from the Study: *(Non-compliance, illness, adverse reactions, etc. Need to state that there will be no adverse consequences for the participant should they choose to withdraw)* **When the participant feels the need not to participate anymore**

Remuneration : *(Will the participant receive any monetary or other types of remuneration?)* **NO**

Costs of the Study : *(Will the participant be expected to cover any costs towards the study?)* **NO**

Confidentiality : *(Description of the extent to which confidentiality will be maintained and how will this be maintained)* **The researcher will not use any personal information such as names, stand number or contacts of the participants in any way on the research document and will not share the information in any form except for the research purpose.**

UNIVEN Informed Consent Page 1 of 3



Research-related injury : (*What will happen should there be a research-related injury or adverse reaction? Will there be any compensation?*) **NO**

Persons to Contact in the Event of Any Problems or Queries:

Please contact the researcher Mulaudzi L (0794584279.), the supervisor Prof WM Gitari (tel no. 0765956869) or the University Research Ethics Committee Secretariat on 015 962 9058. Complaints can be reported to the Director: Research and Innovation, Prof GE Ekosse on 015 962 8313 or Georges Ivo.Ekosse@univen.ac.za

General:
Potential participants must be assured that participation is voluntary and the approximate number of participants to be included should be disclosed. A copy of the information letter should be issued to participants. The information letter and consent form must be translated and provided in the primary spoken language of the research population

CONSENT

Statement of Agreement to Participate in the Research Study:

- I hereby confirm that I have been informed by the researcher, (*name of researcher*), about the nature, conduct, benefits and risks of this study - Research Ethics Clearance Number: _,
- I have also received, read and understood the above written information (*Participant Letter of Information*) regarding the study.
- I am aware that the results of the study, including personal details regarding my sex, age, date of birth, initials and diagnosis will be anonymously processed into a study report.
- In view of the requirements of research, I agree that the data collected during this study can be processed in a computerized system by the researcher.
- I may, at any stage, without prejudice, withdraw my consent and participation in the study.
- I have had sufficient opportunity to ask questions and (of my own free will) declare myself prepared to participate in the study.
- I understand that significant new findings developed during the course of this research which may relate to my participation will be made available to me.

Full Name of Participant	Date	Time	Signature
I, ...	....	....	....

(*Name of researcher*) herewith confirm that the above participant has been fully

informed about the nature, conduct and risks of the above study.

Full Name of Researcher

Mulaudzi L **31/05/2021**
……………………… Date………………… Signature……………………

Full Name of Witness (If applicable)

……………………… Date ………………… Signature……………………

Full Name of Legal Guardian (If applicable)

…………………… Date……………… Signature……………………

Please note the following:

Research details must be provided in a clear, simple and culturally appropriate manner and prospective participants should be helped to arrive at an informed decision by use of appropriate language (grade 10 level- use Flesch Reading Ease Scores on Microsoft Word), selecting of a non-threatening environment for interaction and the availability of peer counseling (Department of Health, 2004)

If the potential participant is unable to read/illiterate, then a right thumb print is required and an impartial witness, who is literate and knows the participant e.g. parent, sibling, friend, pastor, etc. should verify in writing, duly signed that informed verbal consent was obtained (Department of Health, 2004).

If anyone makes a mistake completing this document e.g. a wrong date or spelling mistake, a new document has to be completed. The incomplete original document has to be kept in the participant's file and not thrown away, and copies thereof must be issued to the participant.

References:

