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ENVIRONMENTAL SCIENCES RESEARCH PROJECT PT2

RESEARCH PROJECT REPORT

RESEARCH REPORT:
Impacts of a Defunct Colliery on Water Quality of the Wasbank River, UMzinyathi Municipality, KwaZulu-Natal

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ABSTRACT

The inefficiency of South Africa's previous legislation that regulated the operation and closure of mining activities, has resulted in too many mines being abandoned without adequate rehabilitation (Naidoo, 2017). Therefore, currently, the State has taken a responsibility to identify all these abandoned mines, assess and rehabilitate them in order to mitigate their environmental impacts, mainly the acid mine drainage (AMD) impacts. A defunct colliery in Glencoe, which ceased its operation in 1973, is one of the mines that was identified as an abandoned mine. This mine is located on the upper Wasbank catchment area in KwaZulu-Natal and study was conducted in order to determine whether this defunct colliery has any negative effects on the water quality of this catchment area. A zone above the mine shaft of the defunct colliery was identified and considered as a pristine zone, which was then used as a reference zone, and three more zones were identified, adjacent and below the mine shaft, named sampling zone B, C and D in order to assess the trend of water quality indicators and therefore to determine whether the defunct colliery is contaminating this catchment area or not. Each zone had distinct sampling points within the zone, ranging from one to four sample points per zone. Water quality of this catchment area was tested on a monthly basis during the wet season (December 2017 to March 2018) and the dry season (April 2018 to July 2018). The parameters that were tested in the field were pH, electrical conductivity, and temperature. Furthermore, once a season, water samples were collected from each sampling point in order to determine the concentration of dissolved ions. All results were analyzed against the results of the reference zone and furthermore, against the South African Water Quality Guidelines for livestock farming and domestic use. The conclusion drawn from these results is that this catchment area is altered by mine drainage from the defunct colliery. However, it seems that mitigation measures designed by previous miners are effectively treating the AMD generated which has resulted in the neutralization of this acidity such that any decant from old mine works into the Wasbank River is slightly alkaline. Furthermore, based on SAWQG, the study concluded that this catchment is within the water quality standards for livestock farming and domestic use. However, there are minor restrictions to certain specific uses because of its salty state. Subsequent to the findings of this study, the defunct colliery can be considered as low priority of future rehabilitation efforts due to the state of water quality of the surrounding drainage.

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Acronyms

AMD : Acid mine Drainage

DO : Dissolved Oxygen

DWAF : Department of Water and Forestry

EC : Elecrical Conductivity

EIA : Environmental Impact Assessment

EMPr : Environmental Management Plan report

GPS : Global Positioning System

HDPE : High-density polyethylene

ICP : Inductively Coupled Plasma

IDP : Integrated Development Plan

MPRDA : Mineral and Petroleum Resources Development Act

NEMA : National Environmental Management Act

RO : Reverse Osmosis

SAWQG : South African Water Quality Guidelines

SDF : Spatial Development Framework

SEMAs : Specific Environmental Management Acts

TDS : Total Dissolved Solids

UK : United Kingdom

USA : United States of America

USGS : United States Geological Survey

WFD : Water Framework Directive

WQSM : water Quality Strategy Management

1. Introduction

1.1 Coal mining background

South Africa is the fourth largest coal producing country in the world (Campbell, 2009). Coal production started in the 1860s and its rapid growth took place in the mid-1970s (Campbell, 2009). Coal mining activity has been one of the major sources of economic growth in South Africa for a long time. About 70% of coal mined in South Africa goes to domestic markets for energy and coal liquids production, and the remaining 30% is exported worldwide (Campbell, 2009).

Nineteen coalfields are recognized in South Africa (Jeffery, 2005). Major coalfields are found in Witbank, Highveld, Ermelo, Free State, KwaZulu-Natal KwaNgwane, Springbok Flats, Waterberg, Soutpansberg, Limpopo and Molteno Coalfields (Jeffery, 2005). These coalfields are distributed in the geological formations of the Karoo Supergoup, Ecca group (Vryheid Formation), Beaufort Group and Molteno Formation. The main coal producers in South Africa are Anglo American Thermal Coal, Sasol, Exxaro, BHP Billiton South Africa, and Glencore Strata (Hancox and Gotz, 2014).

1.2 Legislative background

Prior to the promulgation of the National Environmental Management Act No. 107 of 1998 ((NEMA, 1998), the then existing environmental legislation that regulated the operation of mining activities, did not take into consideration the responsibility of closure of mining activities (Naidoo, 2017). Therefore, future negative impacts of mining activities were not taken into account, and hence South Africa is currently facing many environmental issues emanating from abandoned mines (Naidoo, 2017).

