

Assessment of nitrate pollution in groundwater (Chaneng Village, Rustenburg)

SN Ntshangase

 **orcid.org 0000-0002-2335-3613**

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Supervisor: Dr SR Dennis

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ABSTRACT

Groundwater plays a vital role in the water provision for the areas that are so remote in such a way that rendering municipal services (piped water) proves to be cumbersome. While deemed so essential, it is also prone to contamination as a result of human activities. The assessment was done to establish the level of nitrate pollution in groundwater but not excluding the other chemical parameters that define the chemistry of water and give its fitness or unfitness for use. The assessment was undertaken within the Chaneng Village in the North West in the Crocodile West and Marico Water Management Area. A first set of five boreholes grouped as TBHs (TBH01, TBH02, TBH03, TBH04 & TBH05) were identified but TBH05 was found dry and could not be sampled for analysis. These boreholes were sampled in July 2018. Another set of boreholes also used for this assessment are a group of boreholes referred to as CBHs (CBH01, CBH02, CBH03, CBH04, CBH05) and were also used to provide water quality data for this current exercise. These sets of boreholes were identified for the pollution investigation ad hoc sampling exercise that was undertaken in 2010 to be used to compare the trend of water quality in a study area.

Parameters that were analysed are Temperature (in situ), pH (in situ) & EC (in situ), Ca (mg/l), Mg (mg/l), Na (mg/l), K (mg/l), Cl (mg/l), NO₃-N (mg/l), PO₄ (mg/l), Total Hardness, TOTALK (HCO₃) (mg/l), SO₃, TDS, e-coli and total coliform

Mixed results were observed considering the fact that there are a number of water quality standards, objectives and guidelines that are to be considered in South Africa for intrinsic use of water.

Key terms: groundwater quality, pollution, nitrate, health impacts

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CHAPTER 1: INTRODUCTION

1.1 Background

Nitrate is rated as a major contaminant of groundwater world-wide (Muhammetoglu & Yardimci, 2006; Akwensioge, 2012). However, more than 90 % of the rural population in the United States uses groundwater for drinking purposes (U.S. EPA, 2007). According to the Department of Water Affairs and Forestry, (2003), on its *groundwater protocol*, groundwater constitutes a major proportion of all the fresh water that is available for human use. Graham and Polizzotto (2013) estimate that more than 2 billion people worldwide depend on groundwater for their primary drinking water supply. Communities in arid areas such as the Kingdom of Saudi Arabia (Alabdula'aly *et al.*, 2010); Gaza Strip (Shomar, 2011); Botswana (Vogel *et al.*, 2004) and in India (Reddy *et al.*, 2009) entirely depend on it and it is equally prone to contamination, which renders it unfit for use (Alabdula'aly *et al.*, 2010; Obeidat *et al.*, 2007; Reddy *et al.*, 2009; Shomar, 2011; Walmsley & Walmsley, 2002), not only for human consumption but also for the survival of the groundwater ecology and all other intended use of water. It has been found that there are micro-invertebrates habiting the underground aquifers (Water Wheel, 2005). Such organisms are more sensitive to pollution and over-utilization of aquifers than human and livestock (Water Wheel, 2005). Groundwater supplies more than 65% of the rural household in South Africa (Woodford *et al.*, 2009. cited in Akwensioge, 2012).

Groundwater in the North West Province is the immediate alternative source of water supply as a result of inadequate surface water resources, which according to DWAF (2004) on their Internal Strategic Perspective (ISP), surface water resources are fully allocated making it difficult to meet future water demands. Therefore developing groundwater resources becomes crucial (Walmsley & Walmsley, 2002). The fast growing development in the Towns of Rustenburg and surrounding towns make such resources prone to nitrate pollution as a result of mining, industrial activities, agriculture and domestic use (on site sanitation) (Walmsley & Walmsley, 2002). The fact that nitrate is used to manufacture substances that support livelihood, e.g., organic fertilizers; oxidizing agent in the production of explosives (Agency for Toxic Substances and Disease Registry (ATSDR), n.d.; WHO, 2011), glass manufacturing in the form of the potassium nitrate (WHO, 2011), makes it difficult to eliminate. Nitrate is a

component of ammonium nitrate (NH_4NO_3), which is approximately 90% of commonly used commercial explosives by weight (Degnan *et al.*, 2015). Artificial recharge using waste water to the underlying aquifers, also affects groundwater contamination (Seanago & Moyo, 2013).

Although the study undertaken by Maherry *et al.* (2010), in South Africa does not identify North West as a priority area for research and remediation when it comes to nitrate pollution, but others, such as Bezuidenhout (2011), and Tredoux *et al.* (2009) suggest that more than 50% of groundwater assessed in North West exceed the allowable limits of 6mg/l of nitrate set by DWAF (1996). Demonstrated by Kalule-Sabiti and Heath (cited in Bezuidenhout, 2011), is that several areas in the North West Province have been labelled as environmental pollution “hot spots”, which included high nitrate levels in groundwater.

While regarded as an important element of life (Reddy *et al.*, 2009), nitrogen in the form of nitrate is a concern to groundwater resources due to its implications associated with health in humans (Methemoglobinemia in infants) and also in animals (Tredoux, 2004). Methemoglobinemia is the interference of nitrate with red blood cells making it difficult for the cells to transport oxygen through the body, particularly of infants WRIG (WHITLEY River Improvement Group, n.d.).

Many countries have experienced life losses as a result of poor water quality (Shomar, 2011). Obi and George (2011), indicated that according to United Nations (UN) more than 5 million people die annually due to a lack of safe drinking water. In many developing countries, ill-health is due to poor water and sanitation (Shomar, 2011). Indicated by WHO and UNICEF (2010), is that an estimated 2.6 billion people lack access to improved sanitation. Bezuidenhout (2011) identified human health concerns in the North West Province and validated the fact that in some areas in the North West there are high levels of nitrates ($> 20\text{mg/l}$).

Due to the perception that being the underground resource, groundwater is a reliable, safe source of water supply, the Department of Water and Sanitation (DWS, 2013), groundwater contamination remained unchecked for decades. This was also owing to the fact that soil is a sink for waste without thorough consideration of the geological formations (Miller, 1998; Bosman, 2009, Xue *et al.*, 2012; Albertin *et al.*, 2011; Obeidat *et al.*, 2007; DWAF, 2003), which varied from one area to the next (Musekiwa &

Majola., 2011; Bosman, 2009), and the entire physical environment such as climate, rainfall, soil type, depth of groundwater table, soil texture, land uses (Boumans *et al.*, 2008) as well the chemical reactions that affect processes and pathways on nitrogen cycle (Chatterjee *et al.*, 2009).

Awareness on the dangers of nitrate contaminated groundwater prompted testing for nitrate concentration (Walton, 1951) along with other contaminants such as TDS, sodium, chloride, calcium, phosphates, sulphates and total coliforms (Bosman, 2009). Wells continued receiving and retaining contamination until the outbreak of associated health issues (Haller *et al.*, n.d.). Methemoglobinemia, primarily in the rural United States, served as the catalyst for what has grown into a broad awareness and concern for nitrate contamination (Haller, *et al.*, no date), on elderly people, pregnant women, nursing mothers (Vogel *et al.*, 2004). In other cases high nitrate levels are linked to serious health conditions that can cause brain damage or death (WRIG: Whitley River Improvement Group, n.d.), instant abortion as well as livestock losses (Tredoux *et al.*, 2009).

Most of the methemoglobinemia mortalities in the USA and Europe were due to local (private) drinking water supplies that got contaminated due to inadequate on-site sanitation systems such as septic tanks and pit latrines (Walton, 1951; O'Riordan & Bentham, 1993 cited by Tredoux & Talma, 2006).

In Europe, land application of surplus nitrogenous wastes from intensive animal husbandry and dairy farms gained attention (Walton, 1951) after the realization that unlike other nutrients, nitrate cannot be adsorbed by the soil (Kreidler, 1975) or form chelates with organic particles but can easily leach to underlying aquifers (Addiscott, 2005; Obeidat *et al.*, 2007).

Nitrate pollution of groundwater from sanitation systems had also been under-estimated in many of the policies and strategies relating to basic services (water supply and dignified sanitation) and to water quality management in South Africa. The reasons for this are varied, ranging from a historical focus on surface water in South Africa (where nitrate was regarded as aesthetical and environmental problem rather than a potability concern leading to South African Government prioritizing the provision of on-site sanitation to the historically disadvantage communities (Tredoux, 2004) without considering the impacts associated with it. Mushrooming of informal settlements near

big cities also added to the diminishing resources to provide good quality water and dignified sanitation, thus severe pressure was induced to the insufficiently designed sanitation structures (Walmsley & Walmsley, 2002), which leads to groundwater contamination.

Aggravating the situation in South Africa is the fact that in most cases, onsite sanitation and use of boreholes are provided on privately owned households making the intervention of authorities who have powers to regulate water resources more difficult. Often groundwater quality monitoring does not include private households as a result levels of contamination remains unknown (Tredoux, 2004). In addition, platinum related mining activities, which dominate North West Province, do not form part of the national sources of contaminants priority list published by Usher *et al.*, (2004). The report discusses nitrate sources in urban areas, which made the impact of the mining industry receive less attention, probably because mining is normally outside the urban area. Nevertheless, investigation by Bosman (2009) proves that open pit mines in Limpopo pose a risk in terms of groundwater pollution by nitrates emanating from the waste water storage facilities of the mine and from blasting.

Rail (cited by Haller *et al.*, n.d.) mentioned that it took almost 15 years in the agricultural sector to discover that addition of nitrogen containing fertilizers could reach a point where its addition wouldn't improve yield but instead result in groundwater contamination and as a result practices in a sector were to be changed (Reinert & Hroncich, 1990).

It is such an extensive awareness that prompted the promulgation of Regulations on the disposal of waste on landfill (the Department of Environmental Affairs 2013), to prevent further contamination of groundwater and environment due to leachate from waste disposal sites. These Regulations followed the minimum requirements for the disposal of general waste which over the years were proven to be inadequate as the pollution of groundwater resources continued irrespective of the existence and the attempt to enforce compliance with the minimum requirements promulgated by DWAF (1998a).

Regulations on use of water for mining and related activities were promulgated to prevent impact on water resources as a result of mining. Measures that were included relate to lining of waste water and waste disposal impoundments (DWAF, 1999) and many others. These Regulations on waste and mining water management came

after pollution impacts had already occurred on the underground aquifers. Industries that existed before Regulations were promulgated are finding it difficult to comply (Mavunda, 2016; Whiteman *et al.*, 2010).

1.2 Problem statement

Due to an abundance of platinum producing mines in the Rustenburg area and their close proximity to residential areas, this study is appropriate to establish whether tremendous impacts from the mining activities exist. Bezuidenhout (2013), demonstrated that groundwater in the North West Province is contaminated with nitrates and continue to show vulnerability to such contamination. Though there could be naturally occurring compounds of nitrogen due to geology in the Southern Africa (Tredoux & Talma, 2006), it is well documented that human activities with associated land uses predominantly contribute to high levels (Dwivedi *et al.*, 2007).

Also domination of agriculture, septic tanks, waste water works that are malfunctioning and poor sludge management makes North West not an exception to other polluted areas of the world (Kalule-Sabiti & Heath, 2008; Mayomi & Elisha, 2012; Tredoux *et al.*, 2009; Van der Walt *et al.*, 2002; Whiteman *et al.*, 2010; Bezuidenhout, 2013).

Having mentioned that North West Province is dominated with agriculture and mining. Most of the previously considered agricultural land, which left its impacts (Kalule-Sabiti & Heath, 2008; Van der Walt *et al.*, 2002) is also not dealt with and it is even difficult to reverse the impacts.

Access to safe drinking water is one of the key millennium goals, which most of the developing countries find difficult to achieve or will continue to find difficult if measures to control deterioration in water quality are not effective (Shomar, 2011). Therefore more attention and best measures to avoid contamination and exposing human to contaminated water, must be adopted Ceplacha *et al.* (2004) and hence the need for demonstration of water quality status in areas where people live even if they may not be dependent on groundwater due to alternative sources of water. The National Water Resources Strategy 2 states that one of the long-term strategies to overcome water scarcity problems in South Africa is to explore groundwater resources (DWA, 2013). Such resource must meet good quality.

The review by Bezuidenhout (2011), indicates the need for elaborated study on water quality issues. Subsequent to that, a large scale study was undertaken in 2013 (Bezuidenhout, 2013), of which the Rustenburg area was also part. In the study it was shown that 50% of water sampled exceeded nitrate allowable limits. In the study it

was demonstrated that surface and groundwater resources of the North West Province have bacterial contamination, saline and groundwater which were more contaminated with nitrates than surface water. Bezuidenhout (2011), indicates that nitrate concentration in surface water was 0-18 mg/l but may increase if the river is fed by nitrate rich aquifers resulting in eutrophication of dams. Such conclusions require that the study be narrowed to a smaller scale to link the cause and the effect, which is complicated by the fact that areas that are a source of nitrate are in most cases a private entity including mining houses of which without enforcement of law, one researcher may not simply access such information without a permission from the company in possession of water quality records.

Walmsley and Walmsley (2002), highlight that North West Provincial Government is concerned about the water quality issues and had realised that should the scenario not be dealt with, future developments could be jeopardised. As agreed by many, it is thus important that appropriate parameters are measured (Tredoux, 2004) and where appropriate, correct measures be put in place (Bezuidenhout, 2011; Xue *et al.*, 2012). Due to lack of access to clean water and poverty in some of the rural North West, the exposure to contaminated drinking water is very high. The WHO (World Health Organization, 1998) rates poor water quality, together with inadequate sanitation, as the leading cause of death in poorer communities.

Recent publication by the World Health Organization (WHO, 2017) maintains the fact that nitrate has got significant health implications in drinking water, as a result the standard is kept at 11.3mg/l- $\text{NO}_3\text{-N}$ (50mg/l- NO_3). Nitrite is kept at 3mg/l NO_2 (WHO, 2017). The state of nitrate pollution in groundwater undertaken by Maherry *et al.*, (2010) indicates high nitrate levels amongst the mining areas with the average concentration of 40.8 mg/l of $\text{NO}_3\text{-NO}_2\text{-N}$. The study highlights the need to expand monitoring networks as lack of data was indicated as limiting factor to get the full assessment of nitrate levels. The same sentiment was shared by Kalule-Sabiti and Heath (2008).

It was therefore found imperative to undertake a study in order for all stakeholders to understand the status of groundwater quality in the area of Chaneng and its surroundings and to recommend management approaches that will minimize the contamination and identify other sources of contamination.

1.3 Aim

This study is about assessing nitrate levels in groundwater in a rural village of North West (Chaneng) located in close proximity to the mining related activities.

1.4 Objectives

- To describe biophysical environment and to describe how it could impact on groundwater pollution;
- To assess potential sources of pollution, in groundwater in Chaneng Village;
- To determine groundwater quality upstream and downstream of platinum producing mines in the vicinity Chaneng village;
- To determine levels of physico-chemical and microbial parameters in groundwater at the within a village;
- To compare background nitrate concentration to that observed from the boreholes in the study area;
- To identify model potential nitrate pollution plumes to assess if they have an influence on Chaneng's groundwater

1.5 Scope of the study

The scope of this exercise entails the integrative approach of the assessment of the nitrates in groundwater, which will look at how land uses impact on groundwater resources within the A22F quaternary catchment with focus on Chaneng Village.

The assessment will look at the water quality of boreholes located within the village. The potential pollution triggers within the area will be looked at. Cumulative impacts (natural and manmade) will also be assessed, i.e. the soils, geology of the area will be assessed in association with their potential to contribute to nitrate pollution (Tredoux & Talma, 2006; Musekiwa & Majola, 2011). This study will therefore provide the background geology of the area, which will be sourced from the literature.

The use of dynamites or explosives in exploring minerals in the mining activities will also be dealt with. Agricultural practices that could trigger nitrate pollution will be

looked at. Finally, this study will not look at the assessment of nitrates alone but will also include the assessment of other physico-chemical characteristics such as phosphate, sulphates, EC, pH, DO, chlorides as well as e-coli and faecal coliform.

1.6 Study layout

This research exercise consists of six chapters.

- **Chapter 1**

This chapter deals with the introduction and background to the research topic, aims and objectives are outlined, problem statement and the scope.

- **Chapter 2**

Chapter two provides the literature review on the sources, source identification methods associated with diffuse sources, health impacts, and remediation methods of nitrates in groundwater as well as methods available for quantification of nitrate in the environment

- **Chapter 3**

This chapter demonstrates the research design and methodologies adopted in order to achieve each research objective for this current exercise including limitations and challenges.

- **Chapter 4**

In this chapter we deal with the physical environment of the study area and the background information.

- **Chapter 5**

In this chapter results of the study are displayed

- **Chapter 6**

In this chapter discussion, conclusions and recommendations are made.

CHAPTER 2: LITERATURE REVIEW

Having outlined the background, the intended objectives of the study as well as the scope, it is eminent that the existing literature on what this study is aiming to achieve be perused. Therefore the literature review will entail the legal framework that is aimed at preventing water resources contamination and the standards there of; the assessment and sources of nitrates (natural and anthropogenic), the impacts to (human and livestock), the mitigation and treatment measures, nitrate quantification methods and analysis methods as already looked at by other researchers.

2.1 Legal Framework and Paradigm Shift in water law in South Africa

Ghiglieri *et al.* (2009) stated that there are stringent Regulations in many countries that are intended to protect groundwater resources. Laws that compel the authorities to identify nitrate vulnerable zones such as Legislative Decree 152/06 (Ghiglieri *et al.*, (2009), were amalgamated in Italy to reduce pollution potential from agricultural land. In South Africa, the comprehensive piece of legislation was passed into law in 1998 (the National Water Act (NWA), 1998) - (Act 36 of 1998) (DWA, 1998a) to manage, develop, protect, use and conserve water resources and appointing the minister as the custodian for water resources including groundwater. All other subsequent Regulations were made to ensure alignment with the National Water Act.

The Preamble of the NWA recognizes that while water is a natural resource that belongs to all people, the discriminatory laws and practices of the past prevented equal access to water and use of the resource. It also recognizes that the protection of the quality of water is necessary to ensure sustainability of the nation's water resources in the interests of water users.

In attempts to deal with pollution of water resources, the Act set out the procedures to do so in Section 19 and 20. Further to that Section 21 (e), (f) and (g) of the Act by which contamination of water resources has a likelihood to occur is regulated by means of a water use licence, which stipulates the conditions by which the activities associated with such water uses can be undertaken with minimal impacts to the water resources. The conditions include water quality monitoring of water resources by which is meant to assess whether the water quality limits set out in the water use licence are adhered to or there is deterioration. The water use licence is one of the best tools regulating water

resources, which were not part of the old Act (54 of 1956). This attempts to ensure that water can be used whilst being protected, hence the need to protect groundwater from contamination.

Water quality is defined in the water quality guidelines (DWAF, 1996) as the “*fitness of water for a particular purpose*”. It describes chemical, physical and biological characteristics of water dependent on the purpose for use, could it be agriculture, domestic, recreation and so on.

There is a need to understand the level and the extent of groundwater pollution in South Africa in general but lack of data makes it difficult to achieve this goal (Maherry, *et al.*, 2010). Irrespective of insufficient data, maps of nitrate distribution in South Africa have been produced, indicating the high level of nitrates in the northern belt of the country as presented in Figure 2-1.

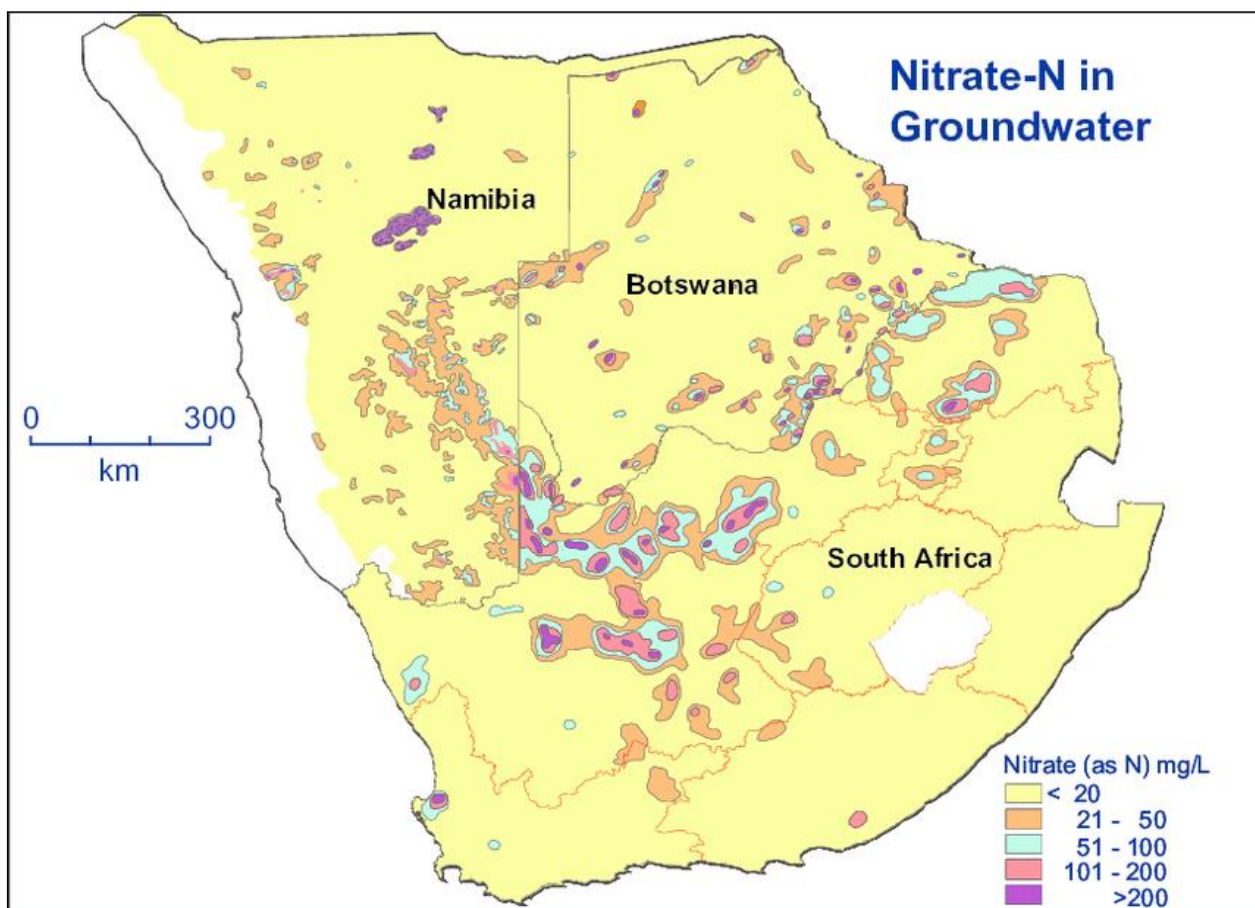


Figure 2-1: Nitrate distribution map of South Africa (DWA, 2010)

Nitrates come in combination with other water quality constituents, which is why there is a need for a combination of relevant variables for assessment. Guidelines for water

quality limits for different use were formulated, which ranges from volume 1 to volume 6. Other existing standards for drinking water such as SANAS 241 (2015) as well as Resource Quality Objectives (RQOs) were released to further protect water resource and such information will be utilised for this assessment against the findings of the study. Such information is presented in Table 2-1.

Table 2-1: Water quality standards (SANS, 241/2105 and WHO 2017), guidelines (DWAF, 1996) and RQOs within Elands quaternary catchment (DWS, 2017)

Variable	Domestic (Class 0- ideal)	Livestock	Irrigation	RQOs	SANS 241/ 2015	WHO, 2017
Physical characteristics						
pH	6.0 - 9.0	---	6.5 – 8.4	6.0-9.0	$\geq 5 \leq 9.7$	Not of health concern
TDS (mg/l)	0 - 450	0-1000 diary, pigs and poultry; 2000	< 260	-	≤ 1200	
Electrical Conductivity (EC) (mS/m)	0 - 70	500	≤ 40	85	≤ 170	
Chemical Characteristics						
Chlorine (Cl) mg/l	0 – 1.00	0 – 1500 non-rum; 0 3000 ruminants	0 - 100	120	≤ 300	5mg/l
Sulphate (SO ₄) mg/l	0 – 200	0 - 1000	200 max	120	≤ 500	
Nitrate (NO ₃ as N)	<6	0-100 as NO ₃	-	≤ 2	≤ 11	50mg/l
Ammonia (mg/l)	0 – 1.0	-	-	-	<1.5	-
Orthophosphate (PO ₄) mg/l		-	-	≤ 0.010		-
Hardness (CaCO ₃) mg/l	0 - 200	-	-	-		-
T Alk						-
Sodium (as SAR) mg/l	0 - 100	0 - 2 000	≤ 70	≤ 100	≤ 200	50mg/l
Calcium (mg/l)		0-1000				-
Potassium (mg/l)	0-50	-	-	-	-	-
Magnesium (mg/l)	0-30	0-500	-	-	-	-

Variable	Domestic (Class 0-ideal)	Livestock	Irrigation	RQOs	SANS 241/ 2015	WHO, 2017
Microbial characteristics						
E-coli (counts/100ml)	0 counts/100ml	-	-	130 counts/100ml	ND- not to be detected	<1
Coliform (counts/100ml)	0 counts/ 100 ml	-	-	-	ND	<1

Furthermore, government introduced the Green drop certification programme (Swanepoel, 2008). This programme together with the Blue drop was established to ensure that good quality effluent is released into the environment and that good quality water is provided to people within the municipal areas. It is essential to bring this information in this research because many authors demonstrate that poorly managed waste water are amongst the pollution sources of which nitrates is among the variables of concern coming to waste water final effluent discharges (Bradley, 2009; Obeidat *et al.*, 2007; Seanego & Moyo, 2013), that get released to the environment.

Authors highlight that certification programmes may seem to address a problem but it actually does not (Swanepoel, 2008), because it does not take into consideration the discharges that occur due to blocked manhole sewers that get incidentally discharged and disposed on land without being treated (Onwughara *et al.*, 2007). This occurs in many towns in South Africa (Seanego & Moyo, 2013), other African countries such as Zambia (Moyo & Mtetwa, 2002).

This is ascribed to overloaded sewer networks as the population growth resulting in demand for housing and associated infrastructure for provision of services, which may not be aligned in terms of capacity. This happens to be the case even in the international countries as highlighted by Bradley (2009). This therefore means that more has to be done regarding water resources and pollution prevention strategies in South Africa. Other legal tools as already mentioned are GN 704 Regulations and Waste Classification Regulations, which became effective in 1999 and 2013 respectively.

2.2 Natural sources of nitrate

There is ample of information regarding natural sources and concentrations of nitrates in groundwater. It is reiterated in many research articles that nitrogen reaches the

earth surface naturally by means of chemical oxidation/reduction reaction (Skinner, 2017), of the nitrogen containing compounds, giving rise to nitrates (NO_3^-) and ammonium compounds (NH_4^+) (Bosman, 2009; Akwensioge, 2012). In semi- arid and arid regions of Southern Africa such as the Northern Cape Province and Namibia high nitrate levels are found in large areas where human influences can be excluded (Tredoux, 2004).

Natural occurrence of nitrates and other chemicals is derived from rocks and soils through which water moves vertically and horizontally to reach groundwater and streams respectively, which may vary from one rock type to another (Tredoux & Talma, 2006; Rosen & Kropf, 2009; Reddy *et al.*, 2009; Akwensioge, 2012; Lowe & Wallace, 2001), and from one soil type to another. This may be influenced by diagenesis (Akwensioge, 2012). Diagenesis refers to chemical and physical changes that occur when sediments are being converted to sedimentary rocks (Akwensioge, 2012).

Due to the dynamic nature of soils, their impact associated with groundwater contamination varies (Heaton, 1985). Soil physics (the structure, texture, soil water movement, etc.), soil chemistry, i.e. chemical content of the soil such as organic C/N ratio and chemical reactions affect the nitrogen cycle with the inclusion of the microbial content (Bosman, 2009; Bezuidenhout, 2011) and pedogenesis (soil formation) (Heaton, 1985; Tredoux & Talma, 2006).

Though it may be true that contamination potential is higher on sandy soils (Reddy *et al.*, 2009) than clay soils (Haller *et al.*, n.d.), it is also true that other clays may increase nitrate levels abruptly (Grobler, 1976; Tredoux & Talma, 2006) due to high levels of shrink and swelling properties (Heaton, 1985). The soil nitrogen pool is found from the most productive soil underlain by basalt rock (Tredoux, 2004).

Depth of groundwater has an effect on nitrate concentration as shallow wells/boreholes are more prone to pollution than deeper wells/boreholes (Zingoni *et al.*, 2005; Bezuidenhout, 2011) except for salinity that was found to be high in secondary aquifers irrespective of depth in Marydale (Staudt, 2003).

Figure 2-2 indicates the sources (natural and those that are due to anthropogenic activities) and the processes that give rise to the nitrogen cycle. Nitrogen cycle is a continuous transformation of the molecules of nitrogen, which begins by fixation of nitrogen from the atmosphere by leguminous plants through the aid of bacteria

(Bosman, 2009). This nitrogen fixing bacteria contained in the root's nodules of plants convert nitrogen into amino acids ($R-NH_2$), which gets released when organic matter decomposes, leading to the process of mineralization (an oxidation process resulting to ammonium (NH_4^+)), which further gets converted to nitrites (NO_2^-) and to nitrate (NO_3^-) through the process called nitrification. Up to this end, it is only aerobic bacteria that run the process. (NO_3^-) is the end product of the nitrogen cycle. It can be consumed by plants or get lost to the atmosphere due to the denitrification process that takes place in the absence of oxygen, thus the anaerobic bacterial activity prevails (Socratic, n. d.).

Excessive nitrate could also leach through subsurface flow and runoff to cause eutrophication of rivers. The combination of anthropogenic activities such as emissions from burning of fossil fuels, agriculture and natural sources as depicted in Figure 2-2 result into excessive nitrogen levels to an extent that water resources gets contaminated (Halloway & Dahlgren 2002).