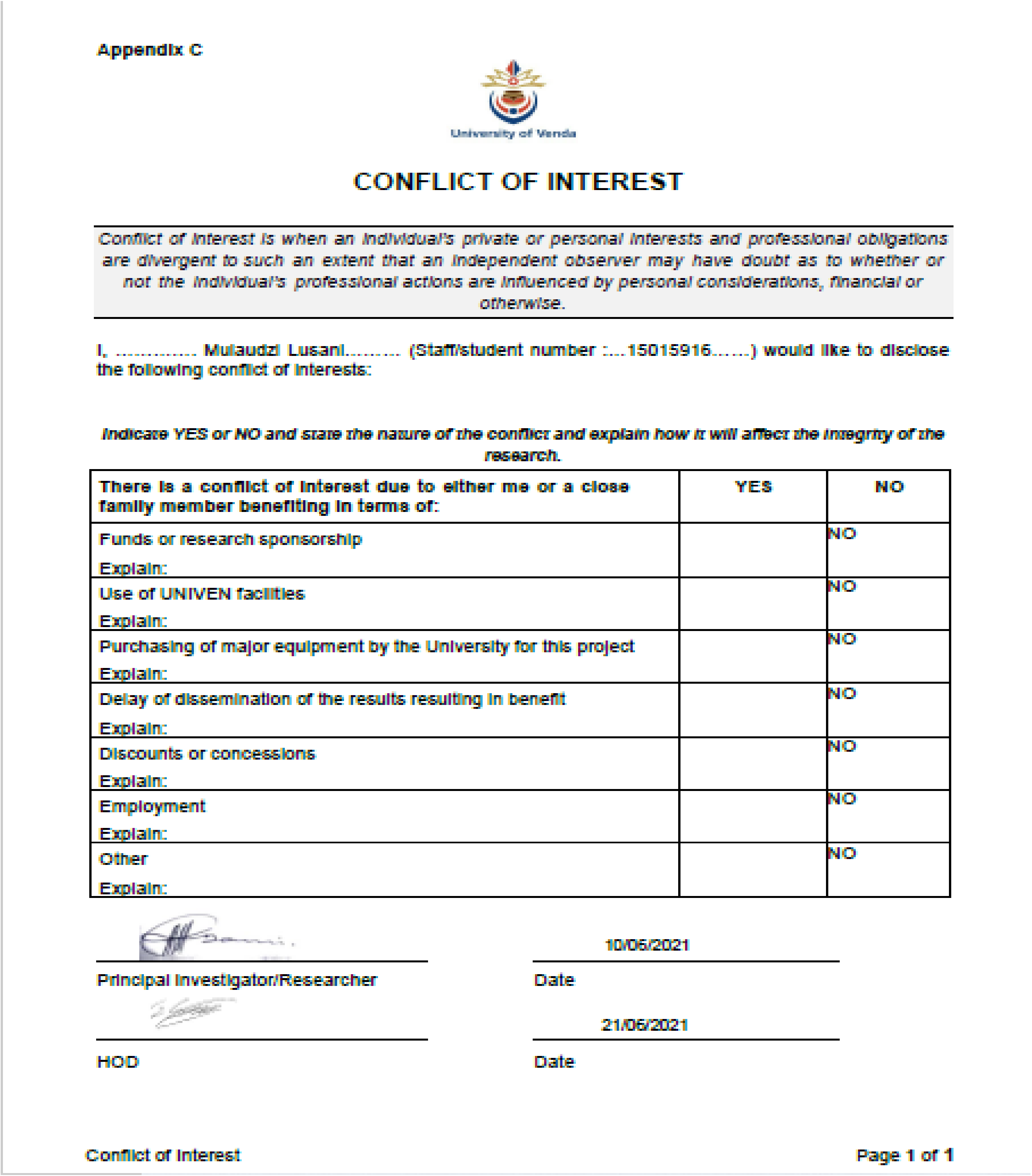
Department of Health: 2004. *Ethics in Health Research: Principles, Structures and Processes*

http://www.doh.gov.za/docs/factsheets/guidelines/ethnics/

Department of Health. 2006. *South African Good Clinical Practice Guidelines*. 2nd Ed. Available at:

http://www.nhrec.org.za/?page_id=14

Appendix C: Conflict of Interest



Appendix C

University of Venda

CONFLICT OF INTEREST

Conflict of interest is when an individual's private or personal interests and professional obligations are divergent to such an extent that an independent observer may have doubt as to whether or not the individual's professional actions are influenced by personal considerations, financial or otherwise.

I, ………… Mulaudzi Lusani……… (Staff/student number :…15015916……) would like to disclose the following conflict of interests:

Indicate YES or NO and state the nature of the conflict and explain how it will affect the integrity of the research.