The responsibility and costs to rehabilitate abandoned mines is now borne by the state because firstly, the original mine owners or operators are no longer in existence and can no longer be identified. A second reason for a state to bear the rehabilitation costs is based on an agreement called the Fanie Botha Accord that was made in 1976 between Government and the Chamber of Mines, regarding the implementation of pollution control measures at the abandoned mines (International Institute for Environment and Development, 2002). The Fanie Botha accord states that all mines that closed before 1976 are the government's responsibility to remediate (Hobbs *et al.*, 2008). The promulgation of the Mineral and Petroleum Resources Development Act No. 28 of 2002 (MPRDA, 2002), that replaced the Minerals Act of 1991, prevents future abandoned mines by ensuring that the new and existing mining activities follow the cradle-to-

grave holistic approach. Sections 22, 27 and 29 of the MPRDA. In summary, MPRDA provides for any person who is willing to conduct a mining activity to apply for a mining right and permit through the minister of the Department of Mineral Resources. Such applications must be accompanied by a full Environmental Impact Assessment (EIA) conducted for the activity, and Environmental Management Plan reports (EMPr) that also addresses the post-mine closure impacts. According to section 37 of the MPRDA, all mining activities are bound to comply with principles stipulated in the National Environmental Management Act 107 of 1998 so as to give effect to section 24 of the Republic of South Africa Constitution. Mining permit holders are given a responsibility to manage the environmental impacts and to bear the responsibility and costs for remedy to impacts caused by the mining activity, according to section 38 of MPRDA. To prevent significant environmental impacts, all mining activities have to comply with MPRDA, NEMA, National Water Act 36 of 1998 (NWA, 1998) and other Specific Environmental Management Acts (SEMAs).

1.3 Abandoned mines and their environmental impacts

Abandoned mines are old mining sites, where the minerals for extraction were economically exhausted and the sites left open and exposed without any restoration, or with partial rehabilitation which may include re-vegetation of the site. Waste materials that were generated during the operation of these sites is usually left in open heaps, dumped into mine pits or often in areas of natural drainage, without any proper treatment and landfilling (Adabanija and Oladunjoye, 2014).

Both active and abandoned mines affect environmental aspects such as water, air and land, and these impacts cause further cumulative impacts on the local ecology, economy and human health (Lechner *et al*, 2017). Lechner *et al.* (2017) further stated that the cumulative impacts in resource rich regions can also arise through the interaction and aggregation of impacts from different activities, such as coal seam gas development and agriculture. "Importantly, cumulative impacts reflect effects of activity occurring in different economic sectors and drawing on different forms of capitals or regional assets - natural, social, human, financial and manufactured" (Lechner *et al.*, 2017). Environmental issues identified around the coalfields include biodiversity loss, decreased species dispersals and land degradation. These result from vegetation clearance and significant ecosystem alterations due to intensive mining methods. Furthermore, coal extraction and processing during mine activity, non-rehabilitated mine sites

and mine dumps, result in dust generation that causes significant air pollution (Lechner *et al.*, 2017).

Surface and groundwater quality impacts are major issues associated with abandoned mines (Naidoo, 2017). Acid Mine Drainage (AMD) is a common environmental problem resulting from coal mining sites due to the oxidation of sulfide that is contained in coal (Mutanga and Mujuru, 2016). A study conducted by Akcil and Koldas (2004) revealed that the possibility of AMD impacts varies with different mine sites, depending on the local rock and its mineralogy, and the availability of water and oxygen. The production of the AMD is usually generated from sulfide aggregated rocks, which is a natural process. However, mining activities can increase AMD production due to increased exposure of sulfide containing rock (Akcil and Koldas, 2004). Petersen *et al.,* (2015) also emphasized the role of drainage and geological characteristics of the site on AMD production.

The water quality parameters for drainage areas affected by the abandoned mines are usually outside the acceptable limits for aquatic life, farming and drinking water standards (Mutanga and Mujuru, 2016). When a mine is closed and abandoned and the pumping of water has ceased, the water level rebounds and reoccupies the strata. Groundwater then eventually drains to the surface from old drainage adits, mine mouths, faults, springs, and shafts which intercept strata. Discharges from old adits and mine mouths are usually gravity flow (Marinos *et al.*, 2001). The potential impacts caused by AMD from abandoned mines include altered water regimes, elevated metal concentrations, lowered pH, accelerated erosion and transportation of sediments, and increased turbidity (Mutanga and Mujuru, 2016).

This research study is focused on monitoring water quality impacts in the upper Wasbank catchment area surrounding a defunct colliery in Glencoe, KwaZulu-Natal. A study looking at gold mining conducted by Naicker *et al,* (2002) in Natalspruit River indicated that the level of the water table plays a role in the significance of the AMD impacts. A contaminated shallow water table, due to gold mining activities, increases the impacts on surface water quality by decreasing its pH levels and increasing the concentration of heavy metals to surface aquatic environments (Naicker *et al.,* 2002). Their study was conducted in a drainage area of the Natalspruit River, where there were gold tailings dumps within its headwaters (Naicker *et al.*, 2002). This drainage area was characterized by an elevated water table throughout the year (Naicker *et al.*, 2002). The pH, redox potential, temperature and electrical conductivity of water were measured on site and further analysis of metal concentration in water samples was done

using Atomic Absorption Spectrophotometry. Their results showed variations between water samples taken upstream and downstream, above and below the tailings dumps, respectively (Naicker *et al.*, 2002). The upstream results had neutral pH and relatively low conductivity, while within the mining area and downstream their results show very low pH values (below 6) and high electrical conductivity that was outside the water quality standards. Results also showed an increased concentration of sulfate, iron and trace metals (Naicker *et al.*, 2002).