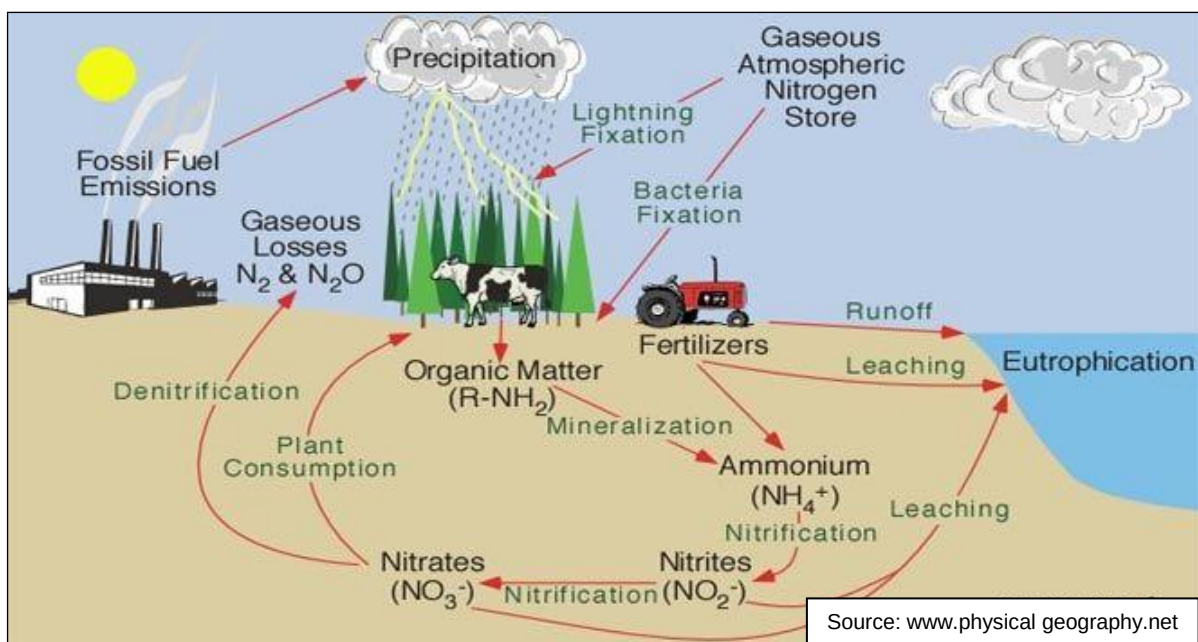


Figure 2-2: Natural Nitrogen cycle

2.3 Anthropogenic activities

Natural sources from which nitrogen originates from, are exacerbated (Halloway & Dahlgren 2002; Kreitler & Jones, cited in Heaton 1985; Rosen & Kropf, 2009; Haschemeyer & Williard, 2008; Interstate Technology and Regulatory Cooperation

(ITRC) Work Group, 2000) by the human activities such as use of septic tanks and pit latrines for sewage disposal (Fourie & van Ryneveld, 1994; Wright, 1999; British Geological Survey (BGS), 2002 cited in Graham & Polizzotto, 2013; Msilimba & Wanda, 2013; Maherry *et al.*, 2010; Obi & George, 2011; Staudt, 2003 cited by Tredoux & Talma, 2006; Maherry, 2010). Discharge of poorly treated effluent (Seanego & Moyo, 2013) and sludge disposal (Xu *et al.*, 1991), manufacturing industries, underground storage tanks for petroleum products (Usher *et al.*, 2004), application of nitrogen-rich fertilizers or waste water irrigation to turf grass, and in agricultural production (Alabdula'aly *et al.*, 2010; Bosman, 2009; Cho *et al.*, 2000; Haller *et al.*, n.d.; Yang *et al.*, 2007; Reddy *et al.*, 2009; Tredoux & Talma, 2006; Faris, 2009; Owens *et al.*, 1994), platinum producing industries by means of using nitrogen containing explosives for blasting (Skinner, 2017; Xue *et al.*, 2012; LaMoreaux *et al.*, 2009; Mavunda, 2016; Bosman, 2009; Degnan *et al.*, 2015; Usher & Pretorius, 2008), and also through waste rocks, tailings and dirty water impoundments, dissolution of ammonium nitrate explosives or waste from explosives due to poor handling, storage and loading of such compounds (Skinner, 2017) and waste streams from explosives manufacturer (Degnan *et al.*, 2015; Elmidaoui *et al.*, 2001, cited by Alabdula'aly *et al.*, 2010), where wells lack or have damaged casing/or protection (Bezuidenhout, 2011; Graham & Polizzotto, 2008). Intermittent use of sludge lagoons (Haller *et al.*, n.d.; Tredoux & Talma, 2006), poor handling of waste water in piggeries (New South Wales (NSW), 2018) is also a culprit. These result in pathways as shown in Figure 2-3. Cultivation exposes the soil nitrate, making it more prone to leaching (LaMoreaux *et al.*, 2009).

Glass manufacturing industries (WHO, 2011), Eskom plants (Skinner, 2017); the Coke plant of Mittal Steel which was known as Iscor at Vanderbijl Park in 1998/2000 (Tredoux & Talma, 2006) are also found to be the contributors to the increased levels of nitrogen in groundwater.

2.4 Impacts of nitrates on humans

Is nitrate in drinking water really a threat to human health?

2.4.1 Methemoglobinemia

There are numerous reports that link this condition to nitrate in drinking water (Comly, 1945; Donahoe, 1949; Bosch *et al.*, 1950 cited in IRIS 1991; Walton, 1951, cited in Fewtrell, 2004; Craun *et al.*, 1981; WHO, 1985; Comly, 1987; Johnson *et al.*, 1987; Rail, 1989; Finley, 1990; Terblanche, 1991; Gustafson, 1993; L'Hirondel & L'Hirondel, 2002 cited in Fewtrell 2004; Abu Naser, 2003, cited by Shomar, 2011; Sadeq *et al.*, 2008; WHO, 2011; Verma *et al.*, 2015; Haller *et al.*, n.d.), but there is controversy in this matter. This is due to the fact that there are cases where methemoglobinemia had occurred in the absence of nitrate or were at low levels in drinking water (<6mg/l) (Avery, 1999 cited in Manassaram, *et al.*, 2006). In another study dosing of infants with nitrate did increase the level of methemoglobin but did not necessarily result in methemoglobinemia (Fewtrell, 2004). As a result, other authors concluded that association of methemoglobinemia with nitrate (only) contaminated water cannot be validated (Toussaint & Selenka, 1970 cited in Fewtrell, 2004; Verma *et al.*, 2015).

Factors such as bacterial infection (Gaoganediwe, 2006; GCIS, 2005; Hemson & Dube, 2004; IRIS & USEPA, 1991), overproduction of gastric nitric oxide, copper contained in water were linked to the conditions (Avery, 1999; Felsot, 1998; Hanukoglu & Danon, 1996; Hegesh & Shiloah, 1982 cited in Manassaram *et al.*, 2006). More oxidizable haemoglobin on babies than in adults (Bouchard *et al.*, 1992; Camp, 2007; Comly 1987; Fewtrell, 2004; Ghiglieri *et al.*, 2009).

Nitrite ions may be more strongly bound by infants' haemoglobin due to the immaturity of certain enzymes; and the kidneys of infants have inferior excretory power which may favour retention of nitrite for longer periods of time (Comly, 1987). Also indicated by Fewtrell (2004), is that boiling drinking water excessively may concentrate nitrates in the case of bottle feeding. Lack of cytochrome b5 reductase (an enzyme responsible for converting methemoglobinemia back to normal haemoglobin (Verma *et al.*, 2015), increased gastric pH, which allows greater bacterial invasion of the stomach influencing conversion of nitrate to nitrite (Comly, 1987; Verma *et al.*, 2015), greater fluid intake relative to body weight (Ayebo *et al.*, 1997 cited in Fewtrell, 2004).

The danger of nitrate/ nitrite exposure is also dependent on how much is one exposed to (the dose) and for how long (the duration) and exposure pathways, i.e. how is one exposed; other chemicals to which one is exposed (Verma *et al.*, 2015; APHA cited by

Manassaram *et al.*, 2006; IRIS & USEPA, 1991; ATSDR, 2015); sex, age, diet, family DNA characteristics, immune system (WHO, 2011; ATSDR, 2015) & pregnancy (WHO, 2011; ITRC, 2002 cited in Akwensioge, 2012).

Compounds of nitrogen could either be beneficial or risky to human health depending on concentration of nitrogen compounds (Powlson *et al.*, 2008; Richardson *et al.*, 2002 cited in Powlson *et al.*, 2008), indicates that endogenous production of nitric oxide maintains normal blood circulation and aid in the destruction of swallowed pathogens that can cause gastro-enteritis, which in turn increase the level of methemoglobin. Powlson *et al.* (2008), also indicate that gastro-enteritis causes the production of nitric oxide, which when oxidizing agents are abundant in the system that the reduction process of nitrate is slower than the oxidation process, the formation of high concentration of methaemoglobin is unavoidable. According to Avery (1999) the process is autonomous from the oral exposure to nitrates.

Methemoglobin is a natural component of human blood and it occurs at levels less than 1% (ATSDR, n.d.). The problem arises when it gets higher than 1% (ATSDR, n.d.) of which if untreated could be fatal (Verma *et al.*, 2015). Once elevated to more than 20% defection in central nervous system begins WRIG, (Whitley River Improvement Group, n.d.). It becomes deadly if the levels of methemoglobin rise to 50% or 60% (Integrated Risk Information System (IRIS) & USEPA, 1991).

Methemoglobinemia (blue baby syndrome) is characterized by bluish baby skin and blue lips (Craun *et al.*, 1981; Sadeq *et al.*, 2008). This is due to the inability of blood to carry oxygen throughout the body (Akwensioge, 2012) due to the domination of ferric (Fe^{3+}) form of iron instead of ferrous iron (Fe^{2+}) thus the globin protein gets low affinity for oxygen (Verma *et al.*, 2015). This leads to slow suffocation in infants which may lead to death (Finley, 1990; Gustafson, 1993; Johnson *et al.*, 1987 cited in Comly, 1987).

Water quality standards for nitrates are set to prevent contamination but were challenged by (Powlson *et al.*, 2008) by proposing consideration in relaxation of such limits due to lack of agreements amongst the researchers on the subject but not withstanding the fact that being different, people responded differently to different conditions including exposure to contaminated water, which thus make the findings drawn over five decades regarding nitrate and health remain relevant. The concern in

their review was that when considering the food security for the growing population, agriculture without nitrogen containing fertilizer (Aires *et al.*, 2013) can never be an alternative but is to be applied at the sufficient quantities.

Other authors believe that nitrate in drinking water should still remain a concern by justifying lack of consistency in studies linking nitrate to methemoglobinemia to the fact that methemoglobinemia is not a reportable diseases (Tredoux, 2004; Manassaram *et al.*, 2006; Manassaram *et al.*, 2010), as it can easily be confused with other health conditions such as nausea, lack of oxygen in the blood, short breath, cyanosis, dizziness, fatigue, headache (Talma & Tredoux, 2006; Terblanche, 1991; Fewtrell, 2004; L'Hirondel & L'Hirondel, 2002 cited in Fewtrell, 2004), mentions that consumption of nitrate through drinking water increases severity of methemoglobinemia.

2.4.2 Cancer

Whether nitrates cause cancer or not had yielded mixed outcomes with other authors finding evidence (Gulis, *et al.* 2002 cited in Alabdula'aly *et al.*, 2010; Forman *et al.*, 1985 cited by Reddy *et al.*, 2009; Jensen, 1982 cited in Bezuidenhout, 2011; De Roos *et al.*, 2003; Moller *et al.*, 1989; Rowland *et al.*, 1991; Mirvish *et al.*, 1992; Kamiyama *et al.*, 1987; Lu *et al.*, 1986; Yi *et al.*, 1993) and others not finding it (Yang *et al.*, 2007).

Though there are mixed outcomes on the matter, it is indicated that some of the N-nitrosamine and N-nitrosamide compounds, which can form due to the presence of nitrates in drinking water, may have carcinogenic (can be cancerous), teratogenic (cause birth defects in embryo or foetus) (Manassaram, 2010) or mutagenic (changes the DNA of an organism) effects (Tredoux, 2004).

Also mentioned by the ATSDR, (n.d.), is that there is high risk of brain cancer when exposed to high levels of nitrate. A high risk of brain cancer was attributed to nitrate's maternal exposure when the mother was exposed to nitrite in drinking water of > 3mg//day. According to ATSDR, (n.d.), brain tumours occurred as a result of combination of amino compounds and sodium nitrite and potassium nitrite (ATSDR, n.d.), and this put emphasis on the fact that endogenous nitrosation of nitrite and nitrate is carcinogenic to humans. NOCs such as (amides and amines of nitrogen) are generally known carcinogens. Weyer *et al.* (2001) found positive associations between bladder cancer and nitrate levels as well as positive association for ovarian cancer.

On the other hand, Yang *et al.* (2007) mention that there is no evidence linking colon cancer and nitrates but Verma *et al.* (2015) is adamant that through N-nitroso compounds give rise to different kinds of cancer and that is as a result of the conversion of nitrate to nitrite.

2.4.3 Other health impacts

Other than cancer and methemoglobinemia, there are other health impacts mentioned in the literature. Those include enlargement of thyroid gland (WHO, 2011; ATSDR, n.d.; Sarne, 2016); headaches (Tredoux, 2004; & ATSDR, n.d.), and diabetes (ATSDR, n.d.).

2.4.4 Conclusion

The assessment of nitrates in groundwater is essential for protection of the environment and the people that depend on it (EPA, 2007). The association of nitrites and nitrates with many ailments could certainly be true due to the fact that for normal body cell function there must be a continuous supply of oxygen so lack of haemoglobin and the abundance of methemoglobin result in a lack of oxygen to the body and would definitely result in many diseases but there could be many other contributing factors.

2.5 Impacts to livestock

According to NSW government, Department of Primary Industries (2018), different livestock are affected by nitrate poisoning in varying degree. Some are more susceptible than the others and some are more, which is ascribed to different digestive systems and the type of feed (NSW government, Department of Primary Industries, 2018). The direct exposure of pigs to nitrites when fed with, for instance, mouldy whey becomes a problem as nitrite cannot be converted to ammonia by pigs.

NSW (2018) reports that ruminants, during nitrification, a process catalysed by rumen microbes have an ability to convert nitrites to ammonia but this process is hindered when nitrates are consumed in large quantities as nitrate poisoning occurs. Sheep are more efficient in converting nitrites to ammonia which is perceived as the reason why sheep are less susceptible to nitrates than cattle.

Nevertheless livestock losses in South Africa is a sensitive issue, making it difficult to discuss the causes of loss openly (Tredoux & Talma, 2006; Tredoux *et al.*, 2009). Nitrate poisoning, which can be consumed through heavily contaminated feed (NSW

government, Department of Primary Industries, 2018), or drinking water (Tredoux *et al.*, 2009), has been reported as a cause of sudden death to livestock (Binta & Mushi, 2012) in Southern Africa countries. It is recognised by damage in internal vital organs, chocolate brown coloured blood and internal bleeding called petechiation (Binta & Mushi, 2012; NSW government, Department of Primary Industries, 2018).

Reproductive toxicity due to nitrates has been reported by Bruning-Fann and Kaneene (1993; Fan *et al.*, 1987; Gruener *et al.*, 1973 cited in Manassaram *et al.*, 2006). Still born calves, abortions, retained placenta, cystic ovaries, low milk production, reduced weight gains and vitamin A deficiency (Tredoux, 2004; Binta & Mushi, 2012), mummified foetus (Fan *et al.*, 1987 cited in Manassaram *et al.*, 2006), lesions on the cervix, uterus; maternal death (Manassaram *et al.*, 2006), may occur as a result of exposure to high nitrate content through a pathway. Tumours in every animal species as a result of N-Nitroso compounds (Lijinsky, 1986; Ward *et al.*, 2005; Mirvish *et al.*, 1987; Germann *et al.*, 1991), have been observed. Sedation motionless and aggressive behaviour at varying doses have been noted at different doses of nitrate containing compounds (ATSDR, n.d.).

Unlike in humans where conversion of haemoglobin to methaemoglobin to a level of 40% or 60 becomes fatal (Integrated Risk Information System (IRIS) & USEPA, 1991), in animals the conversion becomes deadly when it is more than 80% (Tredoux, 2004).

2.6 Conclusion

The observation made here is that nitrate contamination is a serious threat for animals more than humans. Making the matter worse is the fact drinking water sources for livestock drinking is privately owned, even when monitoring programmes are established some of those points may not be accessible due to difficulties to access (Tredoux & Talma, 2006). In addition, environmental factors also contribute to the poisoning episodes, which include drought, high ambient temperatures, low cloud cover, leaching of nitrates from the soil after flooding, soil moisture content and forage nitrogen content and natural geo-formations associated with high nitrate content in the water makes animals to be susceptible to poisoning (Binta & Mushi, 2012) and are difficult to control.

The relevant aspect of problem and source identification and impacts is the key to a solution. Authors have indicated that the complexity of solving pollution problems is when the source of pollution is not known (Tredoux, 2009). In addressing that issue, several researchers have come up with ways of identifying sources of pollution and those are dealt with in the next section.

2.7 Strategies to deal with nitrate pollution

Measures to deal with nitrate pollution have been discussed in depth (Tredoux 2009). Some of the recommendations made had already been implemented, which include understanding the sources; knowledge about hydrogeological information; identification of high risk areas; prioritization and creation of maps of such areas; abandoning of sources if found contaminated; Cooperative Governance, regular water quality testing, changing to bottled water for infants feeding; classification of water resources and determination of RQOs.

Irrespective of all that said, this problem still persists due to the need for economic growth and food security causing expansion in industries and activities that increase pollution and nitrate content of groundwater (Mavunda, 2016; Witheetrirong *et al.*, 2011), making other areas that were not at risk before to be more vulnerable. Therefore, strategies dealing with water resources protection and pollution prevention should always be updated (DWA, 2010) and more investigation work (Bezuidenhout, 2011).

2.7.1 Identification and tracking of sources of nitrates

Although identification of the sources by tracking methods is not part of the scope of this study, it is deemed by other authors a crucial action to deal with pollution that already exists (Esser *et al.*, 2009), but the source is not known or it is from multiple sources (Degnan *et al.*, 2015; Samadpour, 2002 cited in Bezuidenhout, 2011; Tredoux & Talma, 2006). Those include nitrate isotopic composition (Kendall, 1998; Esser *et al.*, 2009), the presence of nitrate co-contaminants characteristic of specific sources; mean age of the groundwater (Esser *et al.*, 2009), combination of isotope technique and microbial analysis (Bosman, 2009; Esser *et al.*, 2009), joint use of nitrogen and other trace metals' isotopes or dual isotope method (Xue *et al.*, 2016), modelling nitrate fate and transport (Degnan *et al.*, 2015), isotopic, chemical and hydrologic evidence (Degnan *et al.*, 2015; Cozma *et al.*, 2016).

These methods have limitations due to the fact that land uses do not exist in isolation (Degnan *et al.*, 2015), and that in a short space of time the signatures or isotopes of nitrogen may be transformed significantly as a result of its cycle to totally differ from the isotope at its source (Degnan *et al.*, 2015), and they also recommend that background water quality and continuous monitoring during the activity and after the activity be considered essential. Such types of assessment can also be made cumbersome due to climate, geomorphology, geology and biotic composition (Dallas & Day, 2004 cited in Bezuidenhout, 2013), as in the case of transboundary aquifers (DWA, 2010).

2.8 Pollution mitigation measures

This section provides a discussion of different measures to deal with pollution from different sources where sources are identified and known. For example if one has to prevent pollution from the on- site sanitation such as pit-latrines and septic tanks, has to take into consideration recommendation made by DWAF (2003), Tredoux (2004), Graham and Polizzotto, (2013); (Lewis *et al.*, 1982; Franceys *et al.*, 1992; Banks *et al.*, 2002; Vinger *et al.*, 2012; Banerjee, 2011; Still & Nash, 2002; Water Aid, 2011; Sphere Project, 2011; Banks *et al.*, 2002; WHO, 2011). These suggest a lateral distance of the on-site sanitation to the source of groundwater and a vertical distance from a groundwater table. These do differ from one place to another due to geohydrological and biophysical environment of the area where sanitation programmes are to be implemented (Dzwairo *et al.*, 2006; Nichols *et al.*, 1993; Pujari, *et al.*, 2012); and also due to land uses and population density (Graham & Polizzotto, 2013; Ahmed *et al.*, 2002; Howard *et al.*, 2003; Tandia *et al.*, 1999).

In addition, Jacks *et al.*, (1999) and Tredoux (2004), suggest that ventilation tubes should be painted black to maximise day time ventilation rates to reduce nitrate contamination as this will increase ammonia volatilization. Sealing pits to pits to prevent nitrate leaching and promote denitrification, increase the pH of latrines to increase ammonia volatilization, diverting urine to use as fertilizer. The formation of the bio-active layer (Scum mat, clogged zone or a bio-layer), that provides liner effects preventing further penetration of contaminants to groundwater (BGS, 2002).

Tredoux (2004) also emphasizes adherence of all users to the conditions stipulated in the water use authorizations and also to the Resource Quality Objectives and that self -

regulation outside regulated areas must be promoted. He also suggests conducting geo-hydrological studies including hydro-census within the 2km radius.

In case of septic tanks, DWAF (2003), recommends the reduction in water used for flushing, establishing of small wetlands, and include wastewater stabilization ponds – facultative; combination of wetland with maturation pond; overland flow treatment and disposal system; mound treatment and disposal system; sand filter treatment and disposal system; evapotranspiration disposal system, or disposing it sufficiently far from the groundwater abstraction point.

The best approach in ensuring that pollution from waterborne sewage system is minimized is through ongoing maintenance of such systems (Reddy *et al.*, 2009; Momba *et al.*, 2006) would be to deal with waste water effectively. Waste water from the waste water treatment works can be reused for irrigation of pastures, which on other hand pose another risk (Corniello *et al.*, 2007).

Prevention of leachate from leaving landfill site may be achieved through waste classification and management Regulations that were promulgated by DEA (2013), are to be adhered for the management of landfill site and any other activity by which waste is to be generated. It requires first and foremost that all the strategies associated with waste management to be followed, i.e. preventing, minimizing, recycling and reuse, treat and finally dispose. Upon disposing, it requires the waste class to be determined. All waste disposal sites must be licenced.

In order to prevent pollution emanating from waste streams within the **mining operations**, there is a need to for adequate liner (Bosman, 2009) at all waste impoundments, and also compliance with the Regulations of the GN 704 is essential. There must be lining of waste water and waste disposal facilities (Bosman, 2009). Motivation for exemption from complying with GN 704 must be submitted to the DWS for consideration to grant such exemption. Adherence to licencing conditions is also crucial in this instance (Tredoux, 2009).

Within the agricultural practices, there are many measures documented to reduce groundwater contamination (Harter, 2009). Those include minimal tilling (Reddy *et al.*, 2009). When the soil is minimally tilled, nitrogen stays in a reduced form and volatilizes as ammonia (Tredoux & Talma, 2006). Other approaches include putting fewer

animals per unit area (Alabdula'aly *et al.*, 2010; Heaton, 1985; Tredoux & Talma, 2006); creation of awareness in adequate use of nitrogen fertilizer or switching to organic fertilizer (Haller *et al.*, n.d.), concrete lining of manure lagoons and dryland agriculture (Haller *et al.*, n.d.). Deeper drilling of boreholes may also reduce contamination (Bezuidenhout, 2013).

2.9 Prevention of animals from exposure

With all that said, farmers need to ensure that animals are protected from exposure. NSW (2018), mentioned a number of practices that are to be employed to ensure that no nitrate poisoning either from feed or from water occurs. If it is suspected that the feed is contaminated, only fewer animals should be allowed to graze and the feeds and forages be taken for analysis and should be analysed regularly. Though feeding on dry hay is better than feeding on fresh immature feed, it is recommended that in the absence of enough dry feed, the farmer must to provide dry risk free hay and then can provide fresh hay (NSW, 2018). This will prevent the stock from over eating immature stalk that may still contain high amount of nitrogen (NSW, 2018). If the hay is recently sprayed for the intention of enhancing growth, animals should never be allowed to graze in such a pasture. Also pointed out by NSW (2018), is that climatic conditions are to be considered when feeding animals. For instance cattle owners/ farmers should prevent their stock from grazing pastures with high levels of nitrate seven days after of rainfall, cloudy days, frosts and high temperatures that result in wilting. This is because of the mechanism associated with precipitation bringing nitrate to the ecosystem becomes imminent (Akwensioge, 2012) and also that high temperatures may cause accumulation of nitrates due to high evaporation (Reddy *et al.*, 2009). In high nitrate pastures, grazing must take place when the temperature is at 15°C. It is best to abstain from feeding animals some mouldy hay (NSW, 2018).

2.10 Remediation options

One of the ways at which nitrate can be maintained at lower levels naturally, is when denitrification process prevails, taking precedence over other process (Akwensioge, 2012). There should therefore be unsaturated conditions in the aquifer (Tredoux *et al.*, 2009).

Other common treatment processes are ion exchange, reverse osmosis, biological denitrification and chemical reduction to actually remove portions of the pollutant, which proves to be rather expensive (Vogel *et al.*, 2004; Mayomi & Elisha, 2012). In these techniques, contaminated water is pumped and disposed of to the treatment plant for treatment (Akwensioge, 2012). However, the most important thing to note about these clean-up procedures is that neither of these methods is completely effective in removing all the nitrogen from the water. Finding alternative purpose for water proves to be advantageous if the need for such activity is less good quality (Akwensioge, 2012). Sometimes contaminated water is pumped and disposed to the evaporation pond, which has to be lined (Bosman, 2009).

Patton *et al.* (2004) describe the use of a cadmium method as an easy and quick method used to reduce nitrate in the process of nitrate testing. This environmentally user-friendly method has been developed by a company nitrate elimination company, Inc. (NECi). Nitrate reductase used in a kit is a stable making enzyme- based nitrate testing method (Patton *et al.*, 2004). A filtered sample is passed through a column containing granulated copper-cadmium to reduce nitrate to nitrite. The nitrite (originally in the sample and reduced nitrate) is determined by diazotizing with sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochloride to form a highly coloured azo dye, which is measured with a spectrometer.

Bezuidenhout (2011) states that drilling boreholes deeper to draw water from a secondary aquifer is another pollution remediation mechanism as is reported that secondary aquifers are usually deeper than the primary aquifers (Tredoux & Talma, 2006), and provide less contaminated water (Harter, 2009). This could be ideal.

Ion exchange treatment is one of the treatment processes to reduce nitrates in ground water. It does not remove it in its entirety but it can reduce it to a level accepted by the (WHO, 2011), which is 11 mg/l.

Tredoux and Talma (2006), state that nitrate may have to be flushed out of the aquifer system, for the quality of groundwater to be remediated. To flush nitrate requires high recharge rates. The study by Corniellio *et al.* (2007) concluded that water treatment processes for reducing nitrate contents cannot be carried out in large areas, where nitrate concentrations will decrease only through a slow transfer of groundwater to surface water and the progressive dilution effect of infiltration water.

Phytoremediation is getting more attention as a remediation technique to remove pollution plume (ITRC, 2000). Such technique may pose water quantity reduction in areas where demand for water is high and the resource is not sufficient (Akwensioge, 2012). He also added that the approach may not be appropriate as a short term intervention measure but can be good for long term implementation plan.

Other techniques include permeable membranes, electrochemical and biological methods. These are mainly influenced by the reduction/oxidation conditions of the aquifer to the membrane constituents so to selectively remove unwanted chemicals in water (IITRC, 2000). Biological methods made possible by the inclusion of suitable microbiological creators to enhance denitrification process.

All these methods are usually site specific. It is essential to investigate the area at which pollution plume has been identified so as to apply appropriate technique (Akwensioge, 2012).

2.11 Methods to quantify the movement of nitrates and associated impacts

Quantification methods to quantify the concentration and movement of nitrates are discussed even though none of them are to be employed in the current study due to resource availability including long term monitoring data of various factors that are to be included in the models used.

2.11.1 Mass-balance

Kringel *et al.* (2016) and Somers (2007), employed a mass balance model to quantify nitrogen content of groundwater. Though it is simpler, it has to take into account infiltration rate of the soil (Kringel *et al.*, 2016), background data relating to groundwater quality and levels and rainfall (Somers, 2007). It is important to take into account the type of land use activity at which it is applied (Kringel *et al.*, 2016). For example, when the nitrate content is assessed from the sanitation point of view, recharge, discharge, area and population has to be considered (Kringel *et al.*, 2016).

2.11.2 Soil coring, ceramic suction cup lysimeter and drainage lysimeter

Zotarelli *et al.* (2007) discuss the use of the effectiveness of the three methods to measure the leaching of nitrogen from the mulched vegetation beds. Though these methods are simpler.

Though simpler to use but the soil coring carries a spatial variability error in soil nitrate concentration. Soil sampling provides an indirect measurement of inorganic N in the soil solution (Webster *et al.*, 1993 cited in Zotarelli *et al.*, 2007). It is time consuming and destructive. The method may measure nitrogen distribution within a soil profile. It needs to be combined with modelling approaches or by linking nitrogen soil distribution with water flow dynamics below the root zone Zotarelli, *et al.*, (2007). Soil coring proved to be challenging under sandy soils conditions that are drip irrigated where there is dominant lateral water and nutrients gradients (Zotarelli *et al.*, 2007).

Ceramic suction cup lysimeters are regarded as a suitable method to monitor N-leaching in non-structured soil, i.e. sandy soil as compared to clay soil (Zotarelli *et al.*, 2007). It is easy to install; can also allow repeated measurements from the exact same locations but this needs soil flux to be determined at the same time (Zotarelli *et al.*, 2007). Uncertainties may occur under dry conditions or in sandy soils as there is a need for sample volume water content (Barbee & Brown, 1986; Lord & Shepherd, 1993 cited in Zotarelli *et al.*, 2007).

Drainage Lysimeters are the best as they capture the entire leachate volume and N-concentration, which can be used to calculate N-loading passing below a specific depth. The method allows for consistent and precise measurement of nitrogen concentration (Webster *et al.*, 1993 cited in Zotarelli *et al.*, 2007). It also provides an integrated approach both in time and in space, which has a potential of being a more realistic method of assessing total N loads compared to other approaches that represent a relatively small spatial dimension (< 5cm) and only provide a snapshot of only leaching patterns. However, the installation causes soil disturbance, which may lead to the loss of nitrogen without it being accounted for.

The best outcome is dependent on the installation technique, which needs that lysimeters are to be installed deep enough to ensure that soil water conditions in the root zone represent overall field conditions yet shallow enough to ensure adequate drainage and also to ensure that time trends match the actual N-displacement below the effective root zone (Zotarelli *et al.*, 2007).

Though challenges may be encountered when applying these methods but according to (Zotarelli *et al.*, 2007), they can provide some understanding associated with the control or minimization of nitrate non-point pollution sources associated with irrigated vegetable

production system so as to apply just adequate amount to be utilized (Powlson *et al.*, 2008).

2.11.3 Chloride method and dominant land use method

Akwensioge (2012), mentions a new chloride method and a dominant land use method. The chloride method is used to estimate leaching fraction. The leaching fraction, seasonal evapotranspiration and $\text{NO}_3\text{-N}$ concentration below the root zone are combined to estimate the $\text{NO}_3\text{-N}$ leaching. Challenges associated with the approach include the need for calibration and boundary conditions as they could not be satisfied in complex land use systems and non-uniform strata (Akwensioge, 2012).

The dominant land use method is about choosing a land use that dominates in the particular area and N- content gets assessed against that particular land use (Akwensioge, 2012).

2.11.4 Geographical Information System (GIS)

Geographical Information System (GIS) is also used in the assessment of nitrates in groundwater (Ghiglieri *et al.*, 2009; Corniello *et al.*, 2007). This method is subjected to error and uncertainty emanating from data collection up to results interpretation (Aronoff, 1993 cited in Dwivedi *et al.*, 2007). This takes into consideration the overlaying of land use, soil map to generate groundwater nitrate contamination vulnerability map in combination with the hazardous factors (HF), which involves all potential pollution sources associated with agriculture (applied fertilizer, livestock manure, sludge (HF_s) and controlled factors (CF), which includes climate (Cf_w), Irrigation rates as well as the Soil factor. The method is not easy to apply in case of diffuse sources (Haller *et al.*, n.d.).

2.11.5 Fuzzy logic approach

Rahim and Mokarram (2012) applied this model. It emulates the biophysical environment, and is a management and a decision-making tool. Its effectiveness is dependent on the empirical knowledge of the person operating the system. A fuzzy controller consists of three operations: fuzzification, inference and defuzzification (Muhammetoglu & Yardimci, 2006). A fuzzy logic system was applied under irrigated agriculture to assess groundwater pollution level. It measures the rate of movement of

contaminants to groundwater. Even though it needs enough data, it does not mean that it may be difficult to use in the absence of adequate data because it has a way to deal with missing data. Its data requirements are soil characteristics; groundwater depth and quality; fertilizer application rate; crops planted and yield information so as to generate Water Pollution Index (WPI), which is ranked from low, moderate to high depending on level of pollution of groundwater and its vulnerability to pollution. It provides a powerful and convenient approach for classifying environmental conditions and for describing both natural and anthropogenic changes.

A fuzzification process allows the system inputs and outputs to be expressed in descriptive terms so that rules can be applied in a simple manner to express a complex system (Muhammetoglu & Yardimci, 2006). Defuzzification is a transformation of inputs which maps the output. It is actually a balancing mechanism between the output and the inputs.