There is a conflict of interest due to either me or a close family member benefiting in terms of:	**YES**	**NO**
Funds or research sponsorship Explain:		NO
Use of UNIVEN facilities Explain:		NO
Purchasing of major equipment by the University for this project Explain:		NO
Delay of dissemination of the results resulting in benefit Explain:		NO
Discounts or concessions Explain:		NO
Employment Explain:		NO
Other Explain:		NO

Principal Investigator/Researcher

Date 10/06/2021

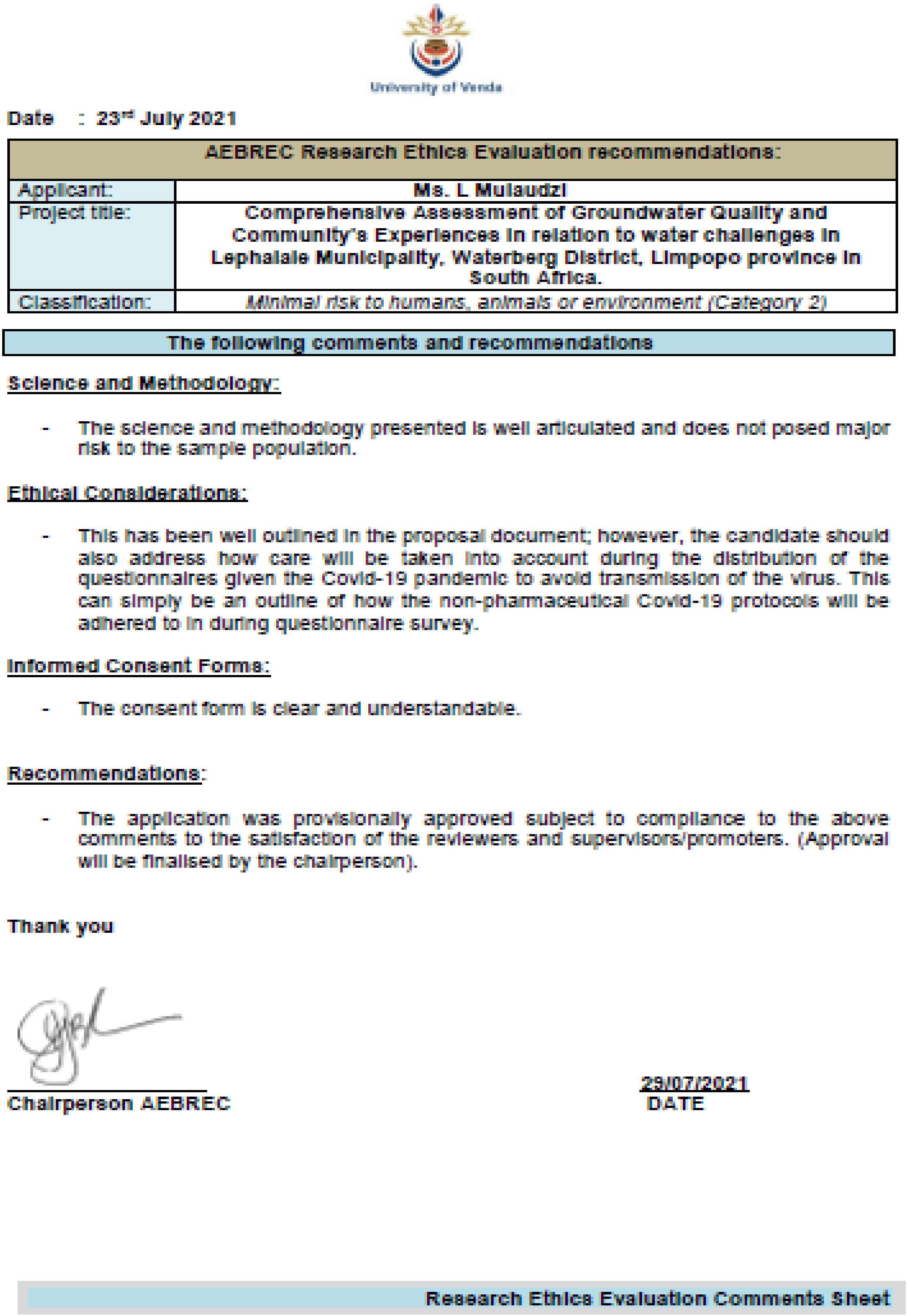
HOD

Date 21/06/2021

Conflict of Interest

Page 1 of 1

Appendix D: Ethical clearance



University of Venda

Date : 23rd July 2021

AEBREC Research Ethics Evaluation recommendations:	
Applicant:	**Ms. L Mulaudzi**
Project title:	**Comprehensive Assessment of Groundwater Quality and Community's Experiences in relation to water challenges in Lephalale Municipality, Waterberg District, Limpopo province in South Africa.**
Classification:	*Minimal risk to humans, animals or environment (Category 2)*

The following comments and recommendations

Science and Methodology:

- The science and methodology presented is well articulated and does not posed major risk to the sample population.

Ethical Considerations:

- This has been well outlined in the proposal document; however, the candidate should also address how care will be taken into account during the distribution of the questionnaires given the Covid-19 pandemic to avoid transmission of the virus. This can simply be an outline of how the non-pharmaceutical Covid-19 protocols will be adhered to in during questionnaire survey.

Informed Consent Forms:

- The consent form is clear and understandable.

Recommendations:

- The application was provisionally approved subject to compliance to the above comments to the satisfaction of the reviewers and supervisors/promoters. (Approval will be finalised by the chairperson).