The Blesbokspruit catchment is another area that has be shown to be affected by AMD in South Africa by the environmental impacts associated with abandoned mines in the Witbank coalfield in South Africa (Bell *et al.,* 2000). The Witbank coalfield is dominated by the Vryheid geological formation (Bell *et al.,* 2000). Water sampling for analysis was conducted in winter and summer seasons. The results of this study showed very low pH values, high total dissolved solids and high aluminum and sulfate concentrations (Bell *et al.*, 2000). Bell *et al*. (2000) concluded that the results of this study show the characteristics of water polluted by the AMD.

Water quality results of a study conducted at old coal mine spoils in the Karoo Basin within the Vryheid geological formation in Free State, showed semi-neutral pH values ranging between 6 and 8, and also showed poor to unacceptable Total Dissolved Solids (TDS) for drinking standards as per South African Water Quality Standards (Gomo and Masemola, 2015). Gomo and Masemola (2015) concluded that the semi-neutral water quality results were characterized by elevated calcium and magnesium content produced by a dolomite-AMD neutralization process.

A quantitative study on the impacts of an abandoned metal mine on the receiving water was conducted in South West England by Beane *et al.* (2016). The study was conducted at Wheal Betsy, a former lead (Pb) and gold (Au) mine located on the North-West edge of Dartmoor, Deron, United Kingdom (UK). Beane *et al*. (2016) tested for water quality impacts by measuring conductivity, pH, and dissolved oxygen (DO). They further measured suspended solids, velocity of water flow at the centre of the stream and at one third depth from the bottom of the stream, and at a point of minimal turbulence (Beane *et al.*, 2016). Results for water quality testing showed that the metal concentration downstream of the mine site, including adits draining the site, exceeded the Environmental Quality Standards of the United Kingdom. Lead (Pb) exceeded the standards by fifty times, other metals exceeded by ten to twenty times the EQS range. Environmental Quality Standards are new standards set by the UK under the Water

Framework Directive (WFD) for metals such as copper (Cu), cadmium (Cd), chromium (Cr), mercury (Hg), nitrogen (N) and lead (Pb) (Beane *et al*, 2016).

The study revealed that historic mine sites are a major source of contamination to terrestrial and river environments (Beane *et al.,* 2016). Many areas in the United Kingdom are affected by major and long-term impacts coming from the old mines sites that are not environmentally managed. The major source of this contamination comes from decant that is released from these abandoned mines. Most commonly, this contamination is in the form of a concentration of metals and they contaminate both surface and groundwater resources, soils and sediments (Beane *et al.,* 2016).

The environmental impacts of discharge coming from abandoned coal mines in the United Kingdom (UK) were assessed by the Coal Authority and National Rivers Authority, in order to rank the impacts which will inform the priority for remediation (Banks and Banks, 2000). The study concluded that the main contamination in drainage areas from coal mining was the increased concentration of iron (Fe) and sulfur dioxide (SO_2) arising from the oxidation of pyrite (Banks and Banks, 2000).

Jill *et al.,* (2015) evaluated the long-term (37 years) changes in pH, sulfate and iron concentration related to geochemistry, hydrology and attenuation processes. Water quality data that were collected in 1975, 1991, 1999 were compared to water quality data that were collected in 2012, from the ten drainage areas above coal mine discharges and fourteen drainages areas below the coal mine discharges in the Anthracite region of Pennsylvania, United States of America (USA). Their conclusion was that coal mine drainage quality improves over time because of the reduced quantities of unweathered pyrite, decreased access of oxygen to subsurface after mine closure, decreased rates of acid production and relatively constant influx of alkalinity from groundwater even though it has not yet reached steady state conditions (Jill *et al.,* 2015). The concentration of iron and sulfate showed a decrease from the sampling results of 2012 compared to sampling results of 1975.

Lambert *et al.,* (2002) also drew the same conclusion as Jill *et al.,* (2015) that water quality of the abandoned coal mine drainage areas improves over a long period. Their study was conducted to assess the long-term changes on water quality of the discharge water from abandoned underground coal mines in Uniontown, USA. It further revealed that high rainfall or flooding can have a major contribution to dilution of acidic water, and therefore water quality

improves more on flooding drainage areas, or rather, areas that receive more rainfall (Lambert *et al.*, 2002).

All the above studies indicate that the main parameters that were measured to determine the impacts of AMD were pH and EC. One of the most important water quality parameters that relates to the acidity and alkalinity of water is pH (Spellman, 2009). The pH measures the concentration of hydrogen ion in a solution (Westcott, 2012). Solutions concentrated with more hydrogen ions have low pH and solutions concentrated with low hydrogen ions have high pH (Westcott, 2012). In that way it determines the acidity and alkalinity of a solution on a scale of 1 – 14, where the pH value is measured below 7, water is considered to be acidic, and where the pH value is 7, water is neutral and where the pH value is measured above 7, water is considered to be alkaline (Lawn and Prichard, 2003). A pH can be measured for various purposes, including to test and sample against legal requirements or to test a chemical against a specification. It can also be measured as part of an analytical method, for monitoring and controlling biochemical and physiological reactions, many of which only take place in a particular and sometimes narrow pH range. It can also be measured for process control in the chemical industry and lastly for environmental monitoring of waste and effluents (Lawn and Prichard, 2003).