2.11.6 The DRASTIC model

The DRASTIC model is one of the most common methods to assess the vulnerability of groundwater to pollution. It identifies areas that are vulnerable to pollution. It can also be used to prioritise areas that need more groundwater monitoring. The higher the DRASTIC Index, the more vulnerable the groundwater is to pollution. It is applied at regional basis. It includes various hydro-geological settings whose physical characteristics are likely to affect groundwater quality. DRASTIC model can be applied on the basis that the following variables are measures (depth to water (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of the vadose zone (I), and hydraulic conductivity (C)) (Ahn *et al.*, 2011). To apply the DRASTIC model in a different aquifer, weights of hydrogeological parameters have to be empirically determined, which may be costly. Pollution vulnerability of groundwater is utmost important in planning and policy making for groundwater conservation and protection.

2.11.7 Chemical Movement in Layered Soil (CMLS)

Ehteshami and Biglarijoo (2014), mentioned numerical models that are used to simulate chemical movement in soil. Those are CHEMFLO, LEACHM (Tredoux, 2004) and CMS (Chemical Movement in Layered Soil). According to Ehteshami and Biglarijoo (2014), CMS is a chemical movement prediction model which allows a soil profile to be divided

into 20 layers; each layer being assumed to have homogenous chemical and physical characteristics. The method is essential in assessing the potential contamination of groundwater and it has got advantages that include accuracy, time efficiency if data is available; it has minimum input requirements. Once the model has been applied, the output can be easily accessible. It can calculate the penetration depth into the soil. Like other models discussed, it also integrates soil, hydrological and chemical characteristics as indicated by (Ehteshami & Biglarijoo, 2014).

2.12 Methods of analysis

In most of the reports that have been conducted to assess water quality, there is an integration of methods used depending on the scope and the objectives of the study. Some of those methods are briefly described but not all of them though it would be prudent for the current research.

2.12.1 Quantitative method

In the study that was undertaken in North West by Bezuidenhout (2011), a quantitative approach was adopted. Rivers and boreholes were sampled according to the guidelines provided in the sampling guide of WRC (1999). Boreholes with pumps (electrical and hand) were selected for sampling. Groundwater was obtained directly from the aquifer by purging for 3-5 minutes before sampling. Triplicate samples were collected per borehole. Samples were transported to the laboratory in ice boxes and analysed within six to ten hours of collection.

Several studies (Reddy *et al.*, 2009; Alabdula'aly *et al.*, 2010; Nkamare *et al.*, 2012; Bezuidenhout, 2013) undertaken for nitrate assessment in groundwater adopt standard APHA (1995) method to analyse nitrates and other variables of concern, which render water quality unfit for drinking (Marais, 1999 cited by Tredoux & Talma 2006). Physical characteristic of water such as electrical Conductivity EC, pH and temperature get to be measured in situ (Bezuidenhout, 2011).

A conventional titration method gets used for total hardness, magnesium (Mg), Calcium, carbonate and bicarbonate. Flame photometry and UV-Visual spectrophotometer gets adopted to for the analysis of fluoride, sulphate and nitrate.

Quantitative research method is commonly used within the natural sciences and is based on the assumption that there is an objective truth existing in the world and it needs to be measured, assessed and explained using scientifically proven principles (Phiri, 2011 cited by Mavunda, 2016). Quantitative method ensures high level of measurement, reliability and precision. It produces quantifiable reliable data that may produce high level of precision. To achieve the best inferences to the study and to paint a better and bigger picture for a research, one will have to use a combination of method, i.e. quantitative be complemented with a qualitative method.

2.12.2 Participant observation method

De Walt and De Walt (cited in Mavunda, 2016), discuss the participant observation method where such a research method makes a researcher involved in daily interactions and events of a group of people as one of the means of learning explicit and tacit aspects of their life routines.

2.12.3 Case Study Method

The Elands River quaternary catchment is huge, thus the study was narrowed to a specific area to make it possible to conclude the study within the required time frame and also to understand how land uses that coexist with one another may impact on groundwater. Therefore the Chaneng Village will be made a case study and the nearby mining activities and other land-uses will be assessed as it was deemed crucial that residential areas and the mines be chosen as case studies. The case study method is the common qualitative method accepted world-wide to understand information systems (Mavunda, 2016).

2.12.4 Physico-Chemical analysis

Bezuidenhout (2013) used the standard sampling and analysis method for physico-chemical parameters. Temperature (°C), electrical conductivity (mS/m) and pH, were recorded on site using a multi-350 probe analyser (Merck, Germany) according to instructions from the manufacturer. Nitrate (NO₃-N), (NO₂-N) and PO₄ levels were determined in the laboratory using methods, kits, reagents and a spectrophotometer from Hach (Hach, Germany).

2.12.5 Microbial analysis

In the study by Bezuidenhout (2013), it was highlighted that microbial analyses are often overlooked when monitoring programmes are designed. The focus is only on physico-chemical analysis. But now it is clear that due to the complexity in the identification of sources of pollution, it is better to analyse a combination of variables instead of measuring just those of interest because best recommendations regarding the measures to be taken to remediate problems has to be made. Such recommendations have to be based on more detailed analysis that is why in their study (Bezuidenhout, 2011), he recommended more research to be undertaken in order to portray the image of the impact of water quality in the water resource of the North West.

This is very critical because the presence of e-coli and faecal coliform together with nitrates may provide an indication as to what could be the source of nitrates. On the other hand the presence of chloride and potassium may depict another source (Bosman, 2009).

As this study will also analyse microbial content of groundwater, as it is imperative to check what other authors have done before. In order to analyse microbial content, the following was undertaken by (Bezuidenhout, 2011):

- Sampling was conducted using the approach as outlined in the WRC (1999) sampling guide.
- Culture-based membrane filtration techniques to count indicator organisms
- 0.45µm filter was used
- Selective agar was also prepared and incubated over five days
- Physical parameters (temperature, TDS, EC and pH) were measured using 350i multi- probe.
- Nitrates were measured using calibrated nitrate probe and appropriate standards in the lab.
- Subsequent to the study conducted by Bezuidenhout (2011), was the large-scale study undertaken in 2013 by Bezuidenhout (2013). Of most interest for this research

are the various methodologies employed to achieve the best results of the study. However, it is impossible to explore all methods for the current assessment due to time constraints. In the study by Bezuidenhout (2013), skills were developed with respect to several research methodologies. Sampling was conducted using standard sampling procedures. Physical parameters were measured using multi-probe equipment. Chemical Oxygen Demand (COD), NO_3 and PO_4 were measured in a lab using Hatch kits and equipment.

- In another study conducted in Limpopo, Seanago and Moyo (2013) undertook microbial analysis as follows:
- One litre glass bottles were sterilized in the autoclave (Model HA 300MD, Hirayama Manufacturing Corporation) at 105°C for 30min and used to collect water samples monthly at each site. The bottles were stored in ice during transportation. Coliform counts were determined using the Membrane Filtration Method.
- A sequential exploratory mixed method design was used for the social water management study. Mixed methods refer to qualitative and quantitative methods used in research to collect and analyse and interpret research data.
- It is important to note that in order to calculate the $\text{NO}_3\text{-N}$ levels from the measured NO_3 one needs to divide with a 4.4: $44 \text{ mg/l NO}_3 = 10 \text{ mg/l NO}_3\text{-N}$ (Rosen & Kropf, 2009; Tredoux & Talma, 2006).
- Interviews, focus groups, observations and discussions were used as the main data gathering methods during the qualitative phase. This was followed by the development of research questionnaire and community survey. A total of 1000 participants were involved during the quantitative phase of the study (Bezuidenhout, 2013).

2.10.6 Modelling

A model is a tool that helps to predict changes in a particular system before they happen. Groundwater modelling is a practical method to determine the flow of groundwater and the associated pollutants. There are different types of models ranging physical models to simple analytical models to complex detailed numerical models.

When considering numerical models there are five basic steps that need to be followed as summarised by Sonnenborg *et. al.*, (n.d):

The modelling process can be divided into five main steps:

Step 1: Plan a model study including describing the problem at hand and the objectives of the modelling exercise.

Step 2: Data collection and conceptualising of the site. Data, including field data is collected and analysed. A conceptual model is developed based on the results of the analyses.

Step 3: Construct a numerical model by means of generating a numerical grid taking into account factors such as geology boundary conditions and groundwater stresses (e.g. groundwater abstraction).

Step 4: Calibrate the numerical model by adjusting model parameters in such a way that they best mimic the actual physical system.

Step 5: Run the required predictive scenarios. When information about concentration levels of contaminants such as nitrates, a mass transport model has to be built upon the flow model. The transport model can provide information on concentrations in time and space.

CHAPTER 3: RESEARCH METHODOLOGY

This study will integrate several methods, which will be based on several objectives to be accomplished by the study ranging from literature review, field survey and sampling procedure.

3.1 Objective 1: to describe biophysical environment and to describe how it could impact on groundwater pollution

In describing the biophysical environment of the study area and in describing how it will impact on groundwater pollution, the further review on literature was undertaken to provide information relating to geology, geohydrology, land use, soils, etc. Adding to that, field observations were made and results will be presented in the form of photos. All results are indicated in Chapter 4.

3.2 Objective 2: to assess potential sources of pollution in Chaneng Village

To achieve this objective, field observation and a literature review were conducted including viewing of the google earth image in gathering information on the potential sources of nitrates. The findings related to this objective are provided in Chapter 4.

3.3 Objective 3: To determine groundwater quality upstream and downstream of platinum producing mines in the vicinity Chaneng Village

The google earth observation was made to identify mining related activities that were in the vicinity of Chaneng Village. Several site visits were conducted to identify boreholes that were to be used during sampling. In conjunction with the hydrocensus, letters requesting permission and notifying those affected were distributed.

Boreholes that were identified were still within the village, one upstream (TBH02) and one downstream (TBH01) of the mining related activity in close proximity. This objective was not achieved to the best intention of the research because the mining houses were sceptical of giving out the information pertaining to water quality for the boreholes that might be located in the desired areas to achieve this objective of the study as the request to use their data and making assessment within their operation was declined.

Nevertheless, samples (macro and microbial) were collected and analysed using standard sampling and analysis procedure outlined by the WRC (2001). The 300ml

bottles were used to collect samples for macro elements and were preserved on site using mercury chloride and stored on a cooler box. The 500ml sterilised bottles were used to collect samples for microbial analysis and also stored in a cooler box. Within 24 hours of sampling time, samples were delivered to the laboratory.

3.4 Objective 4: To determine levels of physico-chemical and microbial parameters in groundwater within a village

A similar approach as for objective 3 was adopted. Most of the people in the village are no longer using boreholes as they were told to abandon such boreholes as they have been informed that groundwater was contaminated and currently they make use of the Magalies pipeline supplied by Magalies Water Board via the Rustenburg Municipality. Most of the boreholes are dry, and some have broken hand pumps thus samples could not be taken. Figure 3-1 is an example of a borehole that is no longer in use.



Figure 3-1: Borehole no longer in use

Amongst those that are still using boreholes, they use it for irrigation for vegetable gardens and some for livestock watering. One borehole found was used for domestic use at Charera high school (TBH03).

TBH01 was equipped with a windmill pump, water is pumped to the storage tank that stores water for livestock watering (as shown in Figure 3-2). A sample was collected from a pipe to the sampling bottles after letting the water run for three minutes.



Figure 3-2: Windmill and storage tank associated with TBH01

TBH02 was equipped with an electric pump, when switched on, water could be pumped from a borehole to fill up six storage JoJo tanks to be used for irrigation (as shown in Figure 3-3). A pipe leading to the JoJo tank was disconnected for the purpose of taking samples. It was also allowed to run for three minutes



Figure 3-3: TBH02 or CBH02 situational presentation

At TBH03, the sample collection point was from a tap used for drinking purposes at the Charera High School. The borehole is also equipped with the electric pump, and when it

is switched on, water flows to the JoJo storage tanks and get distributed to the school facilities and collected via the taps (Figure 3-4).



Figure 3-4: TBH03 associated photos

In one case (TBH04) a bailer was used to take a sample. It was only that borehole where the water level was measured as the borehole was not equipped at the time of sampling, i.e. TBH04 in Figure 3-5.



Figure 3-5: TBH04

3.5 Objective 5: To compare background nitrate concentrations to those observed from the boreholes in the study area

The Regional monitoring data from the Water Management System (WMS) database or National Groundwater Archive (NGA) or other existing databases such as Water Resources (2000), where the nitrate distribution map produced by Maherry *et al.*, (2010) was downloaded from and was used to compare with the results obtained from this study. The NGA could not yield any results. The WMS could not provide adequate information as a number of points were established but in most of the points no samples were taken. Only two points seem to have had data, which seem to have been conducted only once even though the programme had been opened for many years, and those results are presented in Table 5-5. This may be ascribed to the unavailability of personnel from the Regional offices of DWS to collect samples. It could also be that the Geohydrological Unit in the Regional office was not established for a long time, or else it could be that accessibility to those boreholes was a challenge and lastly it may happen that boreholes were dry most of the time. Boreholes that are not production boreholes dry out easily. The limited data that was found from WMS could not be presented as it contained a lot of errors.

Due to limitations in data availability, it was found that any data that could make a significant contribution to the study would be used. As part of the participation method and the researcher being aware of the history of the area regarding nitrate pollution, which necessitated pollution investigation to be undertaken in 2010, it was found relevant that the outcome of the pollution investigation undertaken in 2010 be included in this study, just to establish the trend and make comparisons with the current observations. It must be noted that some boreholes that were used then were no longer available to be used in the current study. However, borehole TBH03 was still in use and was part of the investigation then and is also included in the current study as the TBH02. Maps of the location points and the results are presented in Chapters 4 and 5 respectively.

Another method that was used in this study is the case study as the outcome of the study was not only based on the literature review but the case study being Chaneng village was chosen but the assessment is only on its natural environment. No details related to socio-economic issues will be included as it is not part of the scope, to draw a research project towards adoption of the case study method provides a research with a

direction and focus. There were many other villages within the surrounding but they were not part of the case study, hence were not included.

There was no formal purposeful sampling method as it was noted that the majority of the community had now lost interest in groundwater as running water through pipes is being provided to each household but with those individuals who gave a permission to use their boreholes informal discussions were held.

3.6 Objective 6: To simulate the movement of potential nitrate pollution plumes

Potential sources of nitrate pollution were identified within the vicinity of the Chaneng. These sources included mining and agricultural activities. A finite difference numerical model was developed for the area under investigation. Thereafter a mass transport model was developed to simulate the movement of potential pollution plumes.

The grid for the finite difference model is shown in Figure 3-6. The grid consists of 481 x 422 cells in the x and y direction respectively. The cells are 50 x 50 m. Once the grid was generated the Elands River together with its tributaries (the Selons and Leragane streams) were assigned as fixed head boundaries. In addition the following parameters were assigned to the model:

Flow model

- Transmissivity = $20 \text{ m}^2/\text{d}$ (Groundwater resource assessment II, 2007)
- Recharge = 2.6% of mean annual rainfall $10 \text{ m}^2/\text{d}$ (Groundwater resource assessment II, 2007)
- Specific yield = 0.1 (Spitz and Moreno, 1996)
- Storativity = 1×10^{-4} (Spitz and Moreno, 1996)
- Mass transport model
- Porosity = 0.01 (Spitz and Moreno, 1996)
- Dispersivity = 100 m (Spitz and Moreno, 1996)

It is important to note that only a basic calibration could be conducted by means of ensuring the water level remained approximately 15 m below ground level.

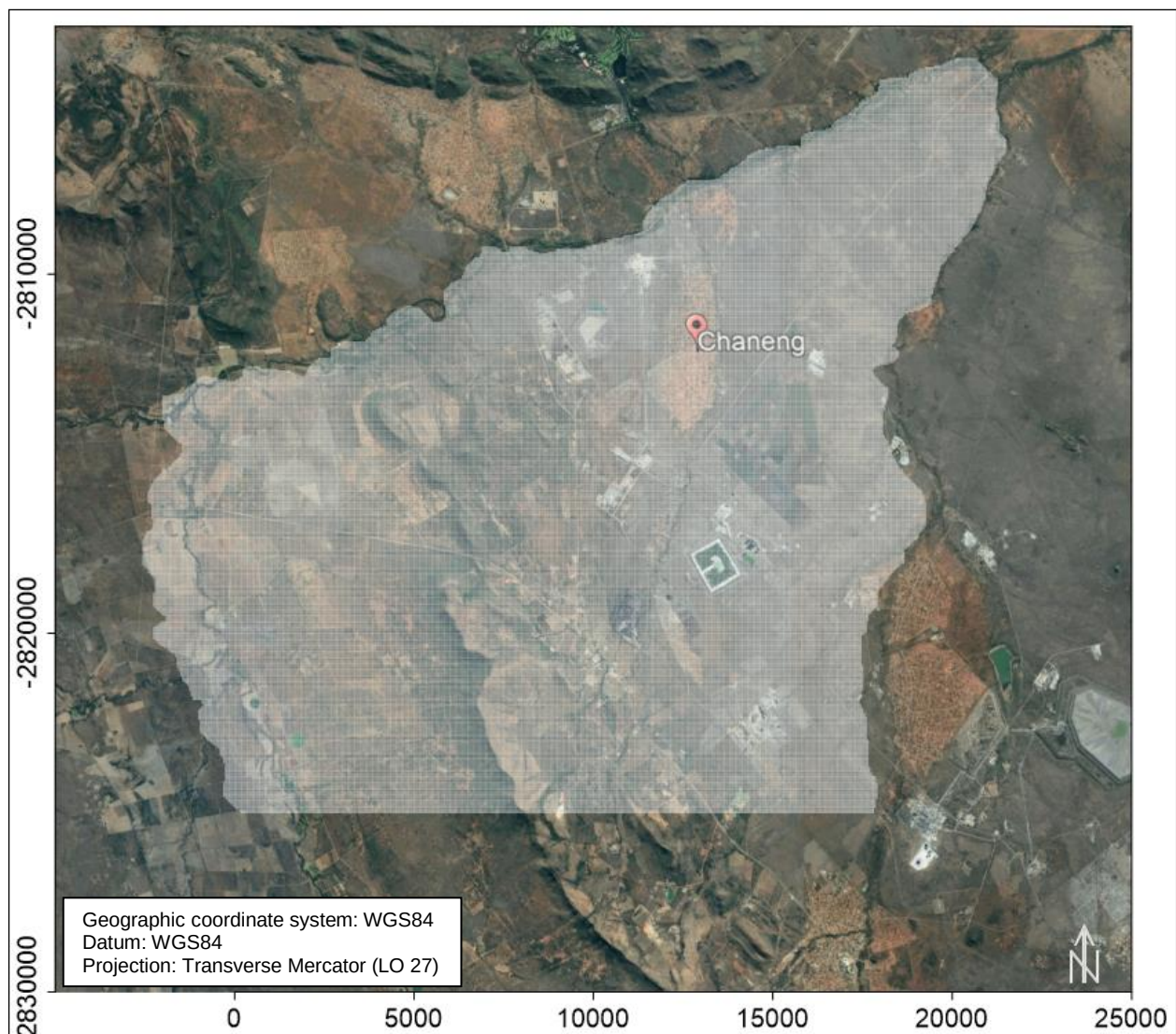


Figure 3-6: Model grid

3.7 Limitations

It was found difficult to access the data from the monitoring boreholes from the mining companies as they could not provide permission to use their monitoring reports that have been undertaken over the years. Adding to the challenge is that NGA could not provide any water quality and groundwater levels in the study quaternary catchment. WMS provided limited data for the quaternary catchment. Though monitoring points were established but monitoring was not conducted. Some of the boreholes that were identified on the eastern side of the village across Bonwagogo stream were found dry because such boreholes were drilled for prospecting and are not production boreholes (TBH05) hence no results associated with such a borehole could be discussed. Though some boreholes were sampled, some of the boreholes were equipped hence not all

borehole levels were measured except for TBH04 and the depth was also measured. Though at the beginning the study was envisaged to examine in detail the pollution sources from the mining operations but access was denied. Due to insufficient long-term monitoring data and the background data, not all methods described in Chapter 2 could be applied in this study. Also contributing to that is that fact that sampling was conducted once.

CHAPTER 4: BIO-PHYSICAL ENVIRONMENT

This chapter provides the locality of the study area including location of boreholes that were sampled for the current study shown on a satellite image and those boreholes that were sampled in the past, most of which are no longer in use. There is also a presentation of the biophysical environment.

4.1 Locality of the study area

Figures 4-1 and 4-2 outline the study area, which is Chaneng Village located in the North-West Province within Bojanala District Municipality under the jurisdiction of Rustenburg Local Municipality. The study area is located in quaternary catchment A22F (Figure 4-3) and is drained by the Elands River within the Crocodile West and Marico WMA.

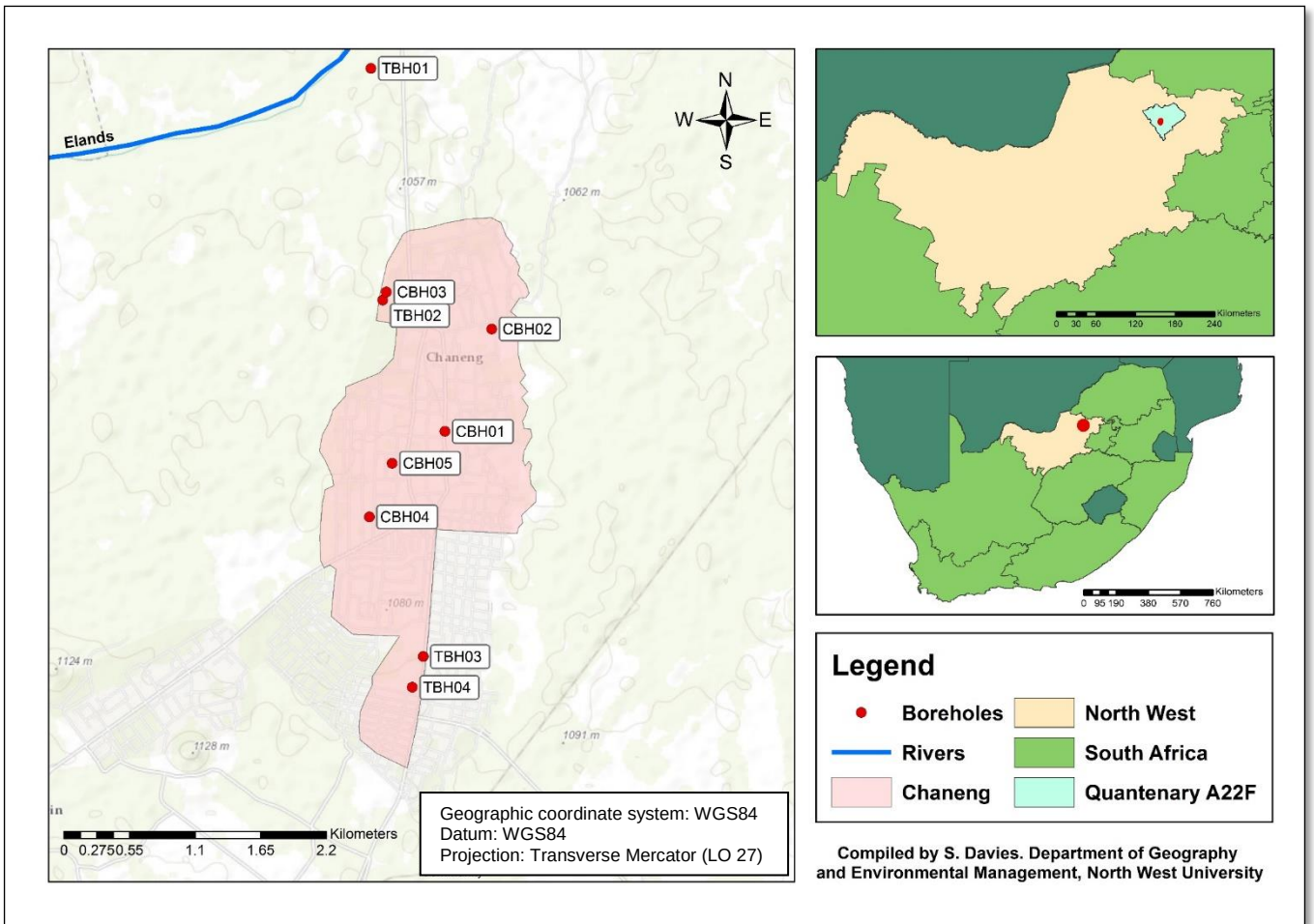


Figure 4-1: Locality map (Davies, 2018)

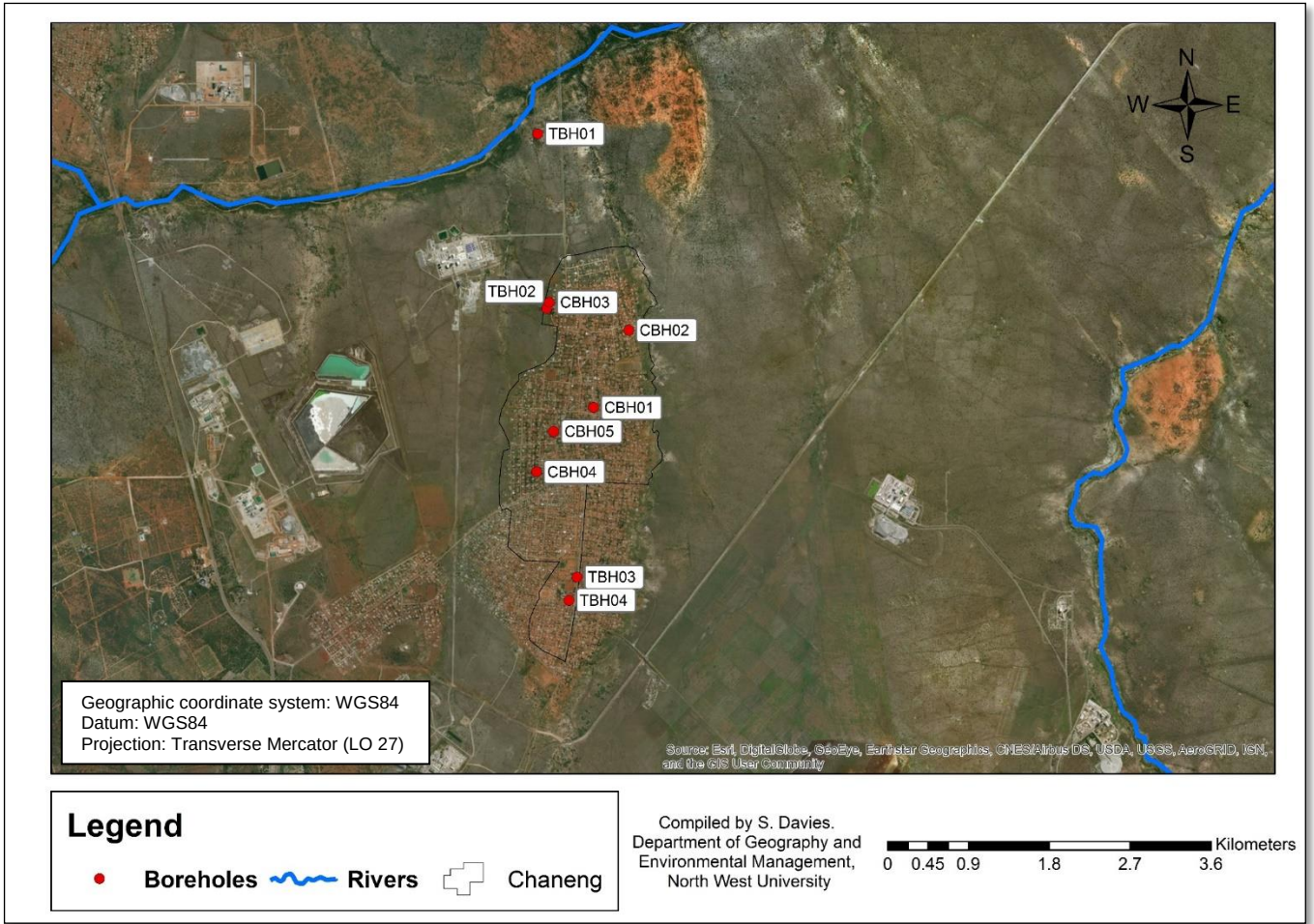


Figure 4-2: Satellite image of the locality area (Davies, 2018)

Figures 4-1 show the location of sampled boreholes in Chaneng village for measured parameters' concentration that was undertaken in 2010 and 2018 respectively. Those that were measured in 2010 were used for comparisons with those measured in 2018 to establish water quality deterioration or pollution trends in this study. Some of the boreholes that were used in the 2010 investigation are part of the current study as in the case of CBH03/ TBH02 and the results will be shown in Tables 5-1, 5-2, 5-3 and 5-5 of Chapter 5.

The discussion of the trend observed on common boreholes in the two studies will be discussed jointly in Chapter 6 as the CBH03 of the 2010 pollution investigation also appear and was still in operation to be available for this study and is referred on the study area as TBH02.

Please note the CB boreholes were sampled in 2010 and the TB boreholes were sampled in 2018.

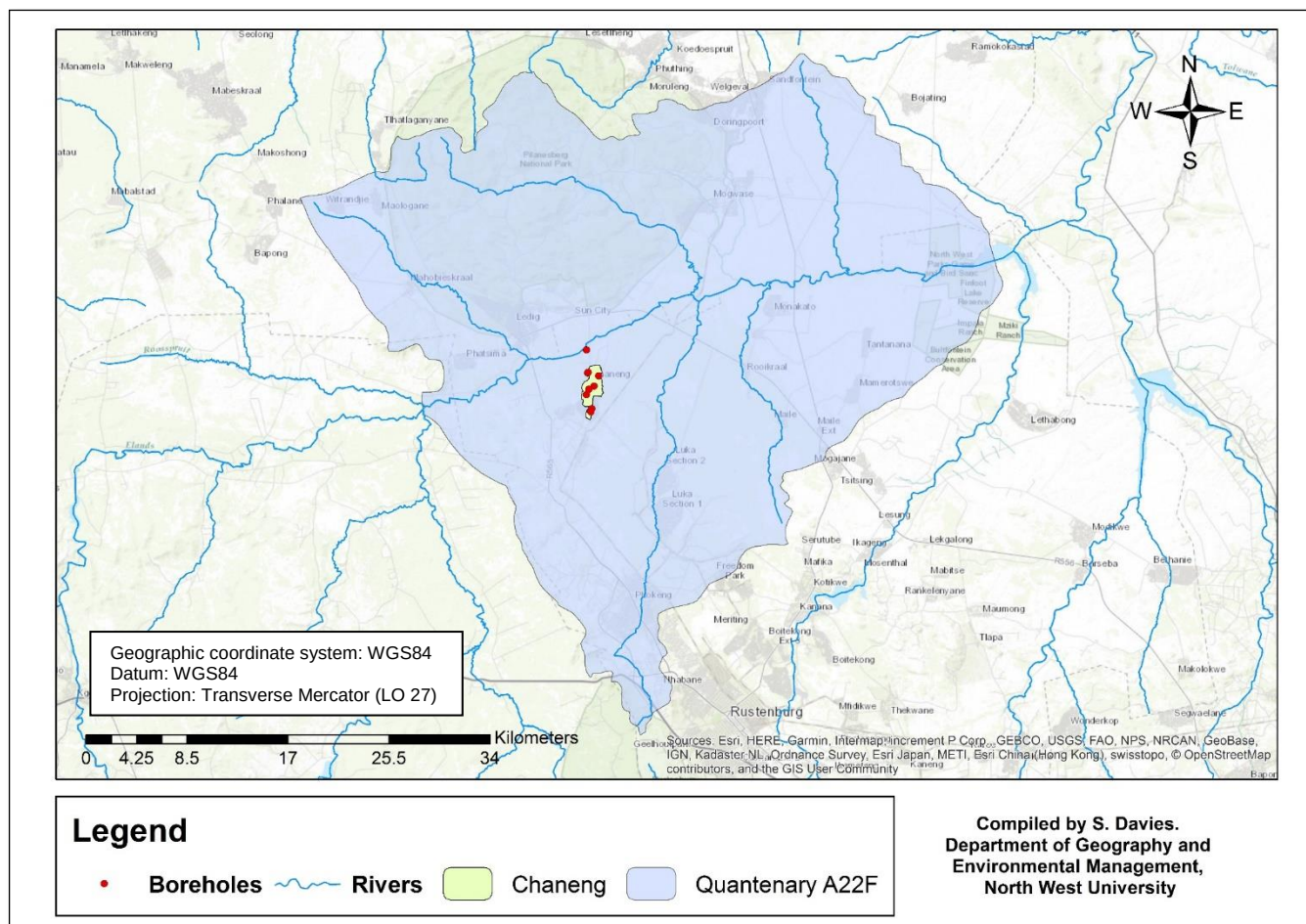


Figure 4-3: Location of study area within the quaternary catchment (Davies, 2018)

4.2 Bio-physical environment

This section attempts to achieve **objective one** of the study, which requires the description of the bio-physical environment within the study area as it influences pollution migration from the potential sources and hence the groundwater quality. As seen in Chapter two of this study, the probability of nitrates or pollution reaching groundwater is highly influenced by bio-physical environment such as climate, elevation, land use, geology, soil, groundwater depth and the rate of recharge. The interconnection that exists in the ecosystem makes it difficult to explain how each of the aspects of the physical environment affect groundwater pollution without bringing the other aspect as will be seen in the subsequent discussion.