Thank you

Chairperson AEBREC

29/07/2021
DATE

Research Ethics Evaluation Comments Sheet

Appendix E: Lephalale groundwater mean table

Village name:	pH	EC	TDS	Teperatu	Alkalinity	HCO3	CL	NO3	SO4	F	Na	Ca	Mg	K	Si	B	Al	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Sr	Mo	Cd	Ba	Pb
		us/cm	mg/L	°C	mg/L		mg/L	mg/L	mg/L	mg/L	mg/l	mg/l	mg/l	mg/l	mg/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l
Steve Biko Phase 1	7	1 498	897	27	118	144	87	44	28	4	121	69	33	2	25	0	-	0		0	-	0	0		0	0	0	0	0.0	0.0	0.0	-
Steve Biko Phase 2	7	1 680	1 007	27	82	100	71	52	35	4	108	53	26	4	31	0	-	0	0	0	-	0	0	0	0	0	0	0	0.0		0.0	0.0
Seleka Ward 2a	8	751	432	28	159	194	30	76	31	1	86	72	46	4	36	67	1	9	1	3	1	0	0	2	5	0	1	309	1.9	0.0	152.7	0.0
Seleka Ward 2b	8	1 057	570	28	182	222	109	172	52	1	165	98	69	9	40	156	2	14	1	4	2	0	0	6	61	0	2	335	3.3	0.0	79.5	2.0
Seleka Ward 1a	8	655	339	28	146	178	40	40	32	1	82	40	25	8	43	116	4	14	1	1	2	0	1	4	4	0	1	147	2.2	0.4	27.4	0.1
Seleka Ward 1b	8	1 106	585	27	174	212	76	59	46	1	104	79	56	9	39	82	5	10	0	1	2	0	0	3	50	0	1	212	0.8	0.2	65.4	0.1
Seleka ward 1c	7	1 527	749	33	207	253	111	170	65	1	106	100	74	8	47	185	-	22	1	2	-	0	-	1	6	0	3	495	2.7	0.0	101.7	-
Kauletsa 2	8	1 061	568	26	89	109	97	107	99	2	132	83	71	11	46	122	-	14	0	-	-	0	0	-	2	0	1	286	1.4	0.0	90.8	-
Kauletsa 1	7	1 357	706	28	301	368	95	64	54	2	160	86	73	11	48	312	2	29	1	5	1	0	0	12	18	2	2	687	3.0	0.0	203.3	0.1
Tshelammake 1	7	1 937	1 036	27	252	307	196	11	50	1	205	131	108	10	37	370	2	22	0	2	1	0	0	2	172	1	2	796	3.2	0.0	130.9	0.1
Tshelammake 2	8	1 968	1 004	27	182	222	224	69	97	1	172	151	115	12	36	237	0	12	0	1	2	0	0	5	16	0	1	540	1.9	0.0	86.6	0.1
Letlora 1	8	1 901	974	27	151	184	260	73	82	0	144	172	116	7	25	224	0	7	0	5	3	1	5	11	2	0	2	610	0.4	0.0	85.6	0.0
Letlora 2	7	1 770	995	27	159	194	188	9	45	0	106	214	120	3	20	137	1	5	0	58	6	0	0	4	36	1	3	1 122	0.2	0.1	325.7	0.2