Water that drains from abandoned mine sites can be very acidic and have a pH value of 2 and below (Spellman, 2009). A recommended range of pH for drinking water standards is 6.5 to 9.5. A pH range of 4 to 6 can have toxic effects associated with life and pH range of < 4 can pose a severe danger to health effects due to dissolved toxic metal ions (World Health Organization, 2004). Water that has a pH range of 9 to 11 can have a bitter taste and have a probability of toxic effects associated with deprotonated species, and where water pH is more than 11 can pose a severe danger of health effects (World Health Organization, 2004). "The pH of water does not have direct consequences except at extremes. The adverse effects of pH result from the solubilisation of toxic heavy metals and the protonation or deprotonation of other ions." (DWAF, 1996).

Water in abandoned coal mine sites is normally acidic, characterized by low pH and high concentration of sulfate and other metals (Jensen and Malter 1995). Acidic water can affect the pH of soil by dissolving the soil minerals that are needed by plants and replacing the metallic ions with hydrogen. Acid water therefore influences both quality and yield of agricultural products. It damages the leaves of vegetables and causes blemishes on delicate products (Jensen

and Malter, 1995). The desirable pH range for irrigation water is 5 to 7. Water pH levels above 7 hinder absorption of nutrients by plants, whereas water pH levels below 5 cause excessive absorption of certain nutrients which may cause toxicity (Jensen and Malter, 1995).

The required pH range for livestock drinking water standards is 6.5 to 9. Water pH measurement outside this range are not suitable for livestock drinking (Black Mesa Project, 2006). According to Davis and McCuen (2005), the required pH range for aquatic life is 6 to 9. When the water pH level is below 6.0, aquatic life becomes susceptible to fungal infections and other physical damage, because low pH levels causes aluminum in soils to leach into water at levels that are toxic to plants and animals (Davis and McCuen, 2005).

Electrical Conductivity (EC) is a useful parameter in raw and finished water for the measurement of minerals (Jacobs *et al*., 2014). It is a measure of the electric current in water carried by ionized substances. Therefore, the dissolved solids are basically related to this measure, that is also influenced by the conductivity of acids and salts. The unit of measurement for EC is microsiemens per centimeter (µS/cm) (Jacobs *et al.*, 2014). The EC value usually increases in contaminated waters compared to uncontaminated waters. Drainage areas surrounding abandoned mine sites are usually acidic and produce elevated values of EC because of the dissolved metals, sulfate and other hydrogen ions that can all conduct an electrical charge. So basically, the EC value increases with the decreasing pH value, and vice versa in the drainage areas that are susceptible to AMD (Jacobs *et al.*, 2014). The permissible EC range for drinking water standards is between 0 µS/cm and 300 µS/cm (Jacobs *et al.*, 2014). EC can indicate a salinity hazard for crop production. The acceptable range of EC values for crop irrigation is up to 600 µS/cm, with certain restrictions on different types of crops (Connellan, 2013).

1.4 Research problem

The Dundee area is one of the areas identified by the Department of Water and Sanitation as a hotspot affected by AMD issues due to the abandoned mines that were operational prior to MPRDA and were left unrehabilitated. This area is characterized by two main river catchments, the Buffalo and the Wasbank Rivers. These two rivers are the main water sources for the district for both domestic and agricultural use. The area of study, the defunct colliery, is located within the upper Wasbank catchment area. The impacts of this abandoned coal mine on the water quality of the Wasbank catchment can have impacts on the availability of water to the district and can also raise the costs for water treatment by the municipality. Furthermore, the impacts

of the defunct colliery can affect or contaminate a wider range of the UMzinyathi District and outside its boundaries due to the link of the Wasbank River and Sunday River, which flows through UThukela Districts and eventually into the Indian Ocean.

1.5 Research Motivation

The Department of Water and Sanitation, the Department of Environmental Affairs, and district municipalities are working together and have proposed a programme of identifying abandoned coal mines that need to be rehabilitated in order to mitigate the environmental impacts associated with the acid mine decant emanating from them. This study will contribute towards this programme to aid in identifying if the defunct colliery requires priority in terms of rehabilitation. It will also form part of the Water Quality Strategy Management (WQSM) initiated by the state, for the two main catchment areas (Buffalo Catchment and Wasbank Catchment Area) of UMzinyathi District, extending to UThukela Region. The purpose of WQSM is to assess contamination, identify sources of pollution, and identify management actions that are necessary in order to achieve the anticipated water quality of the catchment area (DWAF, 2000).

1.6 Research Questions

- What is the water quality of the upper Wasbank River Catchment area surrounding the defunct colliery based on pH and EC as outlined in the South African Water Quality Standards (DWAF, 1996)?
- Does the defunct colliery cause any downstream contamination in the Wasbank catchment area?
- What are the contaminants that the defunct colliery may be releasing into the downstream Wasbank drainage area?

1.7 Aim and Objectives

The aim of this study is to assess if there is any contamination of the water quality of the Wasbank River mine site catchment area from the defunct colliery.

To achieve the above mentioned aim, this study has the following objectives:

- To describe the water quality based on the South African Water Quality Standards by measuring pH and EC of the identified streams surrounding the defunct colliery compared to upstream assumed to be a clean zone (DWAF, 1996).
- To assess the trends or variation in water quality of the identified tributaries.
- To identify the cause of the observed contamination trends in water quality in the identified streams.
- To identify the sources of contamination by analysis of water samples for anions and cations using ICP.