4.2.1 Climate

According to SRK (2015), the study area falls within the Highveld Climatic Zone which is characterised by moderately warm temperatures, with mild dry winters and hot summers. Based on the data provided by the South Africa Weather Services, 2018 the temperature of the study area is presented in Figure 4-4 at average monthly levels. The average minimum is 21°C and the maximum of 31°C for the station no. 05115234 located for Rustenburg measured from 1993 to 2018. Monthly average rainfall for the same period same station is presented in Figure 4-5 and it shows that the highest rainfall occurs in January. Rainfall in the North West Province occurs as afternoon summer rain (SRK, 2015) in a convective form. Such intense short duration rains result into large amounts of debris carrying along with runoff pollutants flushed to the low lying areas of a catchment, where it gets deposited and where infiltration takes place eventually. Such deposits of pollutants may remain with ponding water and during the hot sunny day, water evaporates and it dries out and soil-water dries up and large cracks form and when another cycle of rain comes which is referred to by Reddy, *et al* (2009) as monsoon, it results into high level of contamination to groundwater which is flushed into cracks of the Arcadia (Turf soils) (Grobler, 1976 cited in Tredoux & Talma, 2006), which could be the case in the vicinity of borehole TBH01, which was found to be the highest contaminated borehole in the current study. This condition of soil influencing on contamination was described in (Heaton, 1985).

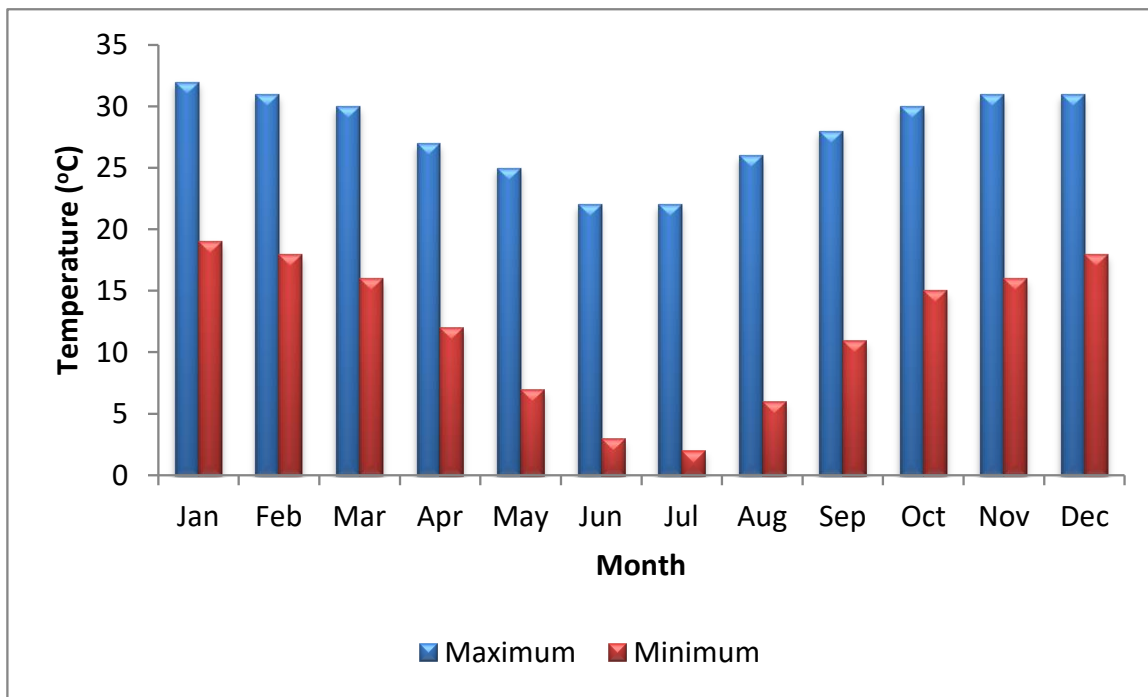


Figure 4-4: Average temperature of the study area (South African Weather Services, 2018)

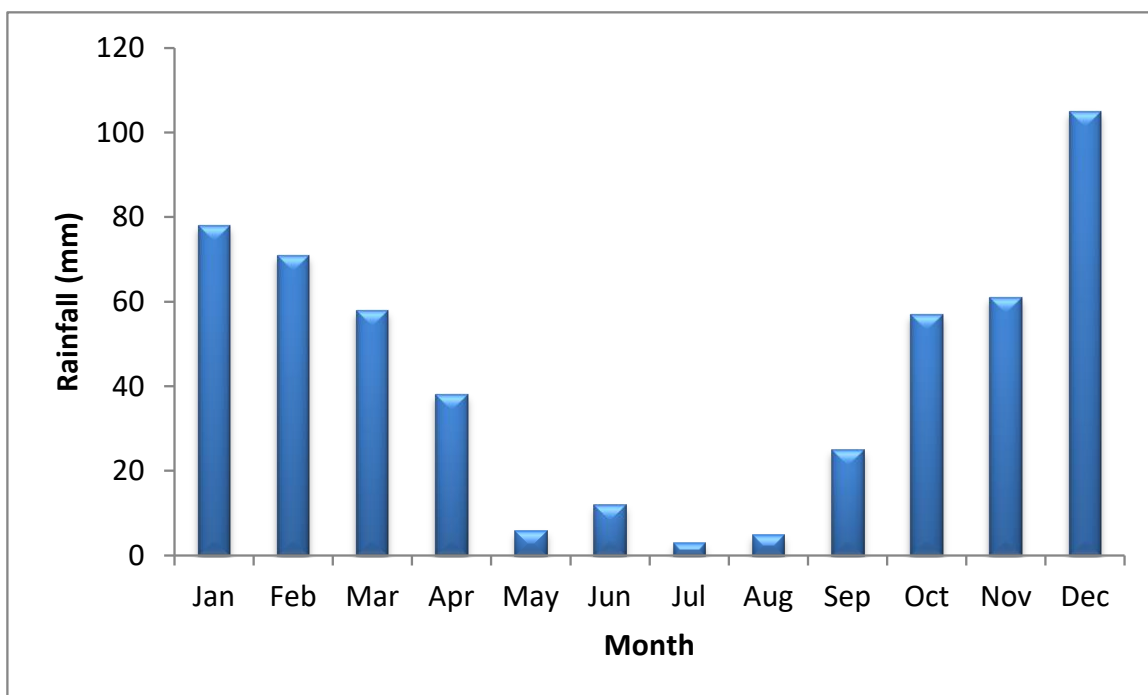


Figure 4-5: Average rainfall of the study area (South African Weather Services, 2018)

4.2.2 Elevation/ topography

Topography is an essential element of groundwater studies. The quantification methods dealt with in Chapter 2 repeatedly make mention of topography as a parameter to be included when assessing groundwater vulnerability to pollution so that prevention measures can be adopted.

Not drawn to scale is the schematic drawing (Figure 4-6) of the location of sampled boreholes in 2018 in association with the activities that are potential sources of pollution in the vicinity.

Though the average topography within the Elands quaternary catchment extends from Phokeng to Pilanesburg south border is 1060 metres above sea level (masl) (SRK, 2015), the recorded surface elevation at the study area during the site visit and of the day of sampling ranged from 1064 masl (TBH01), the lowest points to 1094 masl (the highest point) being TBH04.

A slopes map is presented in Figure 4-7. The slope within the study area is 2-6%, which is an indication of moderate slope, with moderate effect to the vulnerability to pollution, i.e. based on Majola and Musekiwa (2011)

A contour map of the topography is presented in Figure 4-8. Topography influences the movement of contaminants and to determine whether nutrients will get out of a system by running off or will remain on the surface for infiltration (Aller *et al.*, 1987 cited in Majola & Musekiwa, 2011).

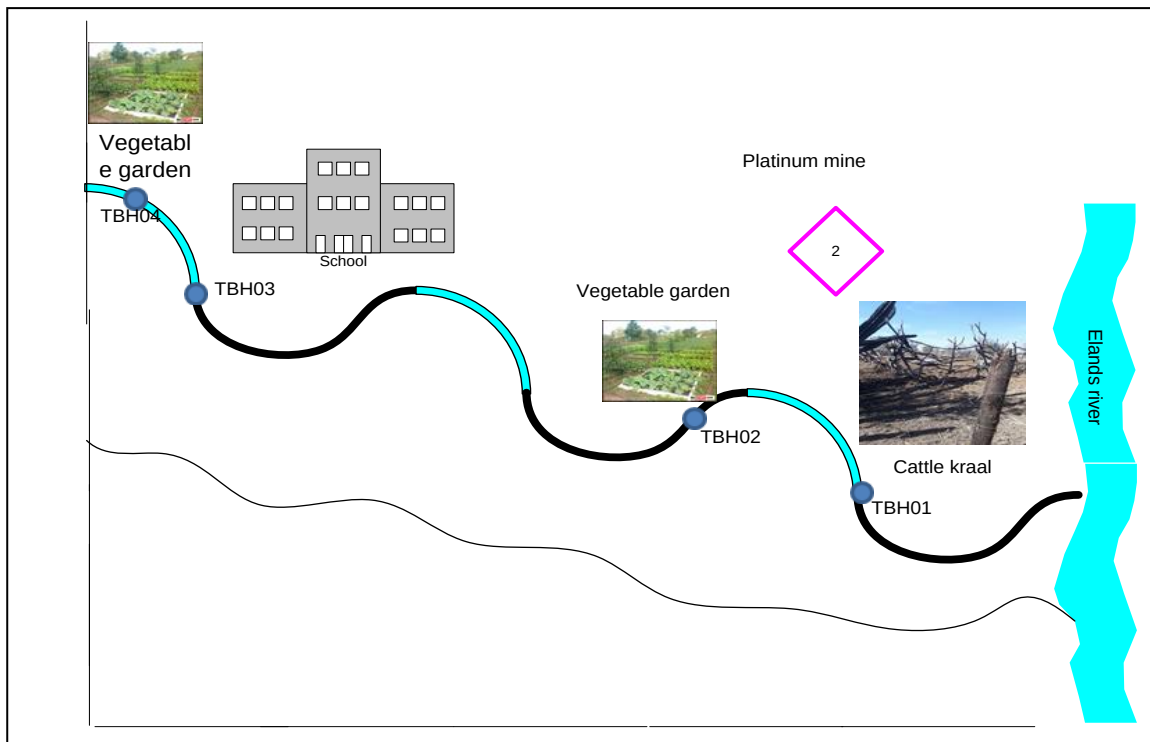


Figure 4-6: Arrangement of boreholes on the Chaneng landscape and their association with potential pollution source (not drawn to scale)

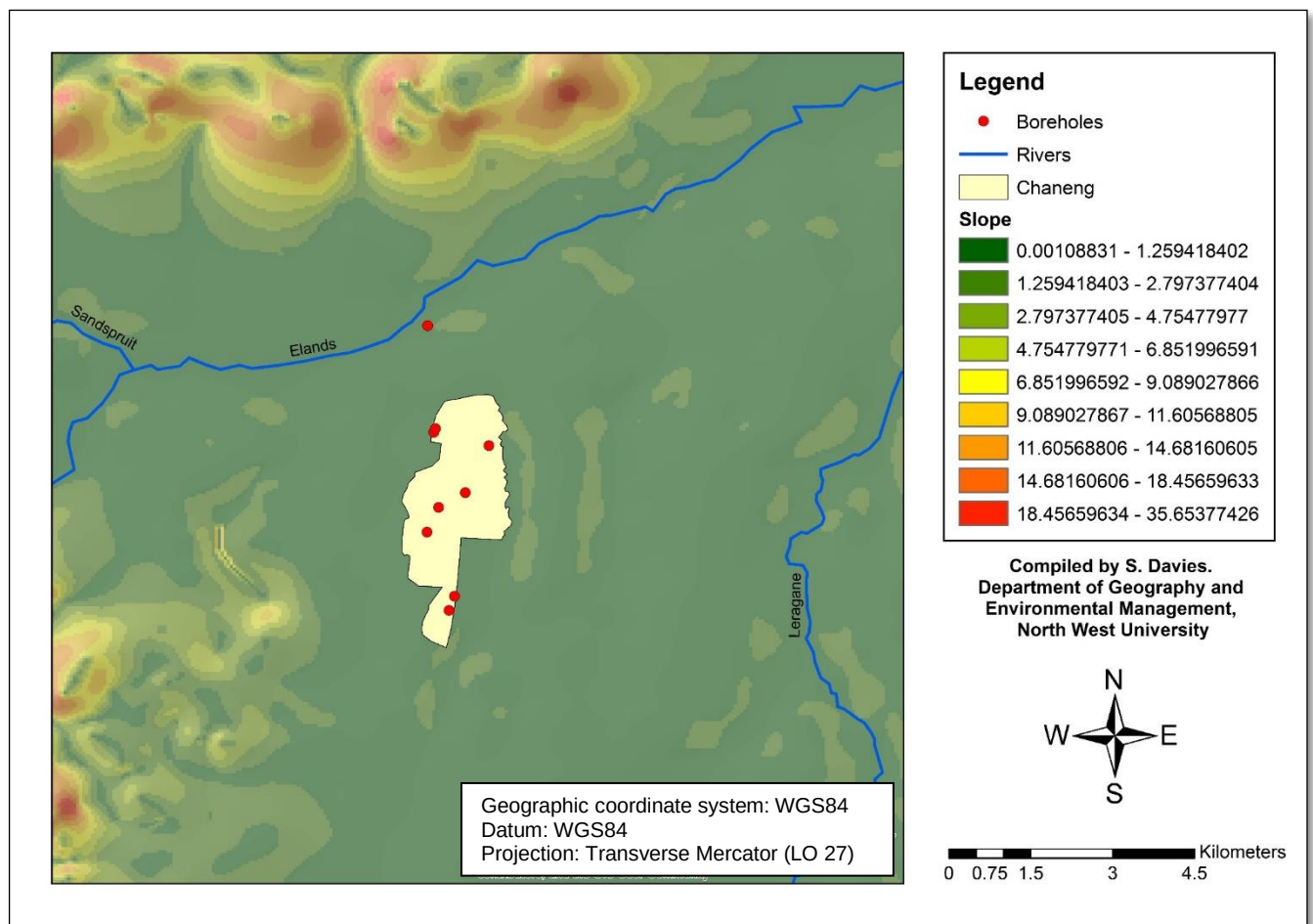


Figure 4-7: Slope map of the study area (Davies, 2018)

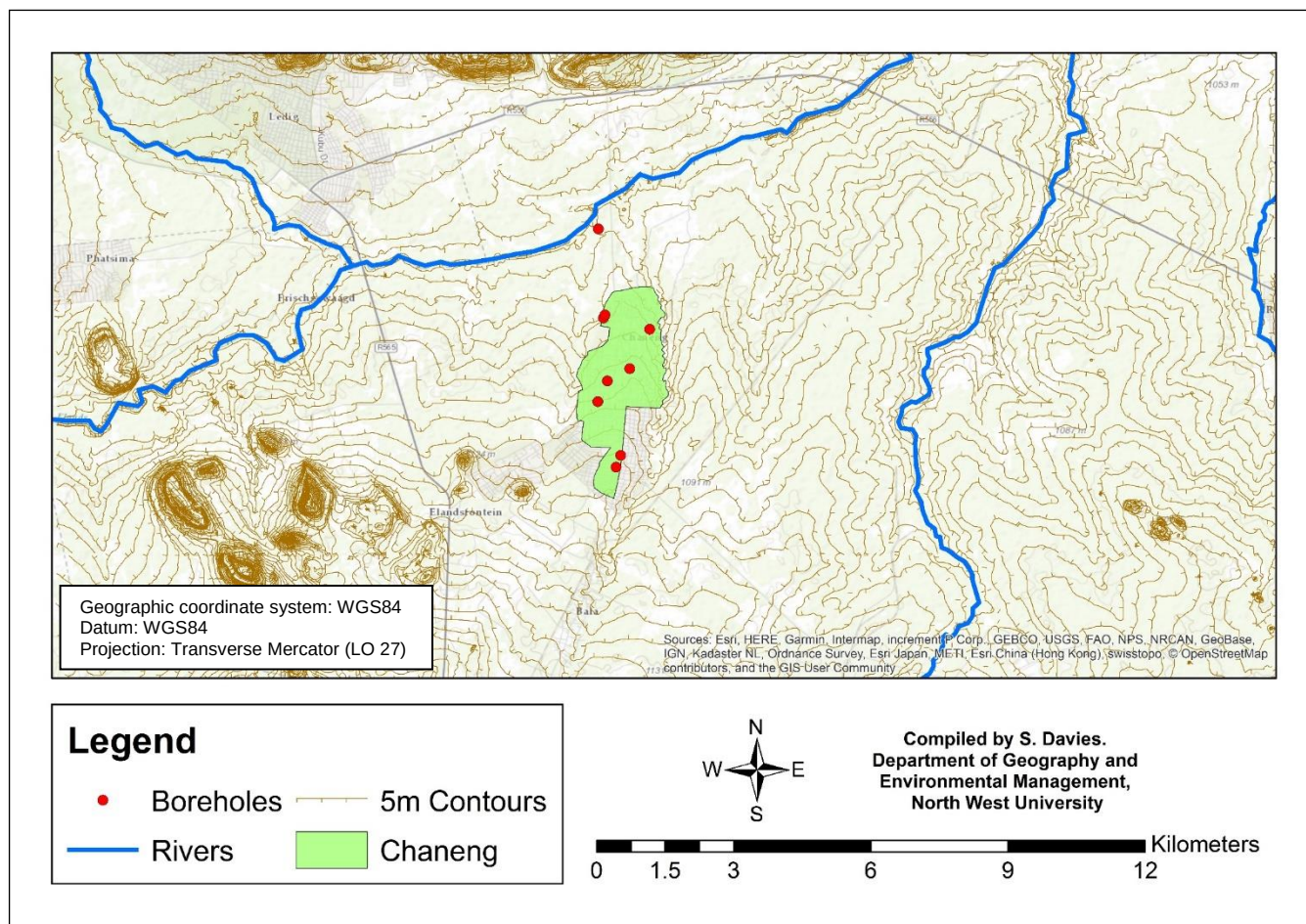


Figure 4-8: Topography map (Davies, 2018)

The contour map presented in Figure 4-8 indicates the direction of surface elevation and that surface water flows to the direction of the Elands River from the side of the study area.

4.2.3 Land cover and the land use activities

Figure 4-9 shows the land cover of the study area. The land cover has an influence on the infiltration rate of the underlying soil and thus influence groundwater recharge and percolation of water taking along contamination which eventually affects groundwater.

Land use activities as shown in Figure 4-10 in the area are predominantly mining, livestock farming that usually get concentrated near water points and mainly residential areas that make use of on-site sanitation and the vegetable garden projects are practised. Though there are still some agricultural activities where dryland crops such as sunflower are being planted, most of the land has been converted to mining activities. Below is the google map representing the land use activities (Figure 4-10) within the area to explicitly indicate what the land cover map cannot be shown in detail.

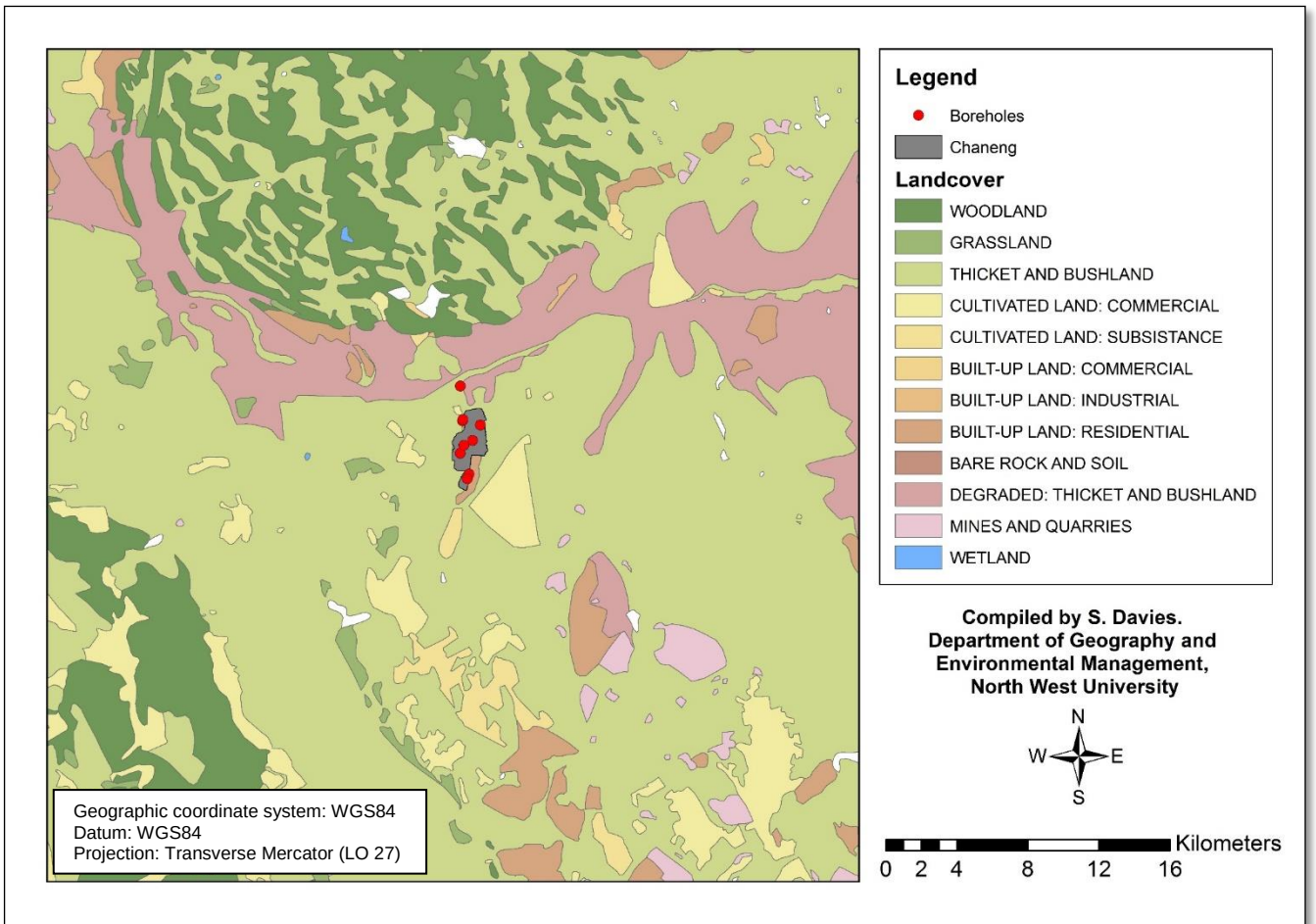


Figure 4-9: Land cover map (Davies, 2018)

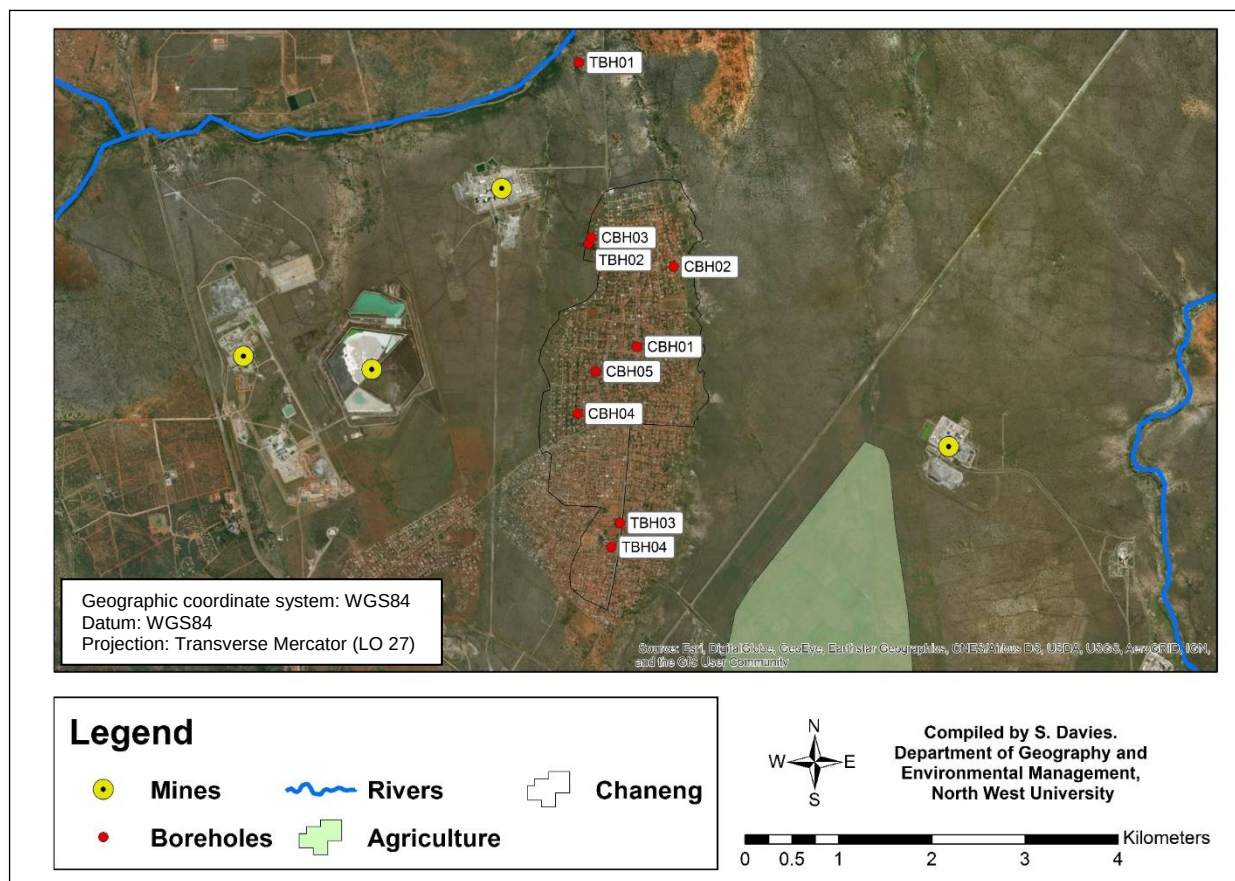


Figure 4-10: Land use activity map (Davies, 2018)

4.2.4 Geology

Figure 4-11 illustrates the geology. It is mentioned that platinum producing rocks may not contain nitrates but during the minerals extraction processes nitrates are introduced (Bosman, 2009). It was also mentioned that in most cases assessment of nitrates focuses on inadequate on-site sanitation and other common sources without examining platinum producing mines as they use nitrate explosives. Geological structures are essential elements that influence groundwater availability and flow which equally influence the rate of pollution as well as the direction of the pollution migration (Tredoux & Talma, 2006). Rain water infiltrates through the unsaturated soil to reach the underlying bedrock in which it (the rain) percolates through the dikes and faults/fractures to reach the underlying aquifers. Dykes are sheet of magmatic or sedimentary rocks that form in between the layers of the pre-existing rocks (SRK, 2015).

Nitrates and nitrites occur together in soil from natural erosion of geological nitrogen (Bosman, 2009). In normal geological processes such as erosion, desertification and soil formation, nitrate release occurs slowly over long periods of time, allowing the release of low levels of nitrogen that is essential for the formation of fertile soil. Metasedimentary and metavolcanic lithologies, such as greenstone and slate, typically contain high levels of elemental Nitrogen which could be released as nitrate (Bosman, 2009).

The study area is, at most, underlain by Rustenburg Layered Suite of the Bushveld Complex, in which Gabbro-Norite (Titus *et al.*, 2017) is the dominant igneous rock that has a bearing on platinum group metals from Merensky and UG2 Reefs. There are numerous faults and north-striking dykes cut across the area (Mavunda, 2016). The dominant feature is the Pilanesberg intrusion to the north and Pilanesberg age syenite and unmineralised dykes occur throughout the complex. Iron Rich Ultramafic Pegmatoid (IUEB) containing Titanium rich Magnetite (SRK, 2015) is also found.

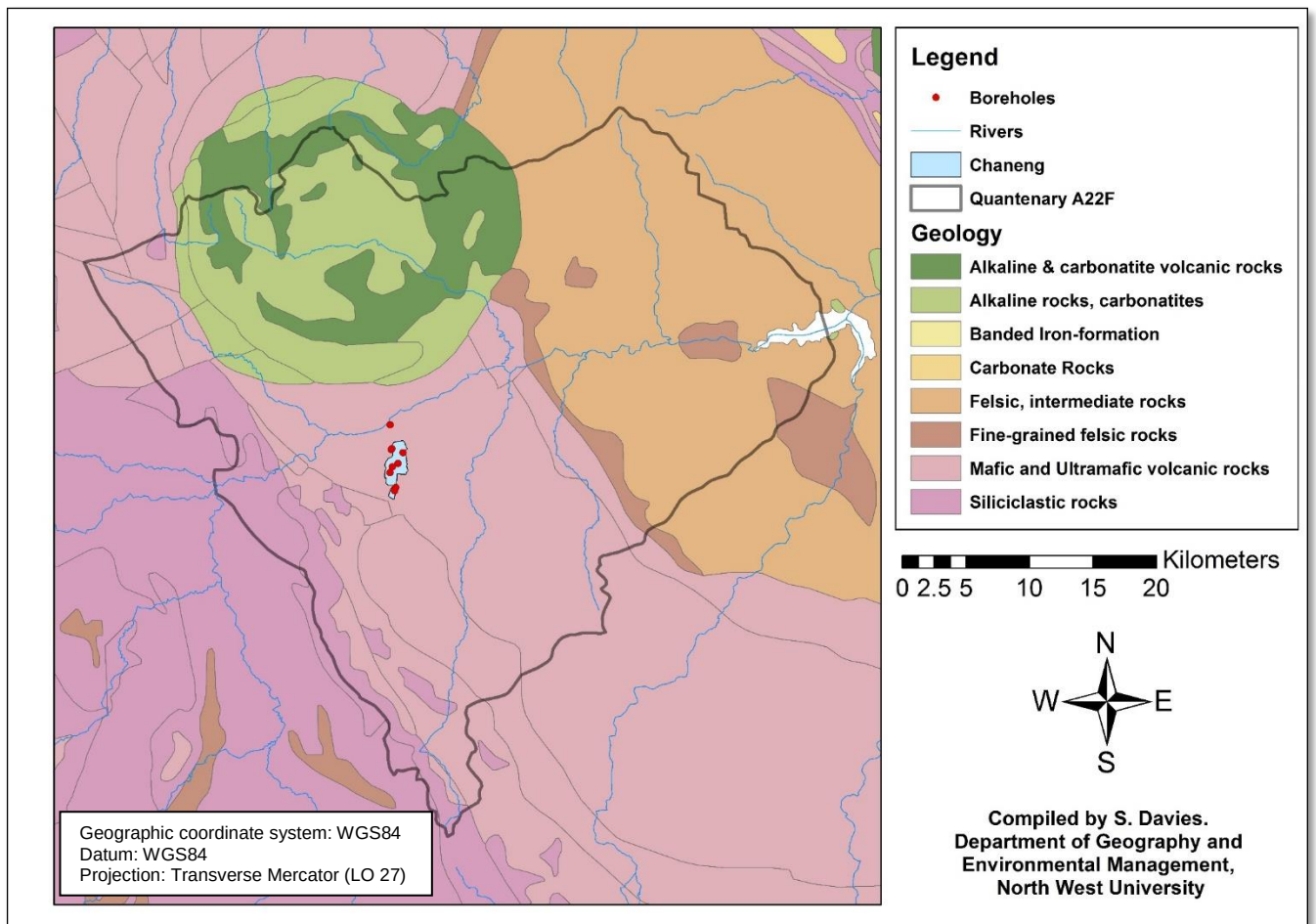


Figure 4-11: Geology map of the study area (Davies, 2018)

4.2.5 Soils

Soil is a natural nitrogen sink or deposit (Bosman, 2009), from which it can be taken up by plants or leach to groundwater and or run off to surface water resources causing eutrophication (Akwensioge, 2012). From the field observation, there were two types of soils that were identified. As one enters the village from the north side (i.e. north of the study area soils are observed as deep dark clay soils and are similar across the Elands River up until one enters the village). These soils are noted with a lot of cracks, depicting turf or Arcadia properties (SRK, 2015). Black turf soils have notably high nitrate values (Grobler cited in Tredoux & Talma, 2006). As one progresses to the village, the soils start to change, within a village, especially at borehole TBH03 and TBH04 soil colour from the topsoil view point was reddish. Figure 4-12 shows variation in soils within the area, which will have a major influence on the drainage potential of the area and hydraulic conductivity. Photos of the soil types are presented in Figure 4-13.