Mmaletswai 1	8	1 383	710	28	194	237	138	135	58	2	151	80	88	10	48	142	1	39	1	1	8	0	0	3	6	1	1	564	0.8	0.1	48.4	0.1
Mmaletswai 2	8	1 692	866	28	185	225	156	169	75	2	175	97	113	11	49	162	23	48	0	2	5	0	1	2	94	1	2	842	1.2	0.1	69.1	0.0
Ditloung 1	7	1 141	589	27	253	309	85	90	60	1	77	111	84	5	48	94	3	17	1	1	4	0	0	2	21	1	1	623	0.4	0.0	33.7	0.1
Tshehlong	8	1 096	564	27	136	166	122	86	69	1	141	71	45	2	38	124	1	37	-	1	0	0	0	2	4	5	0	404	0.6	0.0	24.9	0.0
Matladi	8	1 768	903	30	187	229	165	143	74	7	331	76	36	0	33	256	0	6	-	20	1	0	0	1	2	0	2	246	4.1	0.0	9.7	0.0
Witpoort 1	8	1 019	551	26	108	132	107	9	41	1	123	60	40	6	29	147	0	18	0	1	1	0	1	2	27	1	1	282	0.9	0.0	94.7	0.1
Witpoort 2	7	815	443	25	108	132	127	6	50	1	86	42	29	5	23	104	37	19	0	11	96	0	1	82	190	1	1	232	0.9	0.3	66.0	0.2
Lerupurupung	7	702	396	28	101	123	90	12	47	2	159	47	33	6	25	189	34	18	1	552	13	0	1	3	11	1	1	144	8.2	0.1	19.0	0.1
Monyeki	8	1 069	572	29	308	375	44	114	44	1	130	80	69	2	45	251	1	8	1	1	1	0	0	3	5	1	2	427	1.9	0.0	26.2	0.0
Thabo Mbeki	8	1 149	607	28	194	237	87	109	63	1	103	77	58	5	43	148	13	31	1	27	9	0	1	2	17	2	1	525	0.9	0.0	62.8	0.0
Mokoruanyane	7	1 268	622	28	222	271	112	74	54	1	61	90	75	5	45	89	0	17	0	0	1	0	0	1	80	1	1	375	0.3	0.0	31.8	0.0
Shongwane	8	1 358	666	28	94	115	181	77	74	5	185	57	25	3	14	240	-	0	-	4	-	0	-	-	-	0	0	365	6.8	-	12.1	-
Min	7	655	339	25	82	100	30	6	28	0	61	40	25	0	14	0	-	0	-	-	-	0	-	-	-	0	0	0	0.0	-	0.0	-
Max	8	1 968	1 036	33	308	375	260	172	99	7	331	214	120	12	49	370	37	48	1	552	96	1	5	82	190	5	3	1 122	8.2	0.4	325.7	2.0
Average	8	1 309	694	28	172	209	120	79	57	2	137	89	65	6	37	158	5	17	0	28	6	0	1	6	33	1	1	423	1.9	0.1	73.9	0.1
WHO/SANS	5-9,7	1 500	1 200		200	500	250	45	250	2	200	150	70	50		2 400	100	200	50	50	100	500	70	2 000	5 000	10	40				700	10.0