2 Methods and Materials

2.1 Location and site history

As per the data of the Department of Water and Sanitation for abandoned mines in Kwazulu-Natal, this colliery is one of the abandoned coal mines, located near a small town called Glencoe in KwaZulu-Natal (S 28°10’47” E 30°04’32”). This area is located within the Endumeni Local Municipality which is under the UMzinyathi District Municipality **(Figure 1).** This defunct colliery falls within the KwaZulu-Natal Klip River Coalfield **(Figure 2).** This coalfield is historically the major coalfield in KwaZulu-Natal due to a high percentage of high potential projects in the coalfield (Hancox and Gotz, 2014). Klip River Coalfield is in the north of KwaZulu-Natal Province extending north of Newcastle, continuing to the south of Ladysmith and the south east of Dundee, covering an area of approximately 600 000 hectares (Hancox and Gotz, 2014). It is located within one of the farms in Glencoe, at lot number L219. As per the owner of farm, Mr. Hansen Wessels, this mine operated years ago, estimated to have started operating in 1909 and its operation ceased in 1973. Mr. Wessels further explained that this defunct colliery was an underground mine site where coal was extracted at an unknown depth below the surface through inclined shafts. There are two shaft headframes that are now closed, that indicate the entrances that were used to go underground for coal extraction **(Figure 3 & 4)**, and there was a processing plant a few meters away from the lower shaft where the extracted coal was taken for processing **(Figure 5 & 6).**

2.2 Climate

The topography of uMzinyathi district strongly influences the climate of certain places within the district. The differences in elevation translates into noticeable climate changes within south, south central and north eastern areas, which have more pleasant and warmer temperatures than the colder northern areas (uMzinyathi District Municipality IDP, 2016/17). Endumeni Local Municipality is characterized by a temperate climate, with warm to hot summers and mild to cold winters. Endumeni Local Municipality receives an average rainfall of 600 mm to 800 mm per annum. It experiences an average temperature range of 25°C to 29°C. This area receives its lowest rainfall in June and the highest rainfall in November to January, and its winters are characterized by frost (uMzinyathi District Municipality IDP, 2016/17).

2.3 Terrain and Drainage

This defunct colliery is situated in a valley, at the foot hills of the Biggarsberg Mountains, surrounded by open low mountains a few kilometers from the mine site. It is located on the banks of the Wasbank River that originates on the slopes of the Biggarsberg Mountains, to the north west of the mine, and flows into the Sundays River in the Indaka Local Municipality (DWAF, 2000). The Wasbank River is characterized by a number of small tributaries that flow into it, draining the plateau and slopes of the escarpment, on either sides of the Wasbank River, in the form of a trellis pattern, above and below the mine**.** One of the tributaries flowing into Wasbank River is the Manzamnyama River. The confluence of the Wasbank River and Manzamnyama River is directly adjacent to the mine site. The Manzamnyama River drains the flatland north of defunct colliery and is characterized by agricultural activities and also has an abandoned coal mine called Northfield colliery. The Wasbank River catchment area is divided into two sub-catchment areas, named Upper Wasbank Sub-Catchment area and Lower Wasbank Sub-Catchment area (DWAF, 2000). The Upper Wasbank Sub-Catchment area is characterized by the following main tributaries Manzamnyama, Uithoekspruit, Busi and Biggarsbergspruit River. This defunct colliery is situated at the Upper Wasbank Sub-Catchment area.