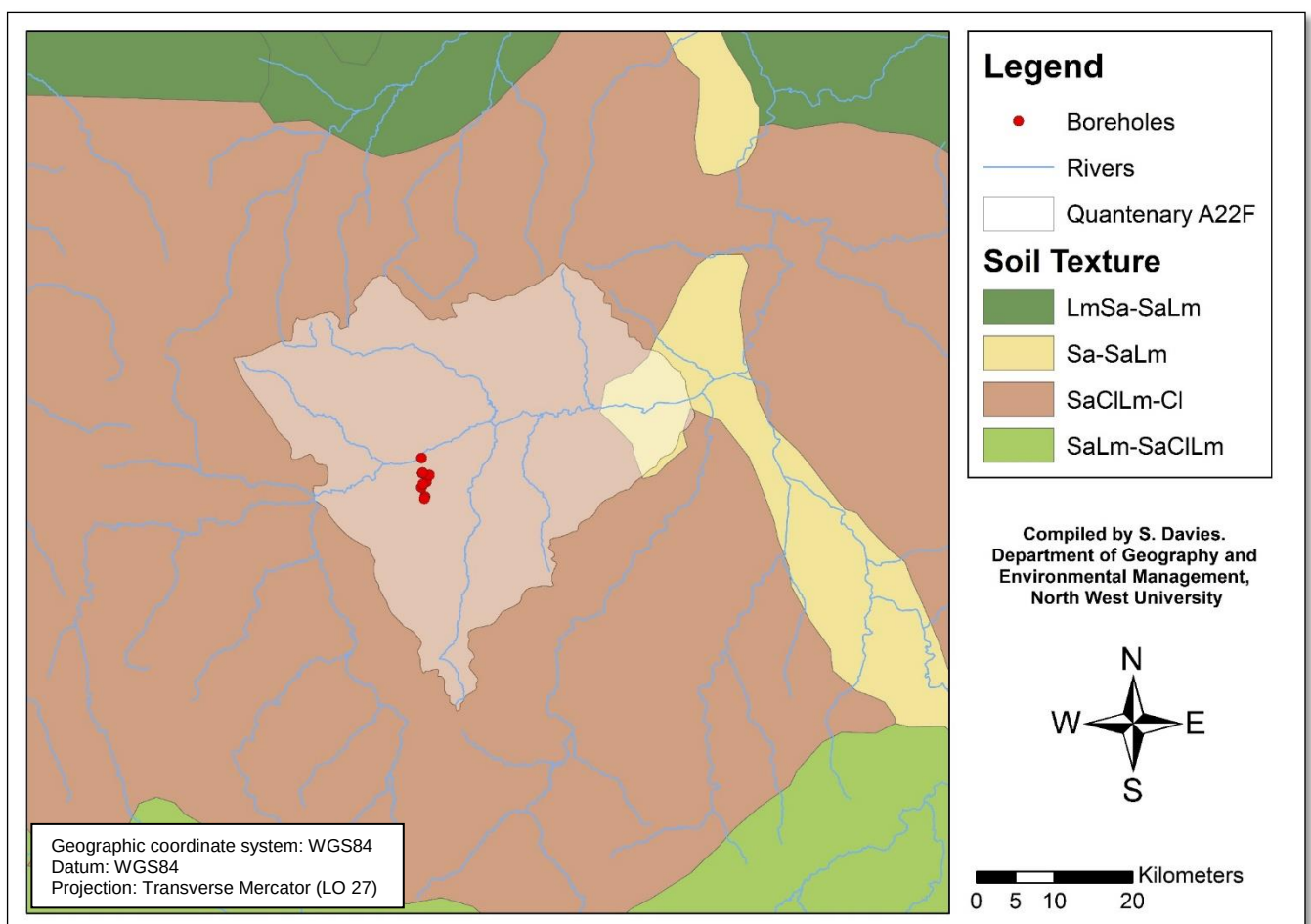


Figure 4-12: Soil variation map within the study area (Davies, 2018)



Figure 4-13: Photos of soil types

According to the map produced by Musekiwa and Majola (2011), the study area falls within the soil texture distribution class of sand clay loamy-clay. Particle size distribution (soil texture) has an influence in soil/water relations such as permeability (hydraulic conductivity), soil water retention, leaching of solutes to groundwater water (Reddy *et al.*, 2009). Soil texture, though not always the case (Witheetrirong *et al.*, 2011), has a role in determining the pollution potential of the area which gave effect to the groundwater vulnerability index of the area (Musekwa & Majola, 2011).

4.2.6 Geohydrology

The geohydrology of the area is characterized by intergranular material, faults and fractures (SRK, 2015; River Health Programme, 2005). Figure 4-14 indicates that the average yield of a borehole is the 0.1 – 0.5 l/s, however this increases in the southern part of the village to 0.5 – 2.0 l/s. According to Parsons and Conrad (1998), the aquifers in the study area have been classified as minor aquifers which do have low primary permeability or have variation in permeability.

According the map produced by Musekiwa and Majola (2011), depth to groundwater within the study area is within the region of 5-15m. According to the measurement made on site during the date of sampling in borehole TBH04, it was found that the level of water table was 14m below the ground.

A national vulnerability GIS cover (Musekiwa & Majola 2011) was generated for South Africa taking into account the following factors:

- Depth to groundwater
- Recharge
- Aquifer media
- Soil Media
- Topography (% slope)
- Impact on the vadose zone

The resultant groundwater vulnerability for the study area is shown in Figure 4-15, with the study area being moderately vulnerable.

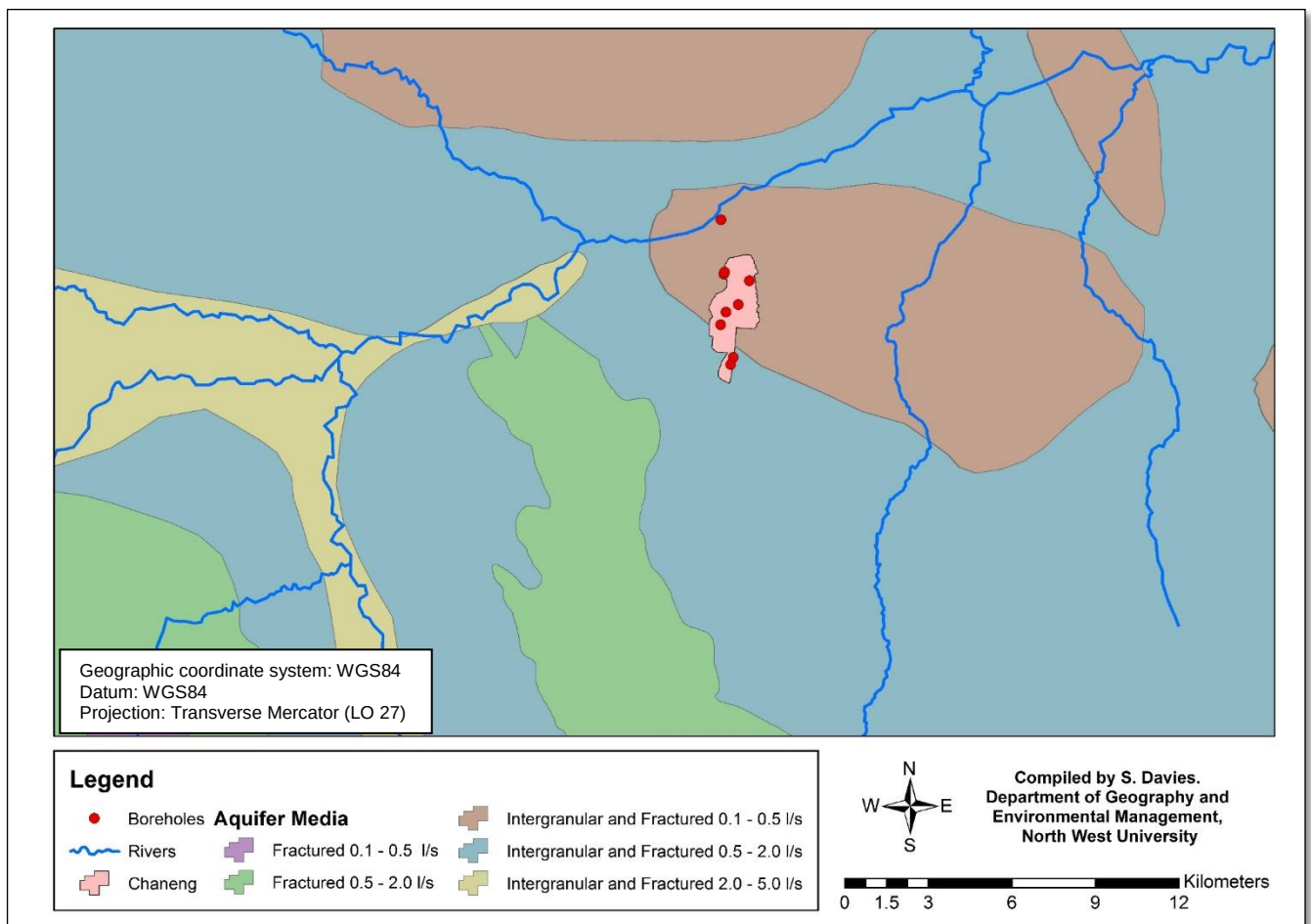


Figure 4-14: Aquifer media of the study area (Davies, 2018)

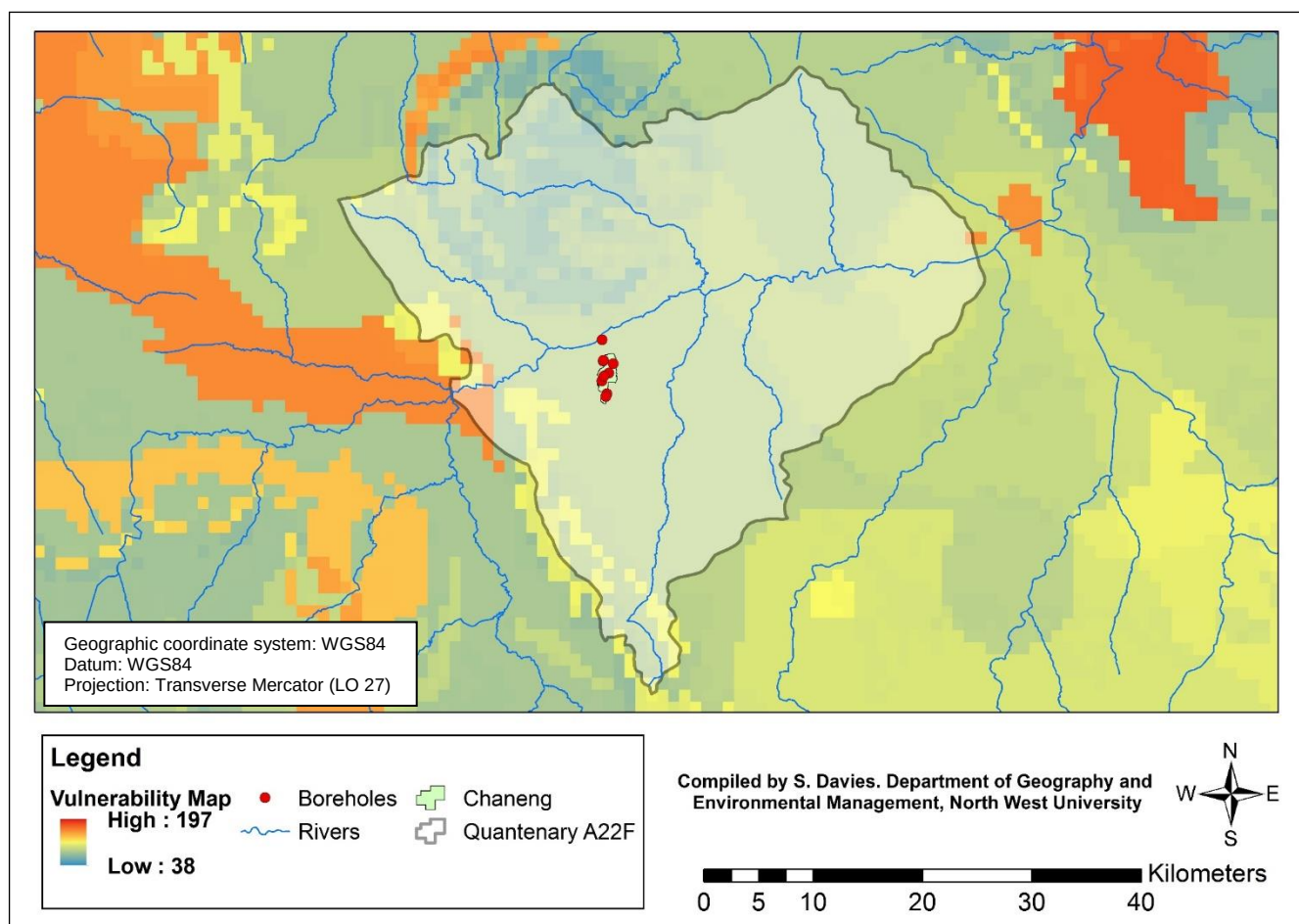


Figure 4-15: Aquifer vulnerability (Davies, 2018)

In conclusion, based on the assessment from the existing literature, the geohydrological characteristics at which the study is being undertaken shows the geological group in the Rustenburg Layered suite, underlain by the Bushveld Complex Sub-group made of Gabbro-norites igneous rocks containing primarily silica minerals, which has an influence on the original chemistry facies of water (SRK, 2015). In this geological setting, one would find groundwater within a fractured, minor aquifer.

4.3 Potential pollution sources

This section responds to **objective two** of the study, which aims to identify the potential sources of nitrates (point source) and non-point sources. Satellite images demonstrating the land use activities that may produce nitrate which eventually pose a threat to groundwater and other water resources in the vicinity. The larger possible polluter activities are presented in Figure 4-10. More detail regarding possible sources of nitrate are documented in Appendix A.

CHAPTER 5: RESULTS OF THE STUDY

This Chapter intends to demonstrate findings associated with **objectives three, four, five and six** of the study, which are:

- To determine groundwater quality upstream and downstream of platinum producing mines in the vicinity of Chaneng village;
- To determine levels of physico-chemical and microbial parameters in groundwater within a village;
- To compare background nitrate concentration to that observed from the boreholes in the study area;
- To simulate potential nitrate pollution plumes

The physical, chemical and microbial parameters of concern that were analysed from boreholes that were accessible to accomplish this study are as follows:

5.1 Physical parameters

- Temperature (in situ), pH (in situ) and EC (in situ)

5.2 Chemical parameters

- Ca (mg/l), Mg (mg/l), Na (mg/l), K (mg/l), Cl (mg/l), NO₃-N (mg/l), PO₄ (mg/l), Total Hardness, TOTALK (HCO₃) (mg/l), SO₃, TDS, EC (mS/m)

5.3 Microbiological parameters

- E-coli and total coliform

Table 5-1 demonstrate the water quality results from the boreholes that were sampled in 2018 and Table 5-2 demonstrate the result of water quality that was sampled as ad hoc on pollution investigation incidence in 2010 (unpublished assessment). The microbial results are demonstrated in Table 5-3. Samples or water quality reports from the boreholes that are located near the potential pollution sources within the mining operations could not be included in this assessment due fact that request to use such data was not granted.

Table 5-1: Groundwater quality results as sampled in July 2018

Macro- elements										
Borehole number	Ca	Mg	K	Na	PO ₄	SO ₄	NO ₃	NO ₃ -N	Cl	HCO ₃
mg/l										
TBH01	159.11	52.01	1.17	54.95	0.05	71.59	186.80	42.2	87.43	
TBH02	121.44	91.14	0.78	36.32	0.11	119.18	156.91	35.6	148.11	
TBH03	70.94	54.20	3.13	59.31	0.15	95.18	37.64	8.5	118.74	
TBH04	86.97	68.78	2.35	40.46	0.09	126.69	1.65	0.35	142.78	
Macro-elements								TDS	TAL	Total Hardness
Borehole number	Fe	Mn	Cu	Zn	B	pH	EC			
mg/l							(mS/cm)			
TBH01						7.60	1.47	955.5	397.5	611.49
TBH02						7.37	1.51	981.5	390	678.56
TBH03						7.35	1.07	695.5	252.5	400.33
TBH04						7.05	1.18	767	320	500.41

Table 5-2: Groundwater quality results as sampled in 2010

Macro- elements										
Borehole Number	Ca	Mg	K	Na	PO ₄	SO ₄	NO ₃	NO ₃ -N	Cl	HCO ₃
mg/l										
CBH01	149.02	54.06	2.17	60.95	0.03	74.68	61.6	14.0	90.43	
CBH02	130.44	98.14	0.88	46.32	0.21	121.18	179.96	40.9	158.11	
CBH03	76.94	56.2	2.88	69.31	0.18	85.18	35.33	8.03	120.74	
CBH04	96.97	76.78	2.65	50.46	0.39	136.69	30.272	6.88	132.78	
CBH05	78.94	66.2	2.18	79.31	0.19	86.18	35.33	18.07	130.74	
Macro-elements								TDS	TAL	Total Hardness
Borehole Number	Fe	Mn	Cu	Zn	B	pH	EC			
mg/l							(mS/cm)			
CBH01						7.5	1.57	958.6	400.5	633.49
CBH02						7.45	1.07	698.5	262.5	420.33
CBH03						7.47	1.55	988.5	490	688.56
CBH04						7.15	1.28	787	330	510.41
CBH05						7.15	1.17	727.5	252.4	430.33

Table 5-3: Microbial analysis

Borehole Number	Total Coliforms (cfu/100ml)	E-Coli (CFU/100ml)
TBH01	<1	<1
TBH02	<1	<1
TBH03	<1	<1
TBH04	<1	<1

The pH of the boreholes sampled at the day of sampling ranges between pH7 and pH7.6. It is known that pH is the important factor in chemistry as it affects chemical reaction of different compounds including the compounds of nitrogen. Different oxidation/ reduction state of elements are influenced by the pH. The observation from analysis of water quality shows that the pH is neutral. Allowable pH according to Target Water Quality Guidelines (TWQG) (DWAF, 1996) for domestic and irrigation is 6.0-9.0 and 6.5-8.4 respectively. According to RQOs pH range is also 6.0-9.0. According to SANS, 241/2015 is $\geq 5 \leq 9.7$. No indication of pH range for livestock had appeared in any standards.

Graphs presented from Figures 5-1 to 5-12 represent the concentration of parameters from sampled boreholes within a study area. There is no particular reason why such variables are grouped within one graph and some not. For instance, Figure 5-1 shows the concentration of **potassium and phosphate**.

Potassium is also presented in a box cut (Figure 5-11). It ranges between (0.88) to just (3.13mg/l). It is in such small concentration that water in boreholes sampled would pose no risk associated with potassium. DWAF (1996) indicates that it may cause vomiting and nausea. In high concentration, it may cause salty taste in water. According to WHO (2017), potassium pose no health risk at concentrations found in drinking water, provided that water is treated. Additional discussion related to potassium is found in Chapter 6.

Phosphate is also presented in Figure 5-1. A statistical presentation by means of a box-cut is presented in Figure 5-12. Phosphate is found in minute quantities between 0.03 -0.39mg/l. More interpretation is provided in Chapter 6.

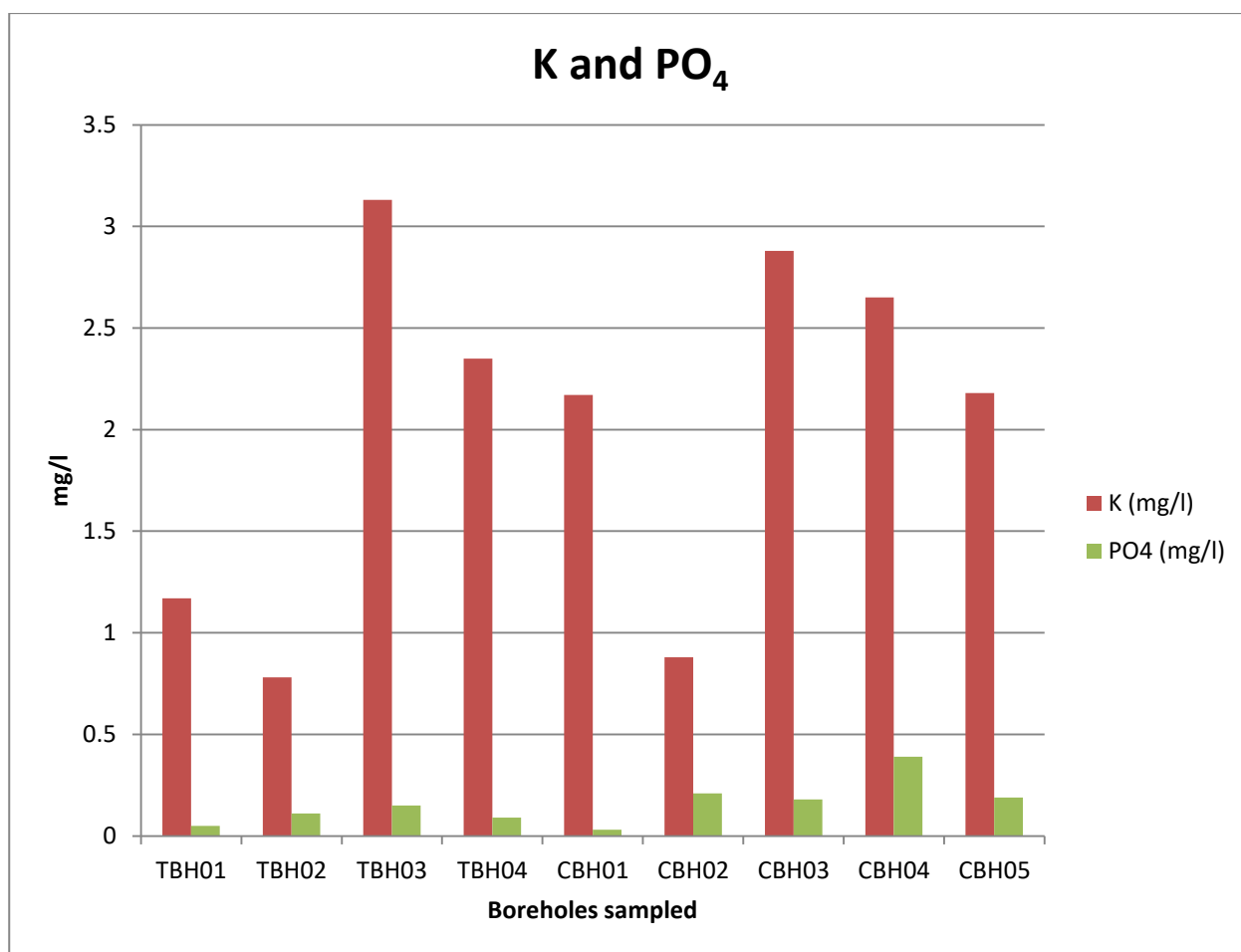


Figure 5-1: Potassium and phosphate

NO₃-N concentration is distributed in Figure 5-2 and 5-8. Nitrate concerns in drinking water are in the lime light in most research studies. This analysis is compared to the limits set for water use purposes tabulated in Table 2-1 and further discussions are in Chapter 6.

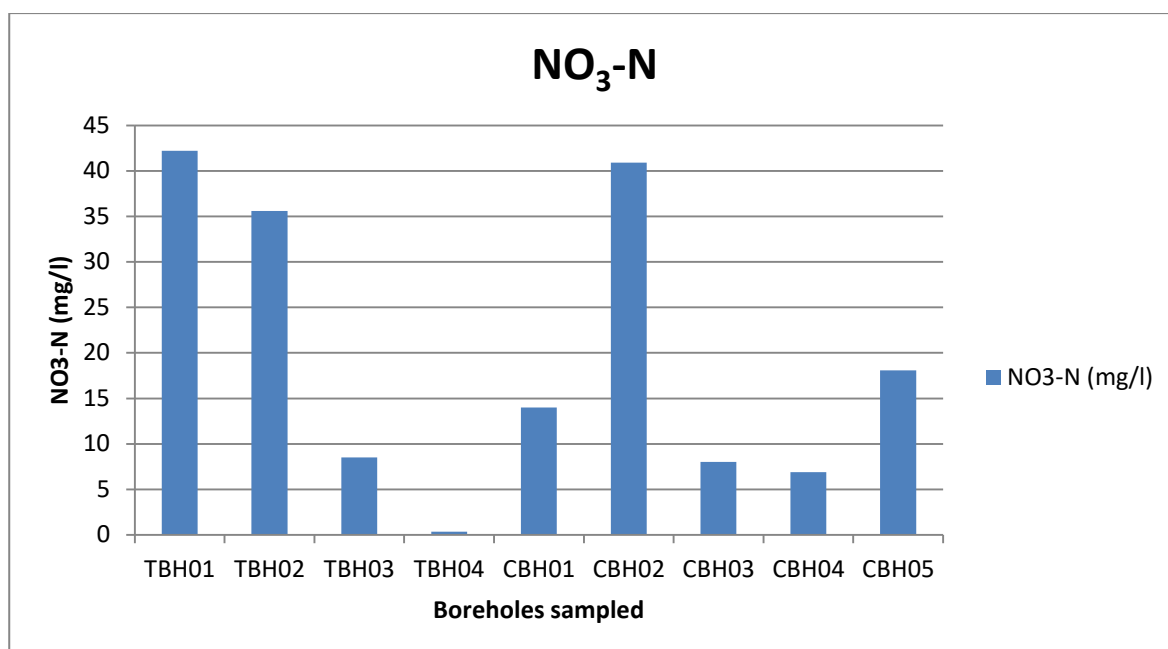


Figure 5-2: Nitrate

Sodium and chloride is shown in Figure 5-3 for the concentration distribution from all boreholes sampled. Sodium and chloride concentration is also presented in box-cut graph Figure 5-11 and 5-12 respectively. More is dealt with in Chapter 6.

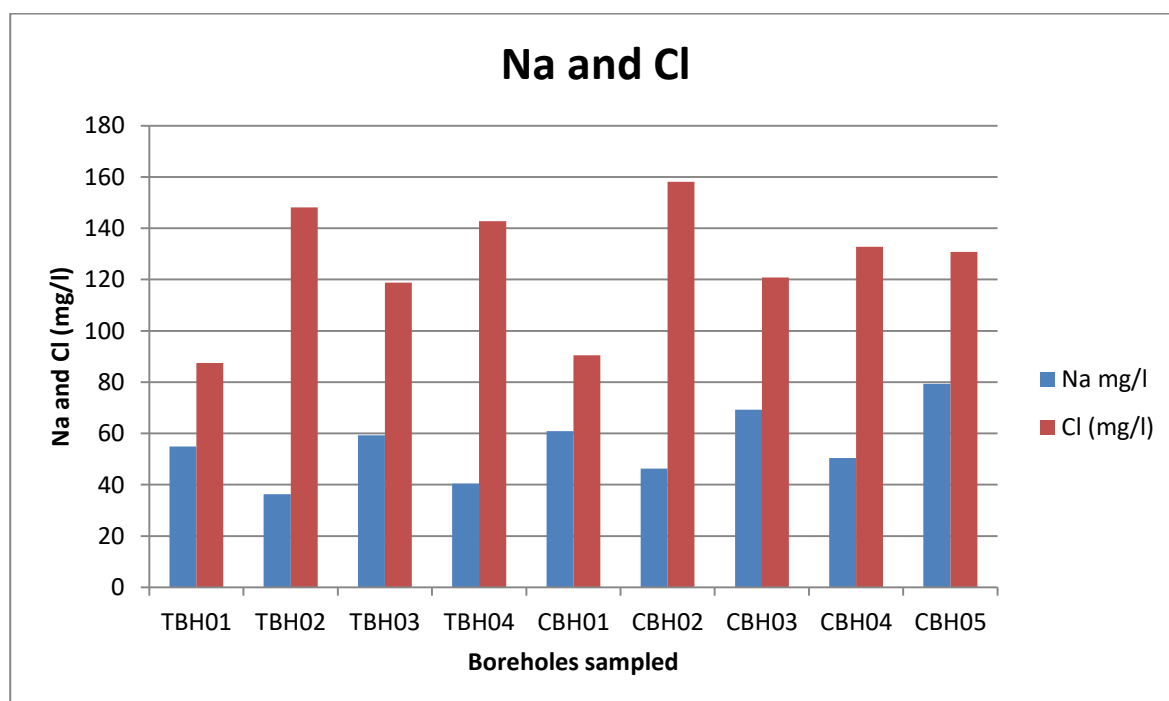


Figure 5-3: Sodium and chloride

Sulphate concentration for each borehole is in Figure 5-4 and Figure 5-8 ranging between 70 and 140 mg/l. Chapter 6 will provide information on whether it is within the set limits compared to this study.

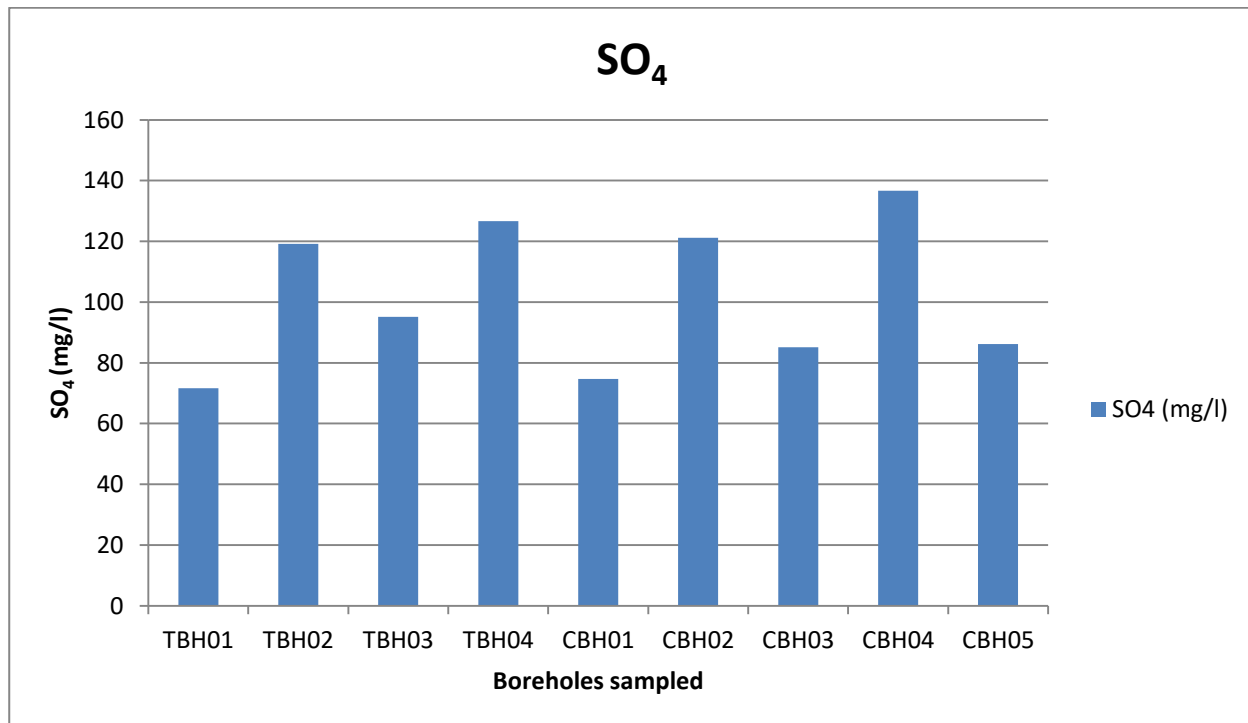


Figure 5-4: Sulphate

Electrical conductivity and TDS are presented in Figure 5-5. TDS is high but Titus *et al.*, (2017), associate TDS to the type of water chemistry which is mentioned in association with Figures 5-13 and 5-14 (the piper diagram). In order to establish whether there are any concerns linking TDS to any water use purpose, Chapter 6 provides such information. The same is the case for EC (mS/m).

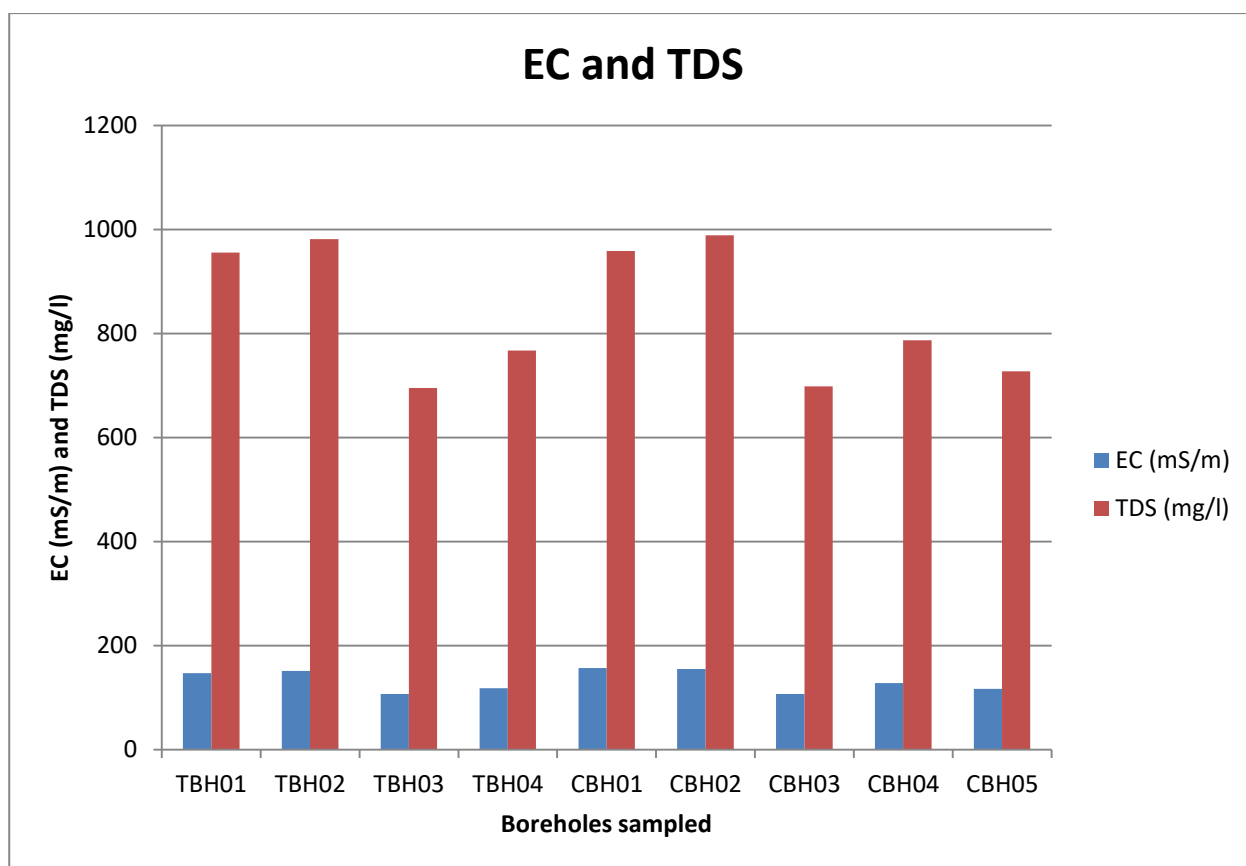


Figure 5-5: EC (mS/m) & TDS (mg/l)

Figure 5-6 represents total alkalinity and total hardness. Total hardness appears to be high from all sampled boreholes. It has been mentioned that total hardness can be treated using ion-exchange to the acceptable levels of calcium or magnesium (WHO, 2017). Discussions relating to Total Alkalinity and Total Hardness are also in Chapter 6. These are also presented in a box-cut in Figure 5-9.

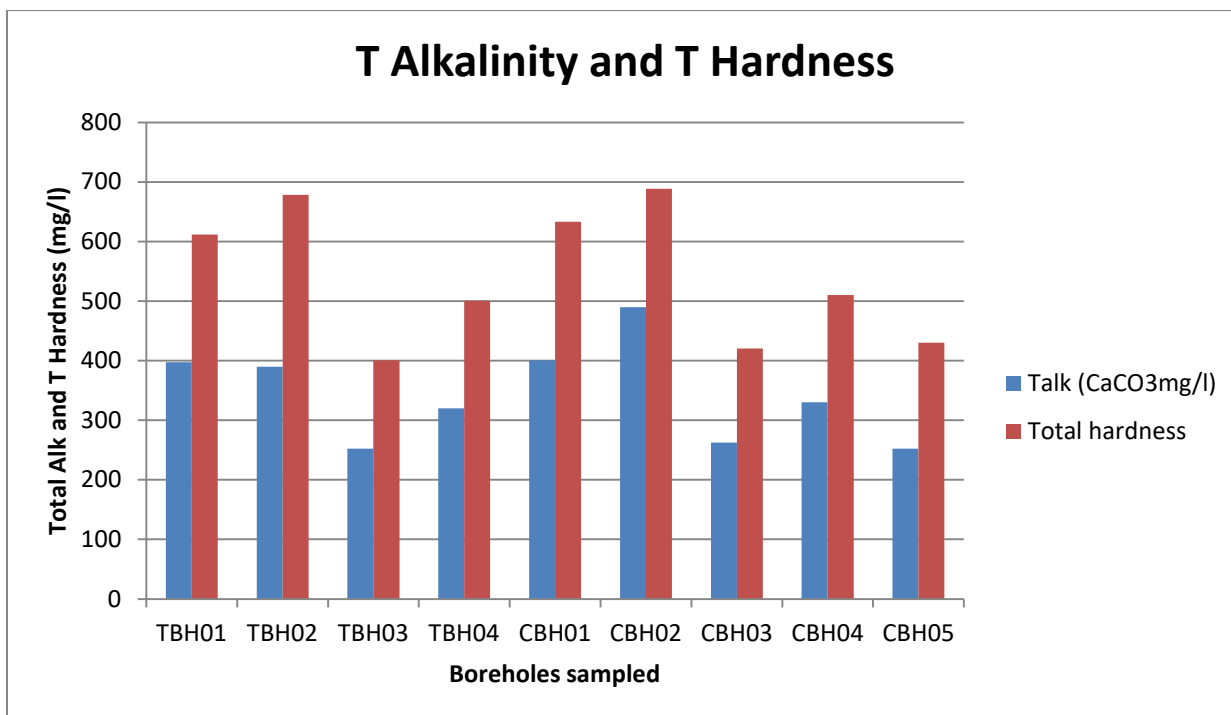


Figure 5-6: Total Alkalinity and Total Hardness

Results graphically presenting the distribution of calcium and magnesium are in Figure 5-7 and 5-10 for distribution curves and box-cut respectively. These parameters are linked to Total hardness.

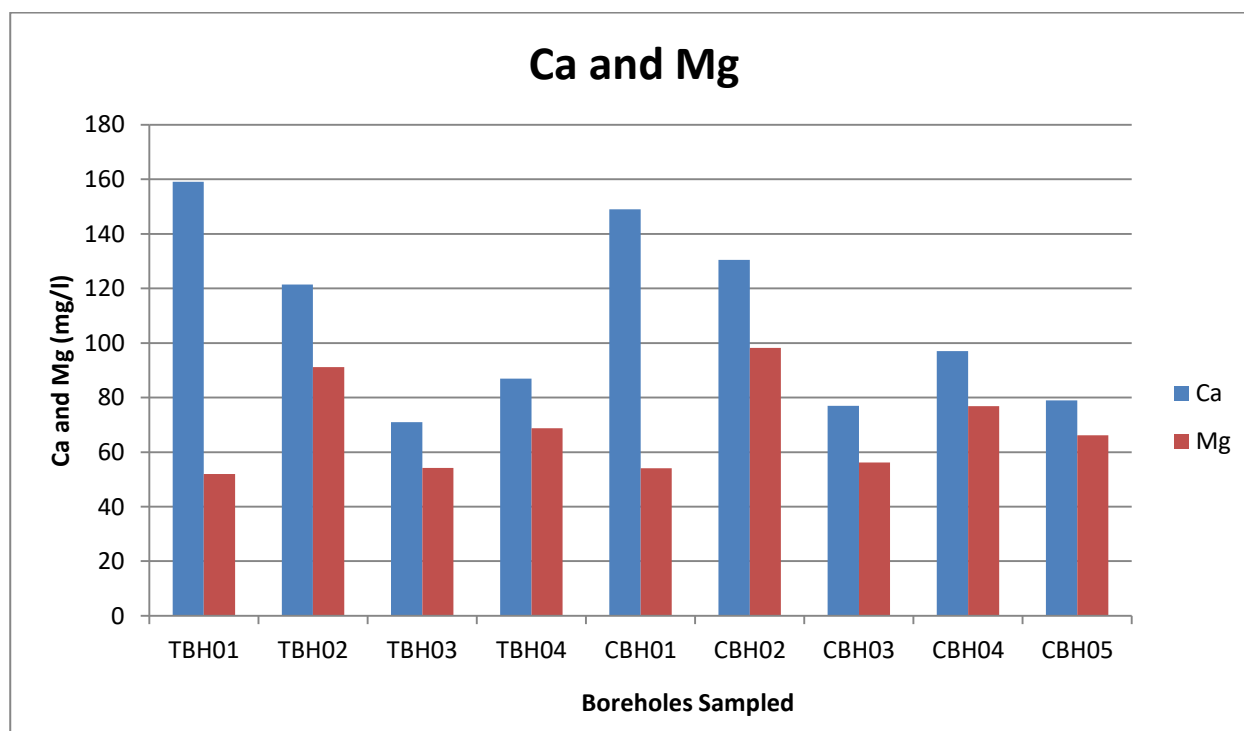


Figure 5-7: Calcium and magnesium concentrations

Box –cut graphs have been referred to in conjunction with the concentration distribution curves presented above since the sampling was conducted once during the dry season, the temporal variation assessment of these variables can not be made but the concentration vary spatially even though boreholes were not too far from each other.

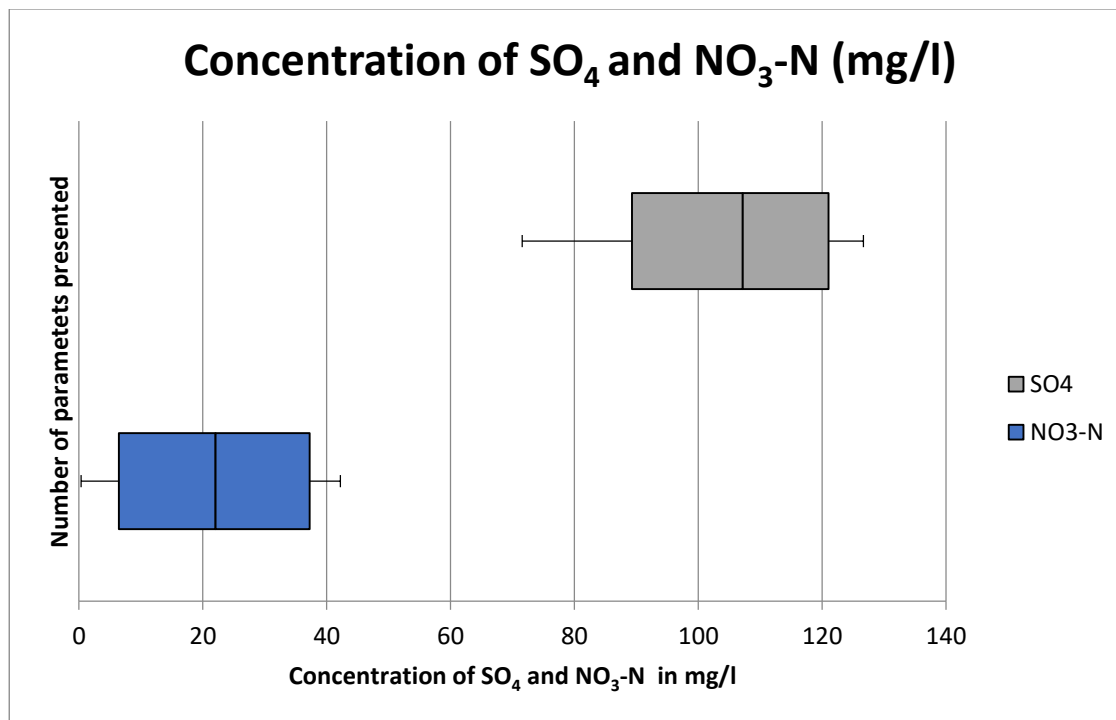


Figure 5-8: Box cut representing NO₃-N and SO₄ in mg/l

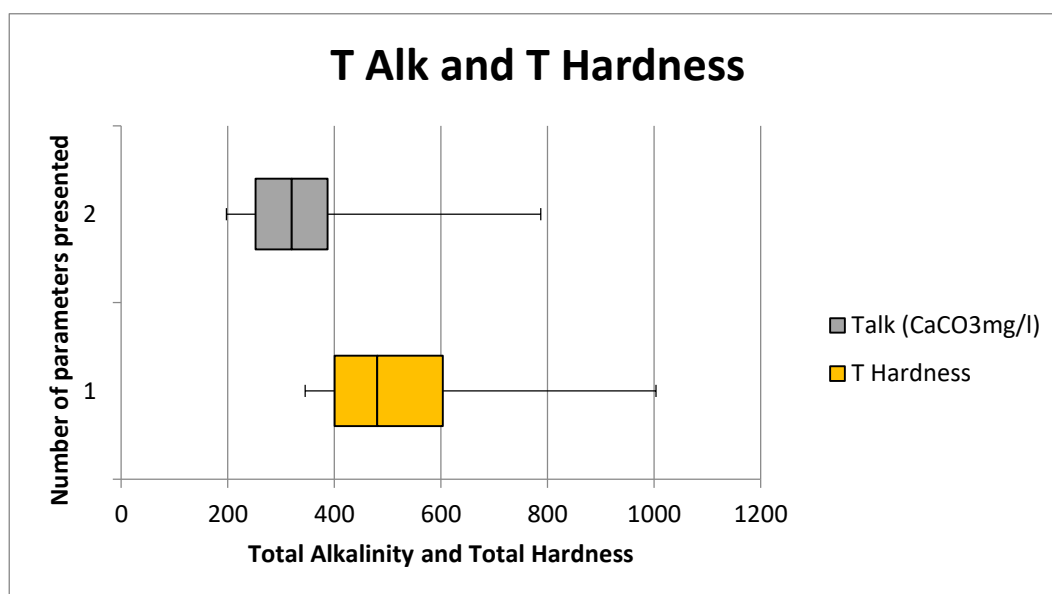


Figure 5-9: Box cut representing T Alkalinity and T hardness

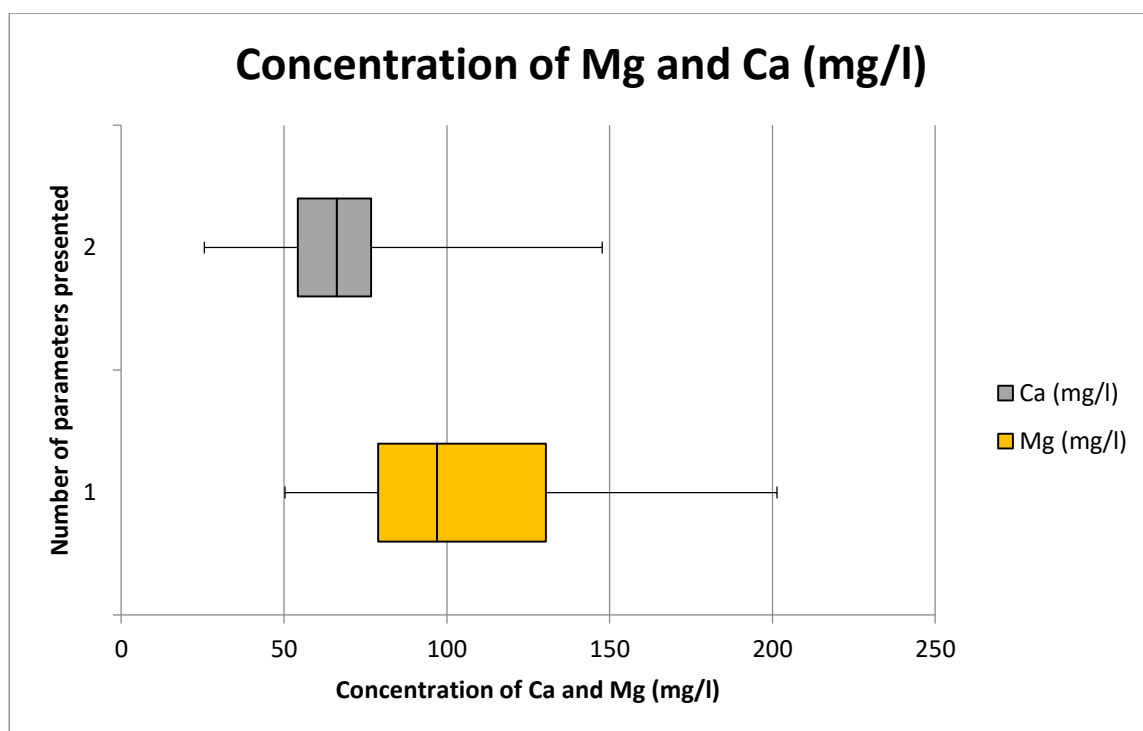


Figure 5-10: Box cut representing Ca and Mg distribution

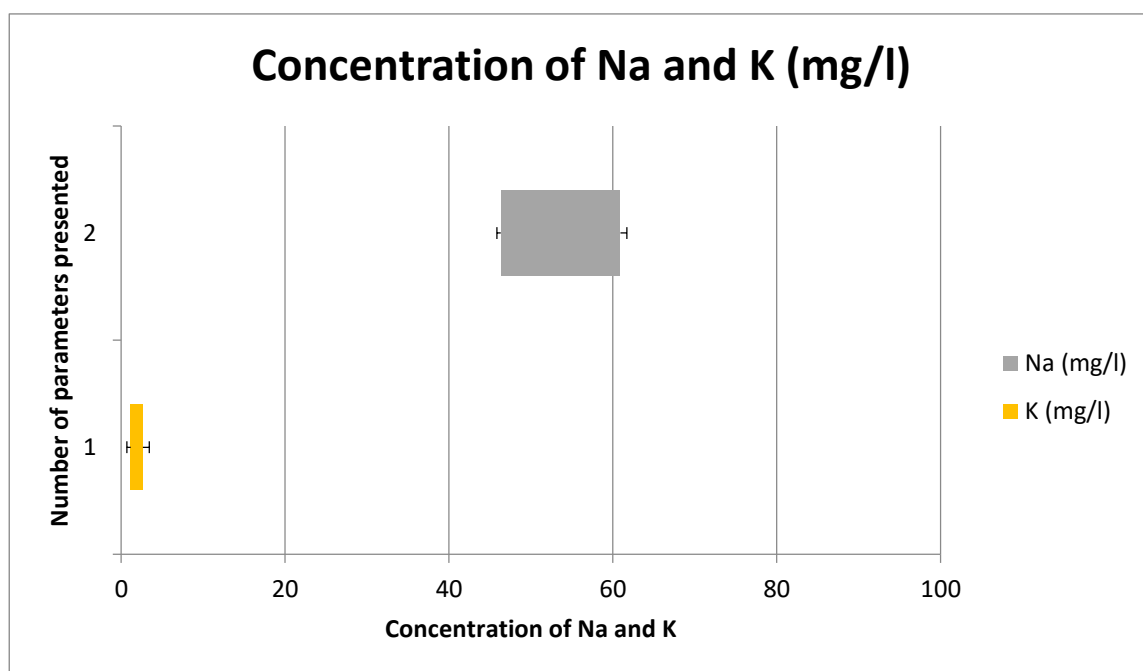


Figure 5-11: Box cut representing Sodium and Potassium distribution

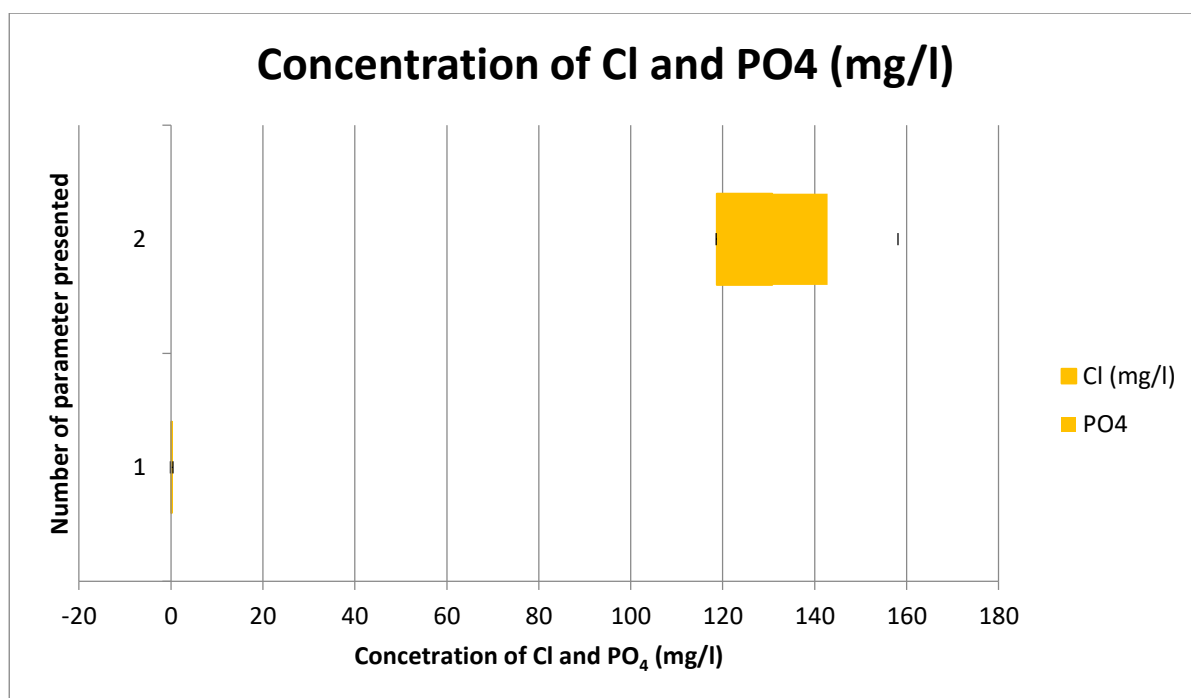


Figure 5-12: Box cut representing Chloride and Phosphate distribution

Piper diagrams represented in Figure 5-13 and 14 represent the origin of water and the extent of mineralization that had occurred in the aquifer giving the chemical characteristics of water (Titus *et al.*, 2017). Hydrochemistry within the fractured aquifer may be influenced by different land use activities such as irrigation and mining. Irrigation will be seen by the domination of Ca-Mg-Cl facies whereas water originating from the mining activity will be indicated by Ca-Na-Cl facies.

According to Titus *et al.* (2017), Mg-Ca-HCO₃ shows the recently recharged and shallow groundwater, which is an indication that water chemistry originate from less mineralized silicate minerals. The TDS in the groundwater sampled in this study as presented in Figure 5-5 and is high (ranging between 600mg/l and to just less than 1000mg/l) and also with high CaHCO₃ ions. This thus is an indication of mixed origin, which includes recently recharged water that has been influenced probably by mining activity (Titus *et al.*, 2017).

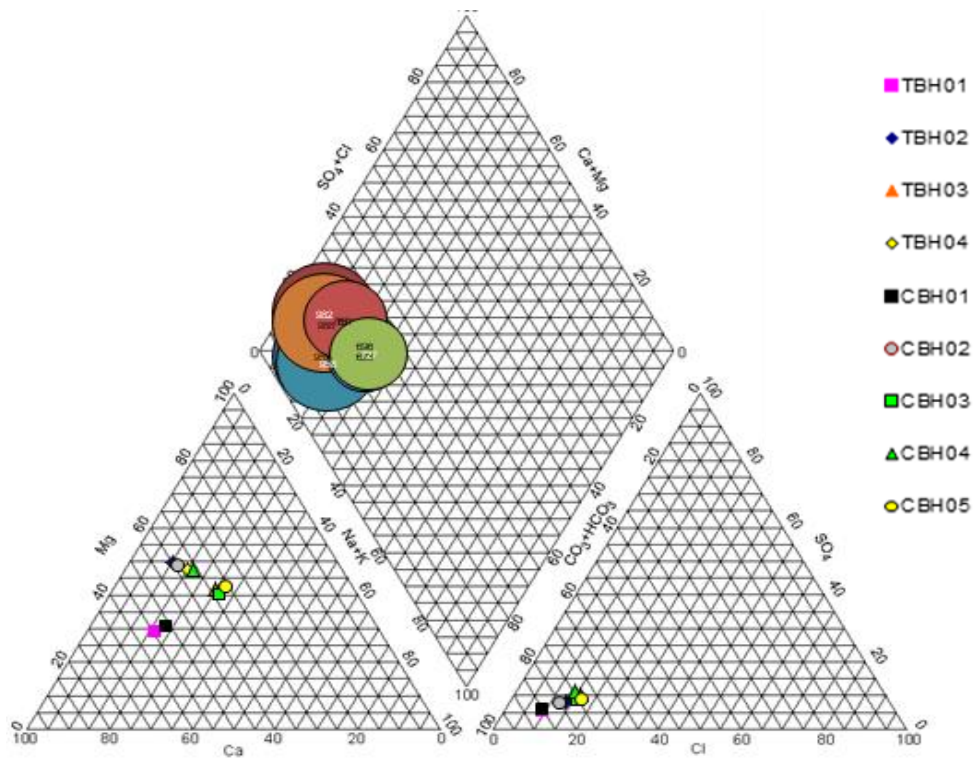


Figure 5-13: Piper diagram showing hydrochemistry of groundwater

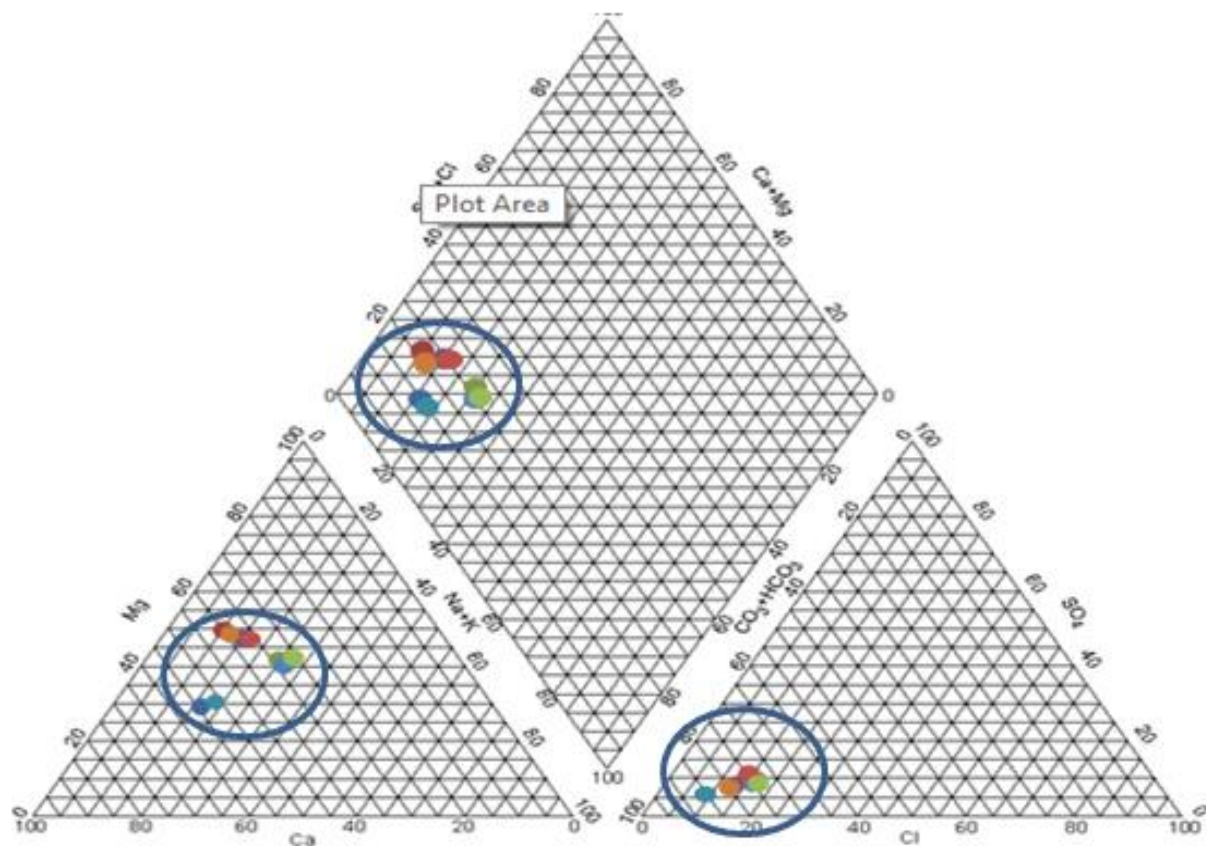


Figure 5-14: Piper diagram representing groundwater facies

5.4 Background nitrate levels

This section attempts to respond to objective 5 of the study, where the intention was to compare the results of the current study to levels of concentration of the variables measured in this research in previous monitoring exercise (the background) so as to establish whether the concentration of such parameters particularly nitrates increase or decrease. In this study the definition of the background data *is data that existed or was obtained by any means within the quaternary catchment area where this study is undertaken before commencement of this study*. The intention is not to divulge from the principles of the case study method which the current assessment is based upon but is to try by all means to identify the gaps in water resources management so that such gaps can be bridged and to show that attempts had been made to obtain existing data for the case study.

Except for TBH02/CBH02, none of the boreholes used in the study were sampled before. The noticeable trend in borehole TBH02/CBH02 is presented in Table 5-4.