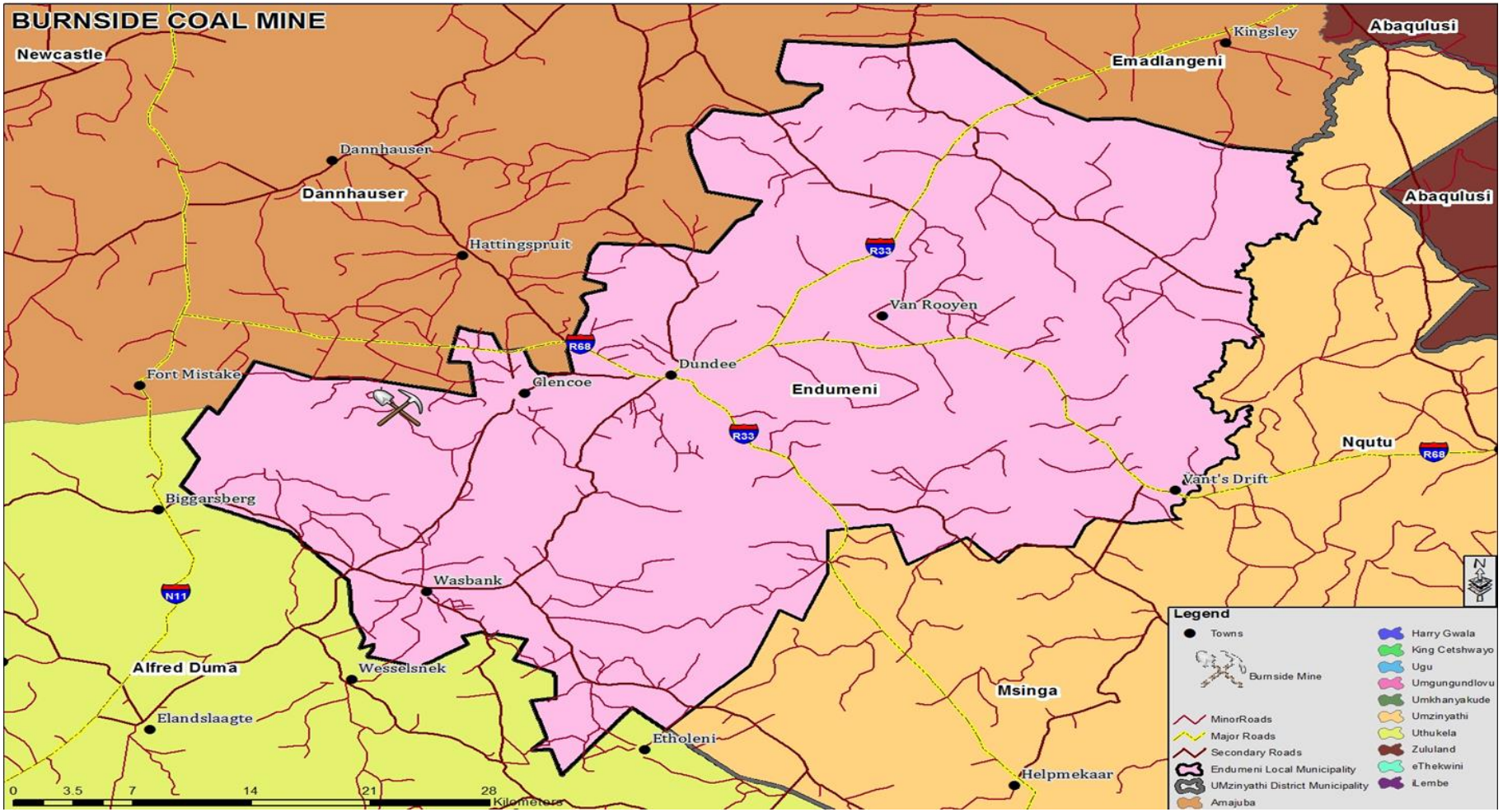


Figure 1: The location of the defunct colliery (Source: uMzinyathi District Municipality GIS Data)