Table 5-4: Presentation of results for TBH02/CBH02

	Ca	Mg	K	Na	PO ₄	SO ₄	NO ₃	NO ₃ -N	Cl
TBH02/CBH02 2010	130.44	98.14	0.88	46.32	0.21	121.18	179.96	40.9	158.11
TBH02/CBH02 2018	121.44	91.14	0.78	36.32	0.11	119.18	156.91	35.6	148.11
					pH	EC	TDS	TAL	T Hardness
TBH02/CBH02 2010					7.45	1.07	698.5	262.5	420.33
TBH02/CBH02 2018					7.37	1.51	981.5	390	678.56

The noticeable trend when comparing the concentration of the same borehole in different dates (October 2010 and July 2018), it shows that concentration of NO₃-N in 2010 is higher than the concentration measured in 2018. One may ascribe such an observation to the season as October is a period with a lot of summer rains whilst July is a dry season (as shown in Figure 4-4). This may link to the observation made by Reddy *et al.* (2009) and Tredoux (2009). Having said that it must be born in mind that the vegetable gardening project on site is continuously under irrigation, indicating that

rainfall season may have to be excluded in attempting to explain the observation. Noticed on site is that organic manure is being used instead of inorganic fertilizer, which according the project manager on site was used in the previous years, and this is one of the pollution mitigation measures recommended by Haller *et al.*, (n.d.).

In search for more information for the existing data in order to achieve objective number five, a shapefile of the levels of concentration of nitrate was found from the Water Resources 2012 website, where all the levels of nitrate >10mg/l were mapped. The background nitrates are above 10mg/l, which are not exceeded in terms of SANAS standard 241 of 2011 but exceeded in terms of TWQR (DWAF, 1996).

In addition to that, data were also requested from the existing systems where monitoring data is uploaded, NGA could not yield any data for the quaternary catchment in which the study is conducted but WMS provided the data and is presented in Table 5-5.

Table 5-5: Background groundwater quality as obtained from WMS

Points number	NO ₃ +NO ₂ -N
96014568	0.275
140234777	10.674

The results in Table 5-5 are from the points that are outside the study area but still within the quaternary catchment A22F in which the study was undertaken and approximately 25 km north-east of the study area. According to the record samples were taken in 1996 and 2014 in **96014568** and **140234777** respectively. The points are located further downstream of the study site where the land use activity is dominantly residential and some grazing, hence the nitrate concentration is lower on site number **96014568** but the point number **140234777** nitrate concentration is found to be above 10mg/l NO₃+NO₂-N.

5.5 Simulation of pollution plumes

Potential sources of nitrates (mining and agriculture) that could have a significant impact on the groundwater system were delineated. It is assumed that all these sources are 100% polluted. Pollution plumes were then simulated for 10, 20 and 30 years as shown in Figures 5-15 to 5-20. Over the 30 years the pollution plume due to agriculture only moves approximately 150 m, this partially due to the fact that the terrain is relatively flat.

On average the mining pollution plumes have extended 700 to 800 m. A concern is that the northern most plume has almost reached the river.

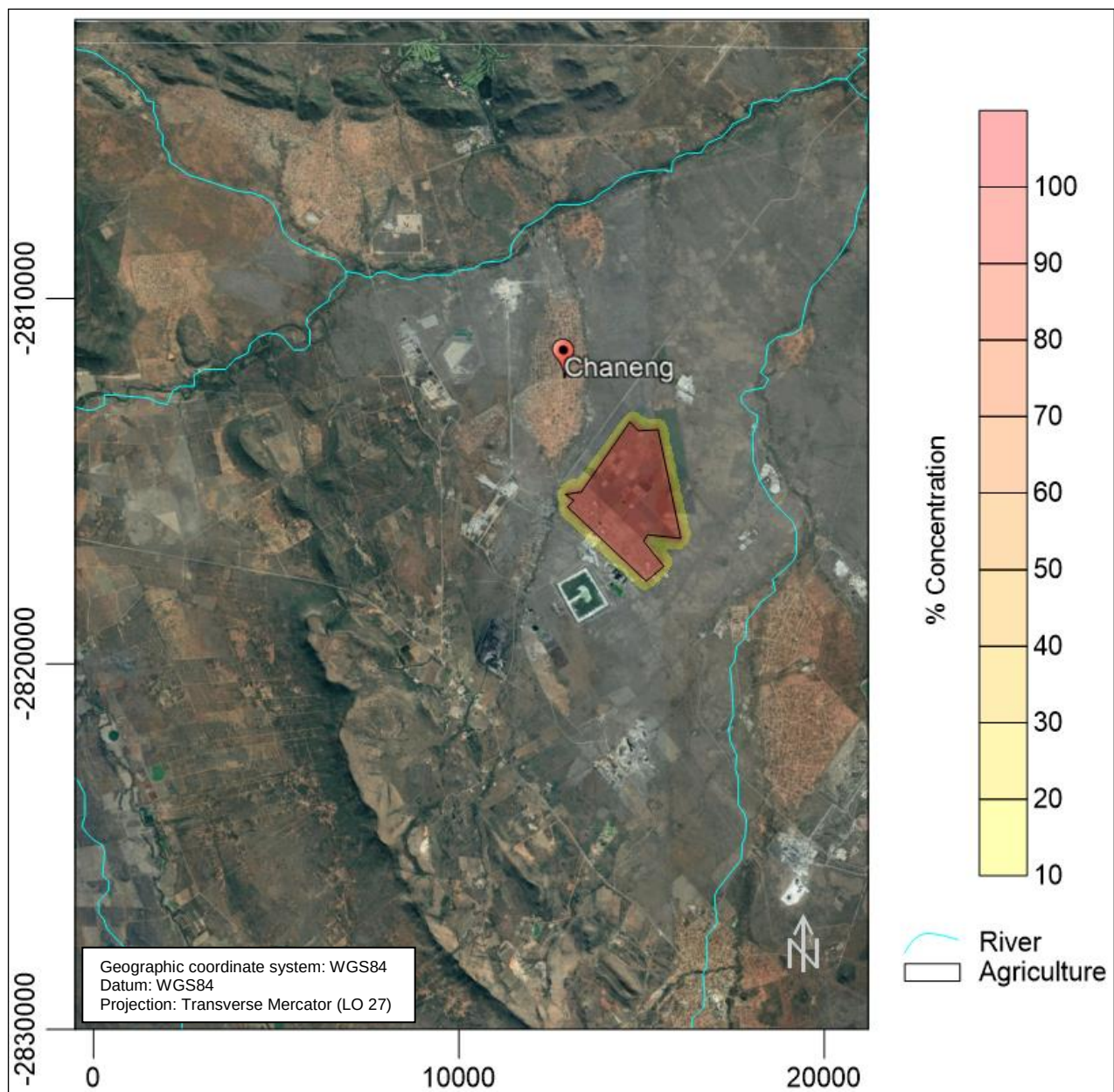


Figure 5-15: Pollution plume after 10 years (agriculture)

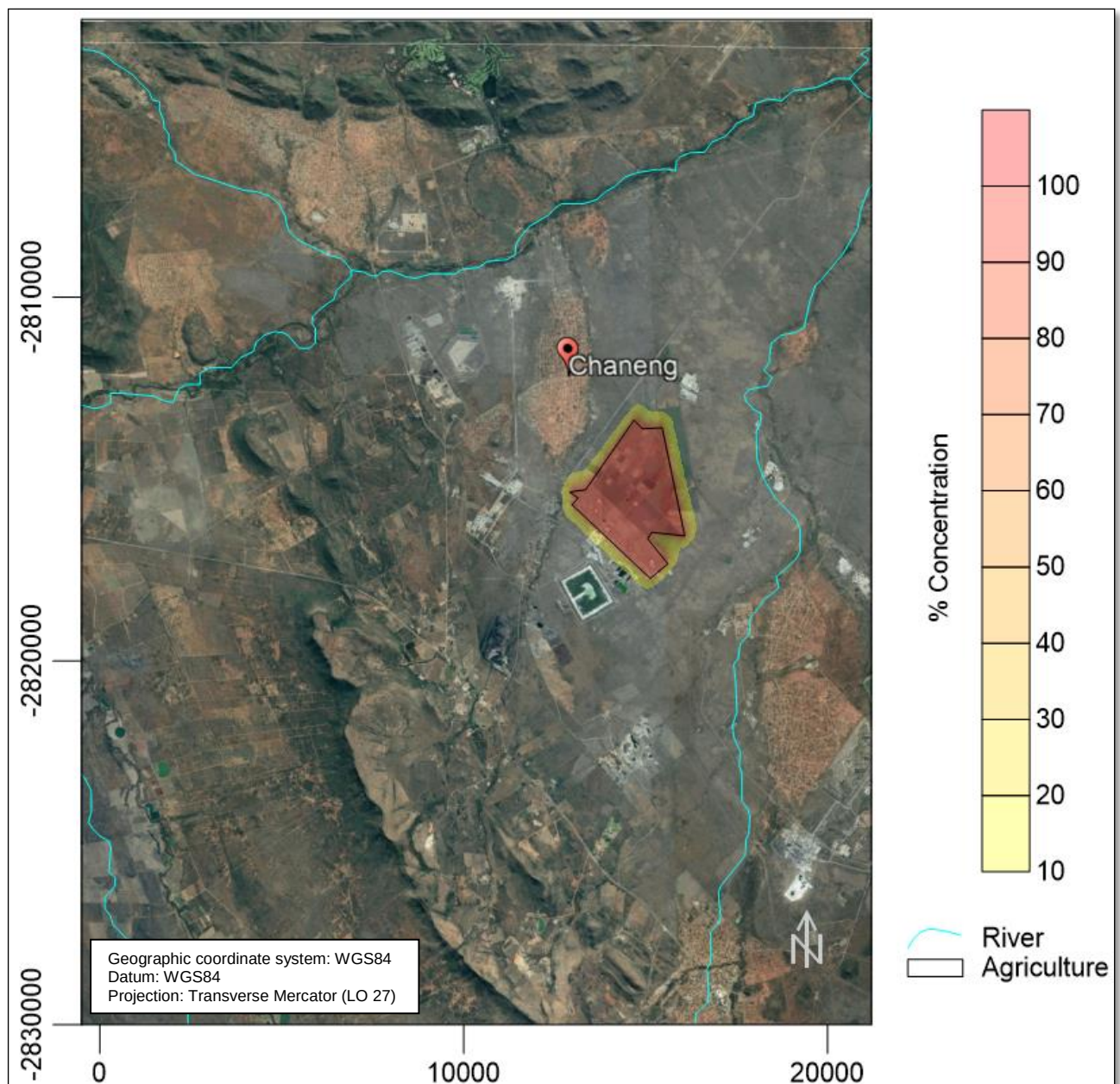


Figure 5-16: Pollution plume after 20 years (agriculture)

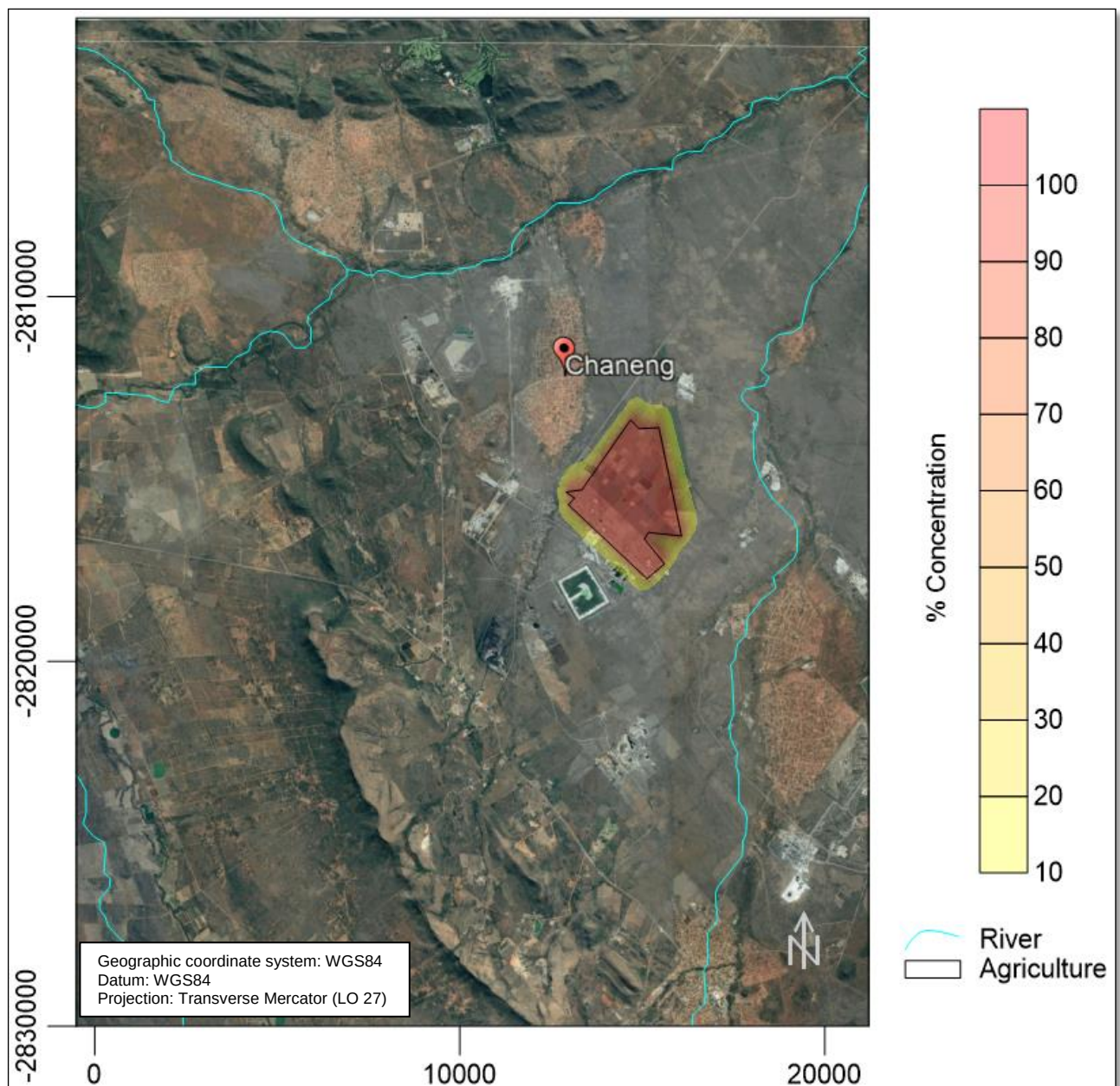


Figure 5-17: Pollution plume after 30 years (agriculture)

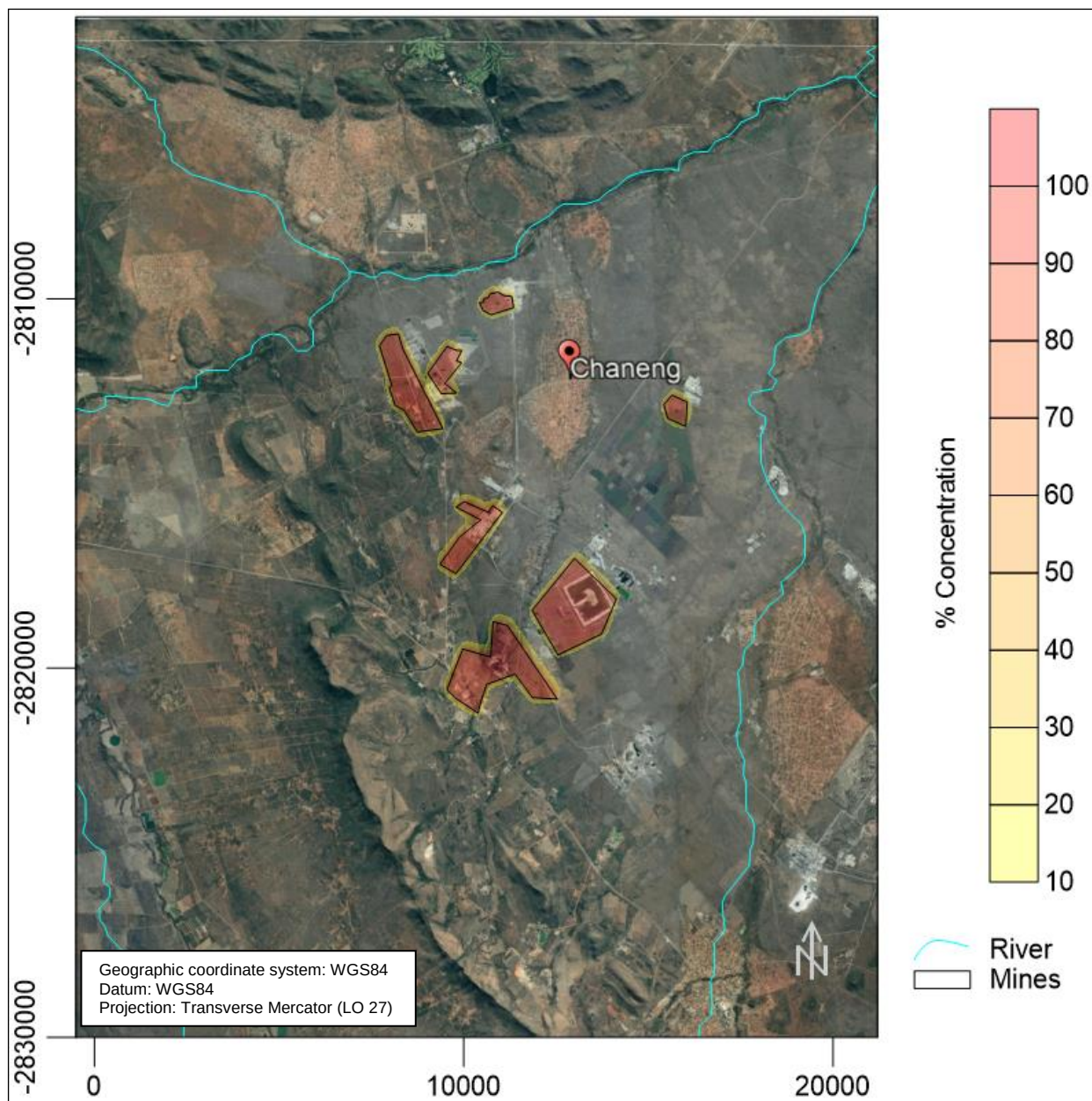


Figure 5-18: Pollution plume after 10 years (mining)

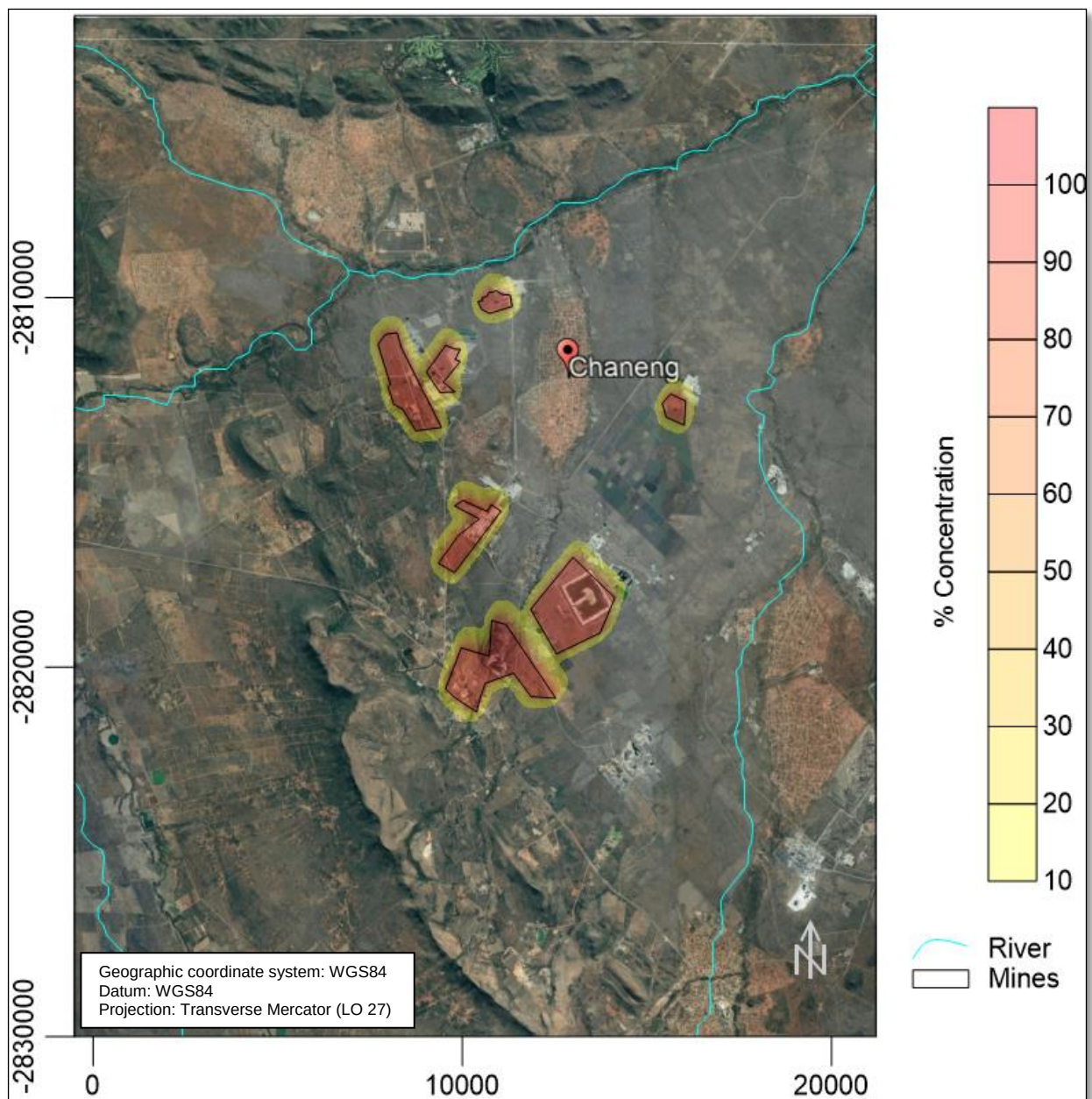


Figure 5-19: Pollution plume after 20 years (mining)

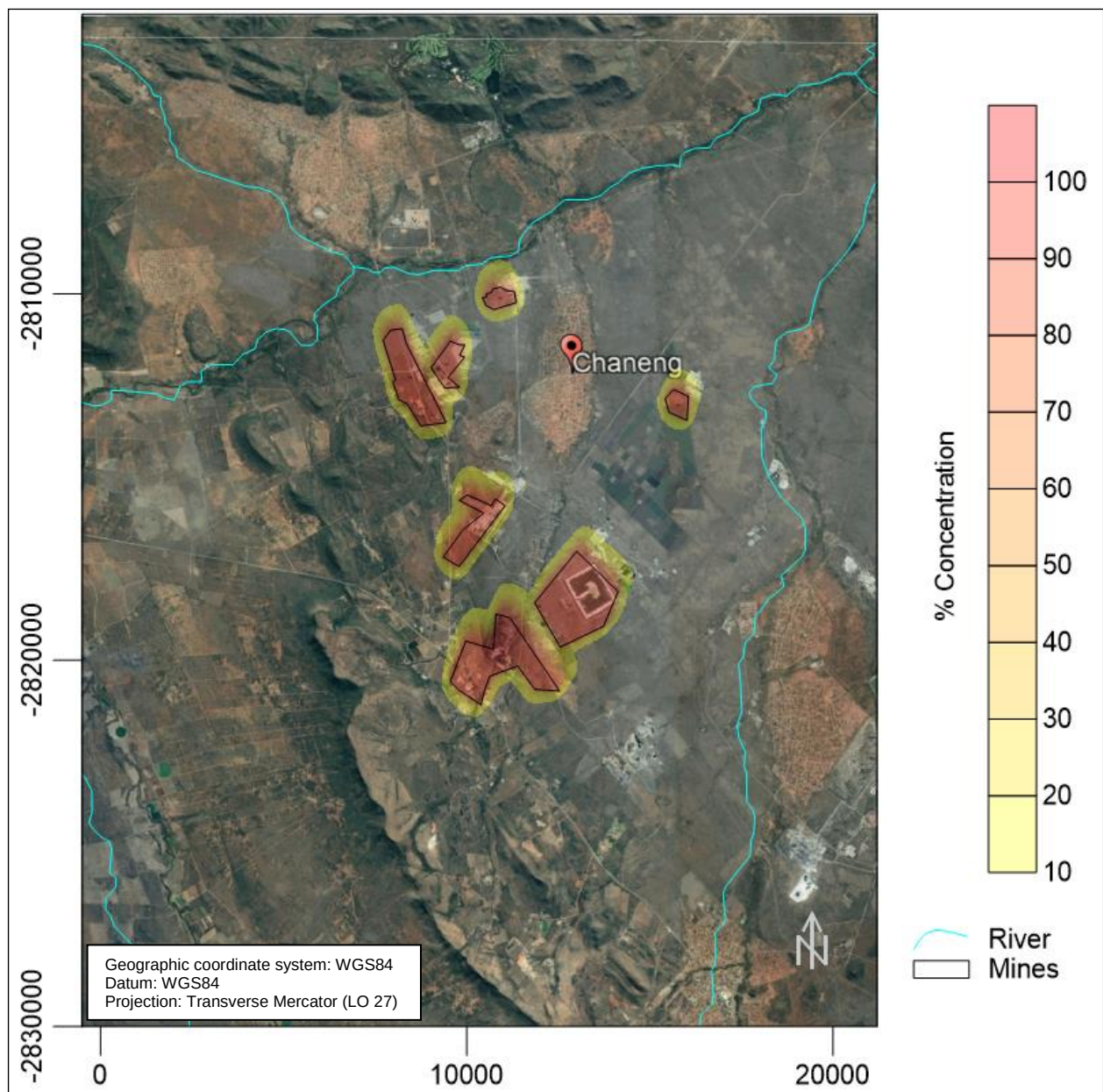


Figure 5-20: Pollution plume after 30 years (mining)

CHAPTER 6: DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

6.1 Discussion

This section will discuss the water quality results as presented in Chapter 5 above. The analysis will look at water quality parameters and the way such parameters might have been influenced by the natural environment and anthropogenic activities. Comparisons will be made with existing water quality guidelines as indicated in Table 2-1 and public health concerns associated with consumption of such water by livestock and human points of view. The discussion will be done bearing in mind that different boreholes sampled are used for different purpose, for example, TBH01 is used for livestock watering; TBH02 is used for irrigation of vegetable garden; TBH03 is used for drinking at the school and TBH04 is a new borehole but planned to be utilized for irrigation of vegetable gardens and for drinking purposes at the school as it was drilled in the school grounds.

Borehole CBH03, CBH04 and CBH05 were household boreholes (all no longer in use), CBH02 is the same borehole referred to as TBH02. Borehole CBH01 was a communal hand pump, which was found broken, which is the reason why it was not included in the current study. In these points nitrate concentration was found to be above the 10mg/l. All the boreholes at the time were found exceeding 6mg/l with three sites exceeding 10mg/l, being CBH01, CBH02 and CBH05 as shown in Table 5-2.

6.1.1 Chemical characteristics pH, EC & TDS

pH in all boreholes is within the limits acceptable within all standards set for water use purposes including the RQOs set for the Crocodile West and Marico WMA on the classification of Water Resources System in the EWR site 6, which is the closest to study site. This is compared to the guidelines tabulated in Table 2-1.

EC was found acceptable for livestock drinking but yet above the limits set in the RQOs of the classification system of the Crocodile West and Marico for that EWR site at which this study was undertaken. The TWQG discusses adverse health effects for associated with TDS on livestock (sheep, cattle, horses, dairy, pigs and poultry). Dairy pigs and poultry are more sensitive as the adverse effects start to show as soon as TDS rise to 1000-2000, with all livestock species having difficulties to tolerate TDS above 13 000mg/l. The TDS for livestock was within the acceptable range as it ranges from 727.7 - 988.5 mg/l. TDS standards for drinking purpose were exceeded as it ranges from 627 to 988mS/m in all boreholes and according to TWQR, it is supposed to be between 0-450mg/l. However, the aesthetic limit for **TDS** is $\leq 1200\text{mg/l}$ as per SANAS, 241 (2015).

EC is ranging from 107 to 157mS/m in all boreholes sampled in 2018 and those sampled in 2010. The results show that the EC for water for drinking purposes set by the DWS standards is exceeded in all groundwater samples as it is supposed to be $\leq 70\text{mS/m}$. EC requirements for crops or irrigation vary from one crop to another and may result to salinity of soil (DWAF, 1996).

6.1.1.1 TALK and Total hardness

Although the water quality guidelines and standards do not specify, the level of alkalinity and hardness in water, the New South Wales (2011) study indicates the following class of hardness.

Table 6-1: Hardness classes (NSW, 2011)

Description of water	Hardness expressed as mg/l CaCO_3
Soft	< 50
Moderately soft	50-75
Slightly hard	75-150
Hard	150 -300
Very hard	>300

Total alkalinity is the measure of the ability of water to neutralize acid. Both total hardness and total alkalinity are measured by the presence of the carbonates of

calcium. These are important parameters in water quality assessment because without it the water resources cannot withstand acidity that could be brought about as a result of anthropogenic activism resulting to acid rain due to the burning of fossil fuels. Total hardness is associated with calcium content in water and also the TDS content. The lower the calcium content, the lower the total hardness but the higher the calcium, the higher the total hardness. Total hardness was found to be extremely high as it has a concentration ranging from 400,33 to 688 mg/l. Total hardness is of concern to groundwater because as groundwater percolates through the soil layers to aquifers, it dissolves along the minerals of calcium and magnesium, increasing hardness of water. Such minerals may have some benefit to livestock but at high concentration it lowers the lifespan of the equipment used to handle such water including pumps and cause scale build up. Scale build up will lower the volume of water being transported through the pipes resulting into less amount of water having to be discharged from the aquifer.

The NSW (2011), also suggests that equipment on dairy farms can tolerate hardness of up to 150 $\text{CaCO}_3\text{mg/l}$. Equipment on domestic uses can tolerate hardness of up to 200mg/l. Equipment for dips and chemical sprays can withstand hardness up to 300mg/l. Total alkalinity is also high, ranging from 252.4 to 490mg/l CaCO_3 .

6.1.1.2 Calcium (Ca)

Calcium was also found to be within the acceptable limits for livestock requirements in TBH01 as it is 159.11mg/l. The TWQG (DWAFF, 1996) indicates that the calcium concentration for livestock watering should be 0-1000mg/l. However, when looking at overall sampling locations, calcium is high, it exceeds limits for drinking water as it ranges from 70.94 - 159.99mg/l. The range for drinking water is 0-32mg/l (DWS, 1996).

6.1.1.3 Magnesium (Mg)

For livestock watering, Magnesium was also found to be within the allowable limits as it should be 0-500 as per TWQG and was found to be 52.01 mg/l. The standard for drinking water is 0-32. All the boreholes examined exceeded the drinking water standards set by DWAFF (1996), as the range is between 52.01- 98.14mg/l.

6.1.1.4 Potassium (K)

Potassium was found to be far lower than the limits (1.17mg/l) in TBH01, which is an indicator of good quality water as the TWQG suggests the level of 0-50 for drinking water and if found in high quantities it may affects infants and individuals with renal problems. In all boreholes potassium was found to be very low. Potassium, like sodium is an alkali earth metal. Minnesota Pollution Control Agency (MPCA) (1999) indicates that potassium occurs in groundwater as a result of dissolution of rocks and it increases with the residence time. Increased levels of potassium may occur as a result of additions of organic fertilizer that leaches through the soil to groundwater. Even under long standing agricultural project as in the case of TBH02, potassium is still found in low content. Probably this is due to the fact that leaching of Potassium could be significant in coarse textured soil than in clay soils (MPCA, 1999). Other than lack of human contribution to the potassium content making to be low, it is possible that water under the assessment is not very old water.