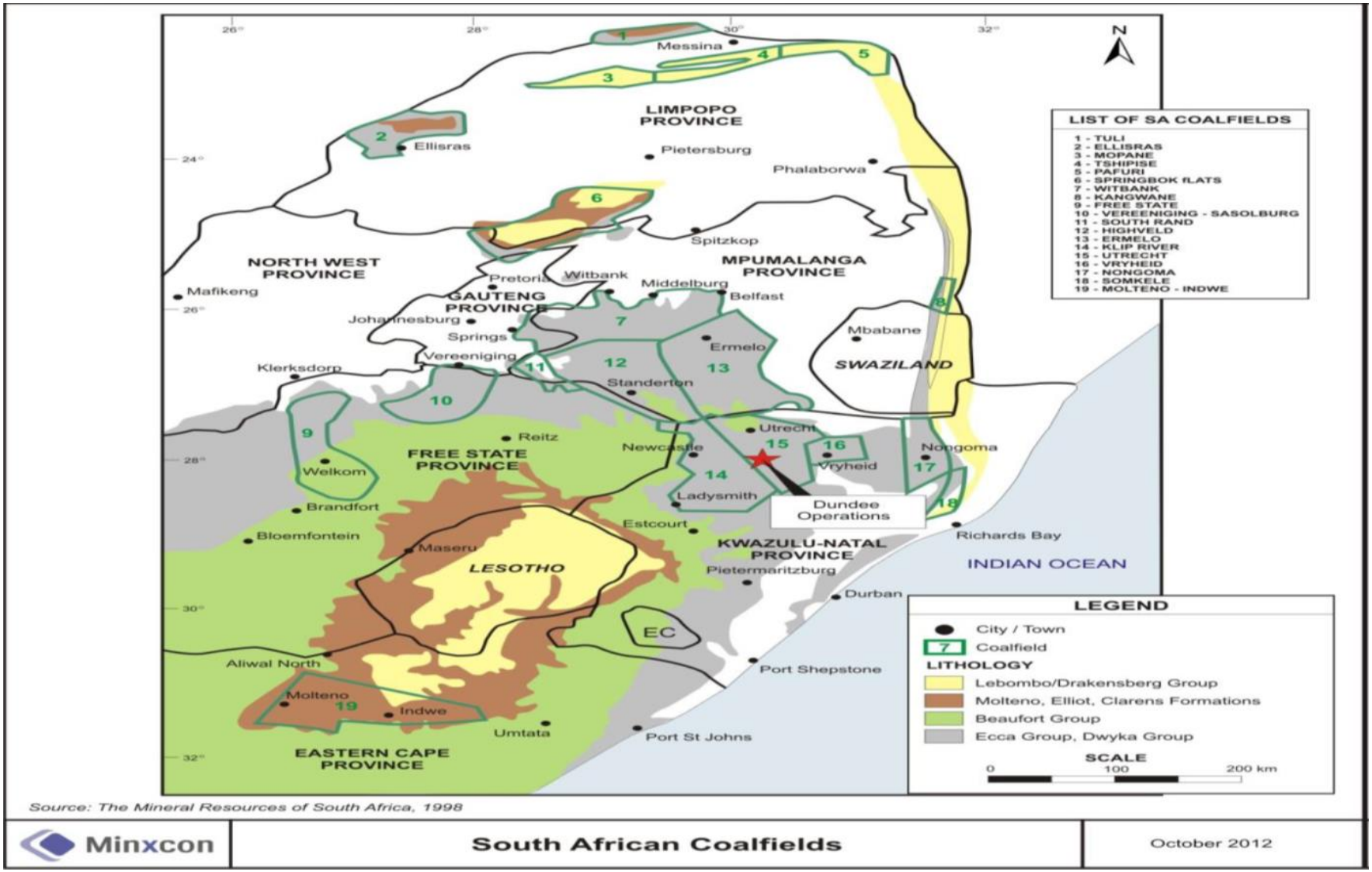


Figure 2: The South African Major Coalfields. (Source: http://www.buffalocoal.co.za/pdf/Technical%20report_NI43-101.pdf. Date: 08 May 2017)



Figure 3: The closed mine shaft headframe (Source: Linah Nyathi (2017), Glencoe)



Figure 4: The side view of the mine shaft headframe (Source: Linah Nyathi (2017), Glencoe)



Figure 5: Old mine residue at the processing plant (Source: Linah Nyathi (2017), Glencoe)



Figure 6: Coal wash blending at the old processing plant (Source: Linah Nyathi (2017), Glencoe)

2.4 Geology

The Klip River Coalfield is dominated by sedimentary rocks of the Vryheid formation and Ecca Group of the Karoo Supergoup. The dominant rocks are Arenite, the most common, and sandstone, shale and coal seams **(Figure 7 & 8)** (Endumeni Local Municipality SDF, 2015). The defunct colliery is characterized by two economic coal seams, namely, Top Seam and Bottom Seam (Meyer, 2009). The two coal seams are separated by coarse grained pebbly sandstone, cross-bedded and fining upwards to shale at the top (Meyer, 2009). The space that separates the two coals seams has the thickness of 18-25 meters. There are various dolerite intrusions in the area (Meyer, 2009). The top coal seam has the thickness of 0.5 to 3.3 meters of coal, whereas the bottom seam has the thickness of 0.5 to 1.3 meters of coal (Mintek, 2007).

2.5 Current Land use

The owner of the farm where this defunct colliery is located, Mr. Hansen Wessels, gave the following information regarding the current land use of the study area: The whole study area falls within the Lot 209 farm, and the current activities within this farm are livestock (cattle and sheep) farming and coal residue processing (Wessels, 2017). The livestock depend on the Wasbank River for drinking water **(Figure 9).** Water from the Wasbank River is pumped and stored in reservoirs during rainy seasons, which ultimately becomes the source of drinking water during dry seasons (pers. comm., Wessels, 2017). There is no current crop planting at the farm, so water is not used for any irrigation purposes, however the owner of the farm is planning to start crop planting in the next two years, therefore water from this catchment area might be needed for irrigation (pers. comm., Wessels, 2017). The neighboring farms that are within the Upper Wasbank Sub catchment area but outside this study area do have fields for commercial farming (pers. comm., Wessels, 2017). All of which further highlights the possibility of increasing water demand in this catchment area, to which if the water is proven to be contaminated could impact negatively on crop production (pers. comm., Wessels, 2017).

Another current activity on this site, is the processing of the old mine residue a few meters from the old mine shaft headframe **(Figure 5 & 6)** (pers. comm., Wessels, 2017). Currently the processing plant is used by the farm owner in partnership with Potco Mining for coal wash blend activity - where the old mine residue is rescreened, crushed and mixed with high quality coal, that is outsourced, and the end product is supplied to Corobrick, Glencoe. Below the old processing plant and the residue dump site, there is a catchment dam that was constructed to collect all the contaminated water coming from the processing plant and the residue dump site

in the event of surface runoff **(Figure 10)** (pers. comm., Wessels, 2017)**.** Water from the site still flows into this catchment dam without any disruptions. However, this contaminated water is not treated and therefore when the dam is full, the contaminated water overflows into the Wasbank River (pers. comm., Wessels, 2017).

2.6 Sampling design and procedure

In situ water quality testing was conducted in the upper Wasbank River catchment area surrounding the defunct colliery at the specific sampling points **(Figure 11).** Hounslow (1995) stated that water samples are generally analyzed at the accredited laboratories. However, it is also recommended to measure some of the water quality parameters in situ at the point of collection to avoid changes in value due to prolonged time and exposure to the atmosphere (Hounslow, 1995).

As far as is known, no study has been done on contamination by this defunct colliery on the water quality of the upper Wasbank River catchment area since this mine was closed 43 years ago. Therefore, there are no previous findings that reveal the nature of any expected contamination of this abandoned mine on the surrounding water quality, and this study is a pilot project to determine whether the defunct colliery is contaminating the water quality of the Wasbank River Catchment area. The design of this study was guided by previous studies' designs that have been conducted on other abandoned coal mines in South Africa and abroad, where sampling zones are usually on the upstream, adjacent to the mine and downstream of the catchment area.