6.1.1.5 Sodium (Na)

The range for sodium in water used for livestock watering is 0-2000. The water sampled from TBH01 was found to have 54.94 mg/l, which was relatively far below the limit (DWAF, 1996) for stock watering but higher for domestic needs. High sodium content is associated with salinity in water. According to SANAS, 241 (2015), sodium has to have an aesthetic limit of ≤ 200 mg/l. High saline will render water undrinkable to the livestock and eventually lower the productivity and even worse for the lactating animals as there will be little milk production. Chronic effects range from a decline in water and feed intake, with subsequent production losses to gastroenteritis and dehydration (DWAF, 1996).

Like potassium, sodium is an alkali metal that get released through dissolution of rocks and its concentration increase with residence time. Sodium is found at higher concentration than potassium, probably due to addition of sodium through salinity as there is high level of TDS in all boreholes. Another possible contributing factor making sodium concentration higher than potassium is that sodium is highly mobile (MPCA, 1999), than potassium.

6.1.1.6 Sulphate (mg/l) and Phosphate

Sulphate was found to be very low in TBH01. It is a compound of sulphur and is found in a VI oxidation state. It is an oxy-anion of sulphur. It forms salts with various cations such as potassium, calcium, sodium, etc. Excessive amounts of sulphate in drinking water result in diarrhoea. Sulphate was found to be well within the limits as it was at the concentration of 71.59mg/l for livestock watering. According to SANAS 241 (2015), sulphate in drinking water has to be ≤ 500 mg/l. It is common in water and it comes from the mineral dissolution of sulphates of rock and soil. Phosphate is a compound of phosphorous. Phosphorous affects surface water bodies than groundwater as little amount of phosphorus can result to the growth of toxic algae, which when decomposes, the dissolved oxygen required by the aquatic organism and will result to death of aquatic organism such as fish. However, it was found that phosphate from the TBH01 was 0.05mg/l. The TWQG (DWAF, 1996), indicate that if the phosphorous is found to be more than 0.03 mg/l, continuous monitoring must be conducted. The distribution of phosphate in all boreholes sampled is ranging from 0.03 to 0.39mg/l. These concentrations were beyond the limit set by DWAF (1996).

6.1.1.7 NO₃ and NO₃-N (mg/l)

Borehole TBH01 was found to have nitrate levels of 186.80mg/l which when converted to nitrate-nitrogen, was found to have a concentration of 42.2mg/l using the conversion factor of 4.4. To maintain optimum health for both ruminants and non-ruminants livestock, the nitrate level of 0-100mg/l is essential. Ruminants can be able to tolerate levels of 100-200 but non-ruminants may begin to show the signs of nitrate poisoning at the nitrate level of 100-200 (DWAF, 1996). It has been mentioned in Chapter 2 that animals such as pigs do not have the capability to convert nitrate to ammonia as ruminants (NSW), which is the reason why non ruminants show nitrate poisoning signs earlier than ruminants. Of the nine boreholes from which water quality analysis and interpretation is being done, it is clear that nitrate contamination prevails within the village as is indicated on Table 6-1.

Table 6-2: The NO₃-N (mg/l) frequency distribution within Chaneng Village according to the DWS water quality standards, potability class and impacts

Distribution (mg/l)	Number of boreholes	Percentage (%)	Potable class	Comments
<6	1	11	Ideal	No health effects
6-10	3	33	Acceptable	Insignificant risk
10-20	2	22	Marginal	Slight risk to some infants
20-40	1	11	Poor	Accelerating health effects
>40	2	22	unacceptable	Severe impacts

6.1.1.8 Chloride as Cl (mg/l)

Chloride levels were found to be 87.43mg/l and according to TQWR the level of acceptable chloride has to be 0-1500mg/l for livestock watering. In concentrations higher than that it will render water unpalatable. It may accelerate corrosion of certain metal equipment. It is stated that pigs and poultry are more susceptible to elevated chloride. Chloride is found to be ranging from 87.43 to 158.11mg/l, which is within the SANAS, 241 (2015), which is set at ≤300mg/l.

6.1.1.9 Microbial characteristics

E-coli and total coliform were found to be less than 1 count of E-coli and total coliform, which was regarded as almost non-detectable. Though, it was not on the scope of this study that the sources be determined as the study is about highlighting the potential sources of nitrate. It has been shown in many studies that where there is high nitrate level in water, causing effects to human, it is in most cases associated with high level of bacterial content. In source tracking studies where high level of nitrate occurs concurrently with high levels of microbial content, the view would be that the contamination source could be cows manure or human excreta. The nearest potential source on the boreholes with high nitrate (TBH04) is cattle kraal; but the contamination is from the mine or from cattle kraals or even other sources as TBH04 is on the downstream of the village. At the TBH03 or CBH02 there is a vegetable garden project which is also fertilized using cow manure.

It was mentioned that the direction of the flow is towards the Elands River, from Chaneng Village towards the north. Therefore TBH01, is probably a collection point of all point and non-point sources or it could be naturally occurring. The boreholes sampled in 2010 grouped as CBHs, there are no microbial characteristics being measured but on all TBHs, there was negligible level of e-coli and coliform in groundwater. The observation made onsite was that the village was making use of the onsite sanitation, in the form of pit latrines, septic tanks there was no water borne system. The presence of sulphate and chloride will indicate impacts from mining related activities (Bosman, 2009).

6.2 Health risk assessment

The health risk assessment of the study area is discussed in association with the information gathered from the maps generated by Musekiwa and Majola (2011), and with the guidelines provided by WHO (2006b). According to the WHO (2006b), in areas where there is high water table, thin soil cover over high fractured aquifer, there is high risk of movement of pathogens that pose high risk to human health. Though it is indicated that the flow of groundwater is to the direction of the Elands River (SRK, 2015), the WHO (2006b) indicates that in fractured aquifers the direction of the flow of groundwater cannot be easily determined thus it makes it difficult to control pollution movement, making it the high risk to human health as the movement of pathogens cannot be known. Having mentioned that, the results from sampled boreholes indicates that there is < 1 counts of pathogens, which means there is less contamination related to sources such as human or animal excretion (WHO, 2006).

It may pose health risks to consume water for domestic purposes from boreholes TBH01, TBH02 or CHB02 due to nitrate content higher than 30 mg/l. according to the WHO (2017), the standard is still 11mg/l of NO₃-N.

6.3 Aquifer vulnerability

Aquifer vulnerability is defined by WHO (2006b), as the susceptibility of the aquifer to receive pollution which is influenced by hydro-geological characteristics. It was found in the study area though based on Musekiwa and Majola (2011), that after the assessment of soils, slope, depth of water table and many other components of groundwater that the aquifer vulnerability within the study area is between low and moderate. Borehole

TBH04, located at higher elevation than other boreholes had low concentration of NO_3^- -N (0.35mg/l) compared to 40mg/l of NO_3^- -N found in borehole TBH01 located at low elevation.

6.4 Impacts of soils

Soils have impacts on recharge and aquifer yield as well as on its vulnerability to pollution such that being classify as Sand clay loam clay. It must be reiterated that clays being referred to in the study area are those that have high shrink and swell still posing a risk to groundwater contamination (Grobler, 1976 cited by Tredoux & Talma).

6.5 Impacts of land use

Presentation of land use activities is shown on a google map in in Figure 4-2 and it is clear that it is dominated by the mining activities, but as to whether there is a high risk of contamination from their sources such as tailings, waste rock dumps other waste water containment facilities, unless the monitoring boreholes are drilled to measure the level of contamination.

6.6 Impacts of groundwater level

According to the map produced by Musekiwa and Majola (2011), the depth of groundwater is not very shallow nor too deep, it is within the moderate scale. Unlike in shallower groundwater table (WHO, 2006), the risk to contamination to such aquifers is moderate, which thus gives rise to the aquifer vulnerability class of low-moderate.

From the pollution plume simulation model it is indicated that over time the pollution gets worse. The assumption that contamination is already there and tested using the simulation model shows that over 10, 20 and 30 years, the plume grows bigger and bigger but the grows much quicker from the mining activities than the agricultural activities. However, in both land use activities, measures must be in place to control further expansion of the pollution plume.

6.7 Conclusion and recommendations

When combining the ad hoc sample that was collected in 2010 during the investigation of complaint associated with nitrate contamination in Chaneng, it can be concluded that more that 80 % of the boreholes included in this assessment exceed the allowable NO_3^- -

N of 6 mg/l. More than 50% of boreholes are more than 10mg/l. In each evaluation it was found in two boreholes' nitrate levels were more than 40 mg/l.

The CBH02 sampled as an ad hoc investigation for pollution incidence in 2010 is the similar borehole sampled in this current exercise but given an identification of TBH02. The noticeable difference or trend is that nitrates concentration decreased from 40.9 mg/l in 2010 to 35.9mg/l NO₃-N in 2018. But TBH01 which is further downstream, the concentration of nitrate-N is the elevating 42.2mg/l. The quality of groundwater in Chaneng is below the water quality standards set for drinking water guidelines. It exceeds the SANS 241 of 2015 and also the RQO are exceeded in more than 50 % of the boreholes assessed. The only borehole that was within the set guidelines for nitrate-N (mg/l) is borehole TBH04, which has nitrate-N of 0.35. TBH03, located very close to TBH04, had exceeded the 6mg/l and has a concentration of 8.5mg/l is used for drinking purposes at the high school. The impact associated with it might not have been significant due to the age group of the pupils exposed not being impacted upon by methemoglobinemia. It has been mentioned in Chapter 2 that high nitrate concentration affects infants less than six month of age that are bottle feeding and the risk is increased when there is bacterial contamination in feeding water. Although other authors call for relaxation of the nitrate standards in drinking water but the WHO (2017), insists that nitrate in drinking water has got health implications.

Most of the boreholes that were sampled are used for other purposes other than drinking as the community has the alternative source of drinking from the Magalies reservoir.

Also noted is that levels of contamination increase with the decreasing elevation, implying that pollution moves from diffuse sources with percolating water either vertically or laterally downgradient of the study area towards the Elands River where it was discovered that the borehole at the bottom end has high concentrations of nitrates and other contaminants.

From the observation made and the pictures presented, it is clear that there are multiple sources of pollution contributing to the groundwater quality starting from on-site sanitation, agricultural activities where cow manure is utilized as fertilizer, livestock gathering kraal, mining activities and also natural contribution from decomposing vegetation and underlying geology.

Significance found in the study is the level of hardness in all the boreholes in the study area, which are not necessarily associated with health impacts when consumed but it reduces the lifespan of the equipment and pipeline used to handle such water, which also affects the lifespan of the clothes used to be washed by water with a high level of hardness. Also noted is the low level of alkaline metals, particularly potassium, which normally provides an advantage of softening hard water in the water systems.

Though the study seems to have yielded better inferences relating to ground-water quality, there are still a lot of challenges relating to management. The observation made from the study is that South Africa is a water scarce country indeed. The growing population, the demand for livestock watering, the demand for irrigation cannot be met by relying only on surface water without developing further groundwater resources, which has to meet both desired quality for the purpose and adequate quantity to meet those demands.

There is a need for a holistic approach and adoption of scientific principles for sustainable use of groundwater resources, i.e. to prevent groundwater pollution and ensuring life time water availability (DWS, 2013). Understanding groundwater pollution is not only relevant for environmental sustainability but also critical for economic and social wellbeing, which is supported by the resource. Such approaches will include developing implementation of strategies such as source directed measures and resources directed measures; extensive groundwater monitoring programmes (Tredoux, 2004). Continuous identification of sources so as to come up with appropriate remediation or preventative measures for prevention such include identifying and tracking nitrate pollution sources (diffuse and point sources).

Mukheibir and Sparks (cited by Mavunda, 2016) acknowledge that surface and groundwater quantities and qualities and its ecosystems should be managed by means of an integrated approach. Lack of participation from disadvantaged communities, developers, Non-Government Organisation NGO's in water resources management result in poor implementation of catchment management strategies and water policies. Integrated approach as enshrined in NEMA (National Environmental Management Act, 108 of 1998), will enable the protection, use and conservation of water resources together with the management of land use and impacts thereof.

It is also recommended that extension of monitoring networks to all villages by the authorities be made a priority, not only to assist those historical disadvantage areas but also to ensure that there is enough and accurate data to feed into data management systems for ease of future research and decision making and to be used as a source to formulate strategies linking water resources management, pollution prevention strategies, policy formulation and decision-making. Another recommendation is that more monitoring boreholes will have to be drilled and measure the water quality towards the direction of the mine.

6.7.1 Recommended monitoring plan

Groundwater monitoring is a cornerstone for groundwater management. Groundwater monitoring plans have to address the following:

- What to be monitored?
- Where?
- How?
- By who?
- To achieve what?

In addressing these questions a plan would have to be developed successfully. Here is the recommended monitoring plan.

What to be monitored?

Groundwater monitoring should include monitoring of the existing groundwater infrastructure. Boreholes collapse and are never refurbished leading to the inability to continue taking samples that are essential to provide information needed for groundwater management decisions (DWA, 2010).

If the infrastructure is kept in good order, then groundwater levels, abstraction levels water quality (physical, chemical and microbial parameter) will then be monitored successfully.

Where this monitoring should be undertaken:

Most places that are often neglected are livestock and game farms where groundwater is used as a source of water supply; communal boreholes; municipal boreholes; in farms where groundwater is used for irrigation. Mines should be included as well or be directed to provide data for public use. It may also assist to extend monitoring network for private households if the capacity is not a problem (DWA, 2010), then how?

Monitoring networks are to be established at the local level using a plan being informed by the regional strategy, which is informed by the national strategy or national plan. Monitoring programmes are to be established at the national level but to be filtered into a provincial and subsequently to local for successful implementation and resources must be provided (DWA, 2010), and by who?

For maintenance, Area Mechanics employed by either National or Regional Office of the Department of Water and Sanitation for maintenance of boreholes that are part of the monitoring network (Ministry of Agriculture, Irrigation and Water Development, 2015).

For collection of water quality and recording of levels, geo-hydrologist are to be employed at all spheres of Government to implement programmes that are within their area of jurisdiction. This has to be done in order to feed the monitoring system that will store such data to be used for policy making, decision making and also research purposes (DWA, 2010). A system has to be accessible to any person that is registered and who would add or use data for purposes mentioned. Proposed monitoring plan is in Figure 6-1 and 6-2 for Chaneng area

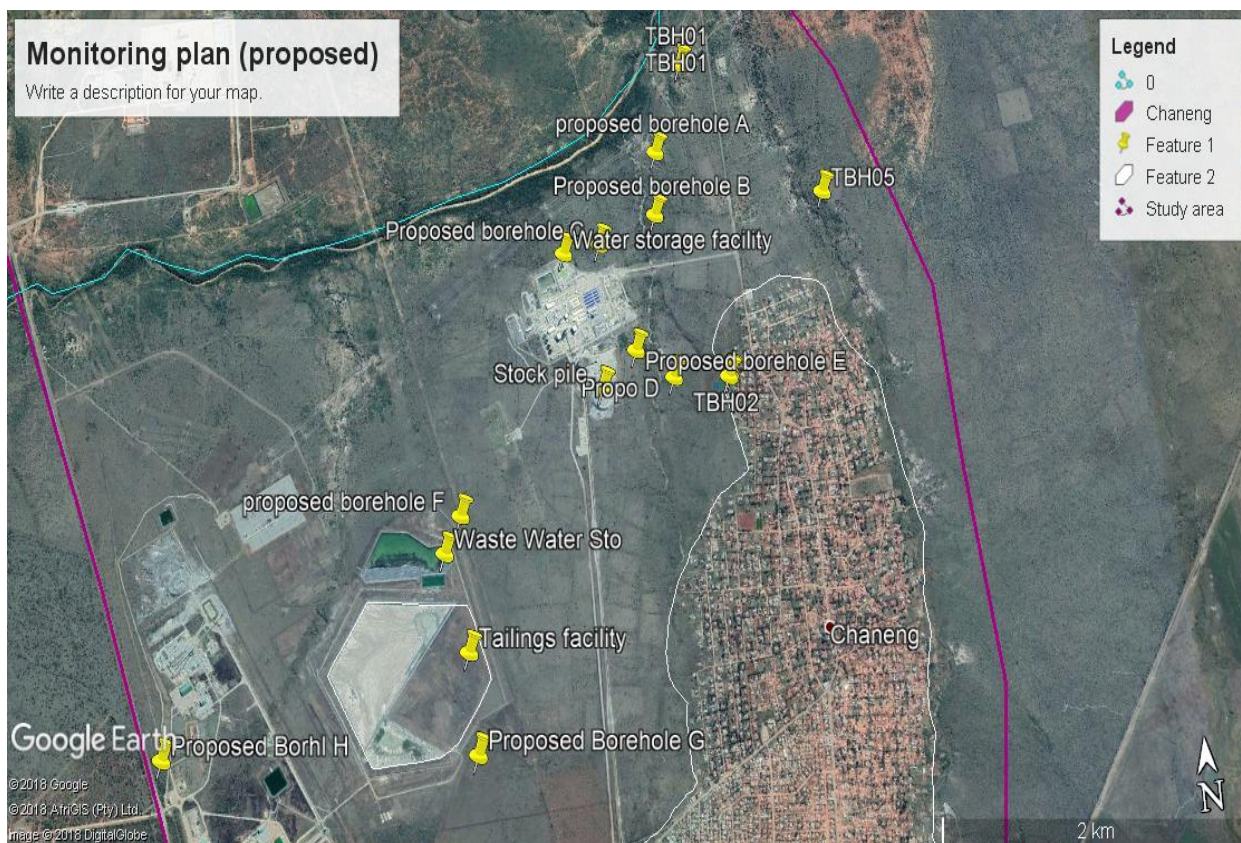


Figure 6-1: Proposed location of monitoring boreholes



Figure 6-2: Proposed Monitoring Boreholes (South of Chaneng)

Another recommendation is that there must be a central or integrated water quality information system where all water users (Water Boards, mines, industries, local municipality, etc.) will have to upload information related to water quality for free and ease of access by the public to be utilized for assessment like these and for policy formulation or decision-making. It is only prudent that such information is not regarded as the private information to an extent that one has to seek permission in order to make use of.

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APPENDIX A

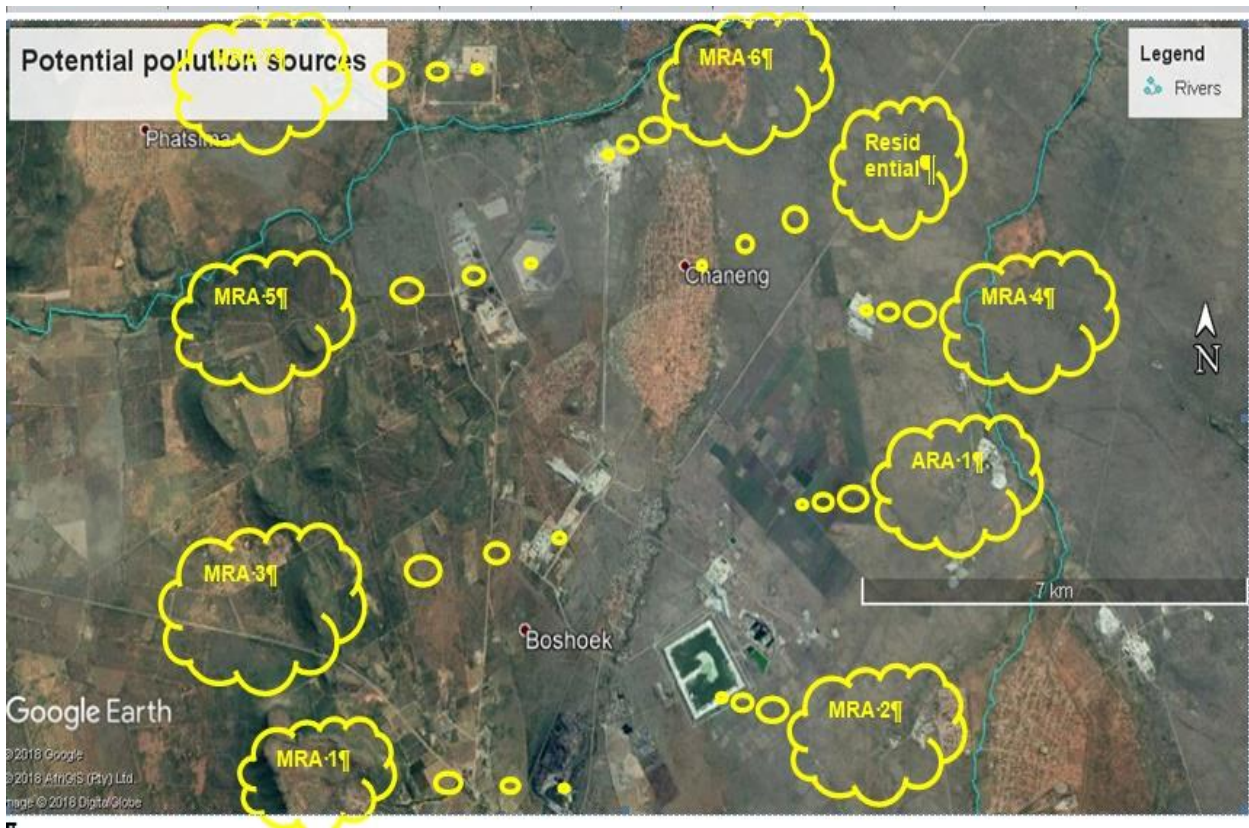


Figure 6-3: Potential pollution sources 1 (MRA denotes mining related activity, ARA, Agricultural Related Activity).

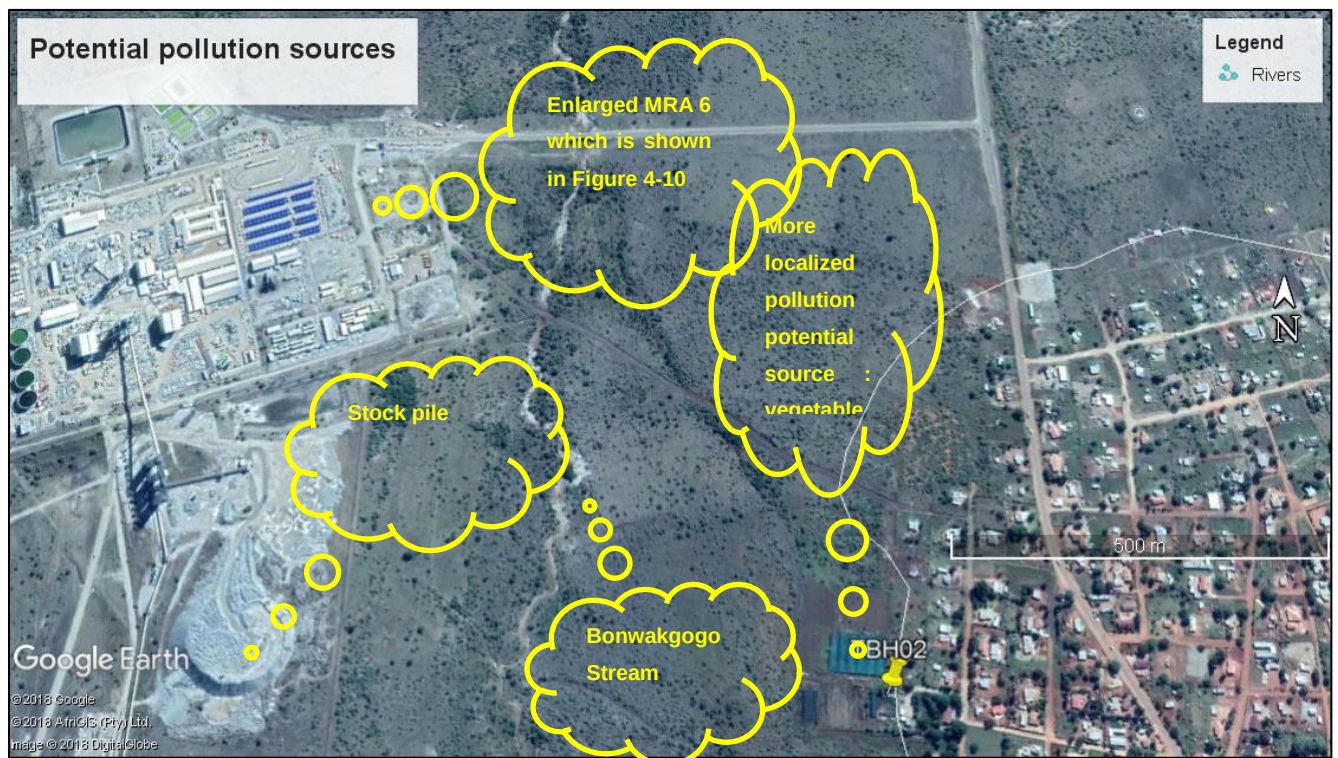


Figure 6-4: Potential pollution sources 2

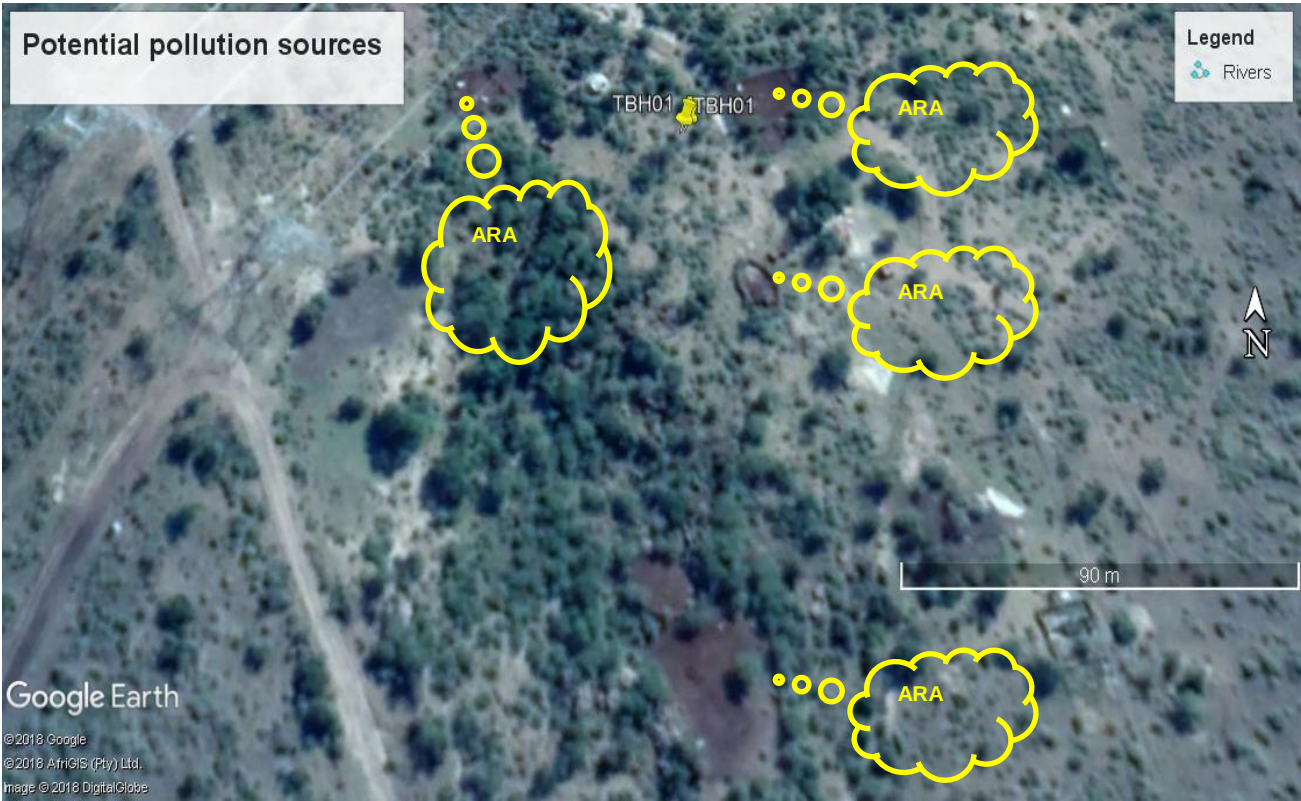


Figure 6-5: Potential pollution sources 3 near TBH01

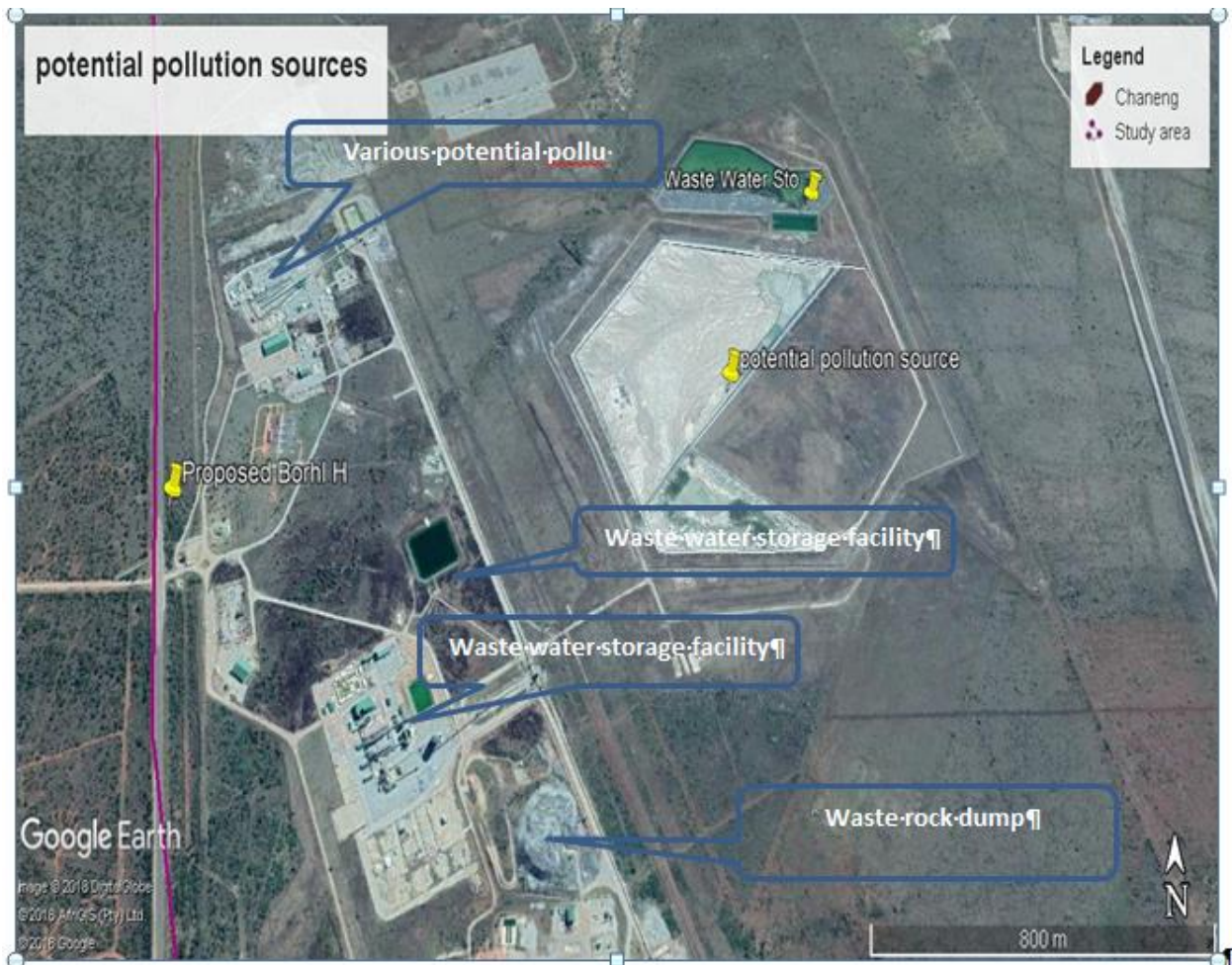


Figure 6-6: Enlarged MRA 5 with its associated potential pollution sources