The initial water quality parameters that were measured on site in order to determine the possible contamination by defunct colliery on the surrounding water quality are the pH and Electrical Conductivity. These parameters are the primary indicators of contamination in water resources where there is AMD (Akcil and Koldas, 2004). Pilot water quality measurements were conducted on the 24th of June 2017, where EC, pH and temperature were measured. The water quality trends showed a decrease in pH value measuring from sampling zone A to C, pH was slightly alkaline and decreasing towards neutral, and EC showed a slight increase from sampling zone A to C. Sampling zone B and sampling point 7 were completely dry, therefore they were not measured. Within Zone D, pH was becoming more alkaline from sampling point 5 to 8, EC was increasing between sampling point 5 and 6, and dropped at sampling point 8 **(Table 1).**

Table 1: Water quality pilot measurements

Sampling Point	pH	EC (µS/cm)	T (°C)
A1	7.99	104.20	24
A2	7.90	126.90	24.7
B3	No Flow	No Flow	No Flow
C4	7.69	149.90	25
D5	8.46	5900.00	24.55
D6	8.90	3710.00	26
D7	7.88	202.00	27.7
D8	8.67	179.00	25

These initial pilot testing results showed significant abnormal trends in pH and EC values measuring from sampling zone A to D, and subsequently the samples for chemical analysis were taken once per season of sampling (wet and dry seasons) in order to establish the cause of the observed trends, precise sources and degree of contamination. Those water quality chemical variables that were measured at the accredited laboratory (REMI Environmental Laboratory and Consulting Services (Pty) Ltd) are the concentrations of calcium (Ca), aluminium (Al), chlorine (Cl), potassium (K), iron (Fe), fluoride (F), magnesium (Mg), sulphur (S), calcium carbonate (CaCO3), manganese (Mn), arsenic (As), boron (B), sodium (Na), sulfate (SO4), nickel (Ni), silicon (Si), nitrates (NO3) as N, and orthophosphate (PO_4^{3-}).

As Akcil and Koldas (2004) stated that the nature of the local rock plays a role in the AMD potential impacts. This study area, as discussed in section 6.4 is within the Vryheid formation, dominated by sedimentary rocks, which is similar to Witbank coalfield. A study conducted in an AMD affected area within the Witbank coalfield had high concentrations of S, Al, and Fe, therefore these are the ions that will be focused on under the suspicion of AMD contamination due to the geological similarities of these two areas (Bell *et al.,* 2000).

The equipment that was used to conduct this stud includes GPS, 33mm nylon syringe filters with 0.45µm pores, camera, latex gloves, portable meter, squeeze water bottle, calibration solutions, cooler box and ice blocks, HDPE bottles and data collection sheet.

Water quality testing using an *in situ* portable meter was conducted at the identified sampling points as shown on **Figure 11**. The sampling points were at the approximated distances from the mine as indicated on **Figure 11** and the GPS coordinates for each sampling point were recorded. The results of the in situ testing were immediately recorded on the data collection

sheet on site. Water samples were collected with 1L acid-washed HDPE plastic jugs, filtered using 50 ml syringes with 33 mm diameter MS nylon syringe filters with 0.45 µm pores from Membrane Solutions (www.membrane-solutions.com) into acid washed 1L HDPE plastic bottles. All HDPE bottles and jugs were acid washed for 36 hours in a 10% v/v analytic grade HNO_3 solution, rinsed in reverse osmosis (RO) water before soaking a further 36 hours in RO water with a final rinse in RO water before drying prior to sample collection. A fresh jug, syringe and filters were used for each sample. However, multiple filters were required to collect at least 500 ml per water sample due to the suspended material in the water from rains in the previous weeks when collection the mid-summer samples. Prior to collecting stream water samples, two samples with RO water brought from the lab were run on site through the sample-collecting equipment as blanks for quality control of the entire sampling process from lab preparation of equipment to ICP analysis. One sample of approximately 500 ml was collected from each sampling point along the Wasbank (**Figure 11**) with the exception of sampling point 8, where three replicate samples were collected for quality control purposes. Samples were stored in a cool box and then fridge until they could be delivered to the laboratory for chemical analysis (pers. comm. D. Furniss, 2017).

The values of *in situ* water quality parameters were recorded from each sampling point for a period of seven months across the wet season. The trends in values of these parameters were compared based on the location of each sampling point and analyzed based on the variations over this sampling period. Water quality of this area was ranked based on the South African National Water Quality Standards that were published by the Department of Water and Sanitation for different utilizations as part of managing water resources for their diversity in South Africa (Schreiner and Hassan, 2011). There are four (04) zones that were identified as the sampling zones in the catchment, namely sampling zone A, B, C, and D respectively.

Sampling Zone A

This is the zone that is presumably considered to be above the mine site and expected to be clean and free from any metal concentration that can emanate from the mine. This zone was selected and used as a reference zone and all other data values from the other sampling zones were compared to this zone in order to determine the change in values and predict if there is any kind of contamination that could be caused by the old mine. Sampling Zone A comprises the Wasbank River on the northwest part of the defunct colliery, which is above the mine. This part of the Wasbank River drains the slopes of the Biggarsberg Mountains and its flatlands,

where the dominant activities are only agricultural activities. Zone A is located at the altitude of 1240 m above the mine site. The gradient is depreciating from Zone A towards the mine site, and the mine site is at an altitude of 1200 m downslope of zone A. So this implies that Zone A may not be affected by the mine site due to its location. There are two sampling points identified within Sampling Zone A, sampling point 1 and 2, respectively **(Figure 11).** Sampling point 1 is on the Wasbank River, 1.27 km above the mine, and sampling point 2 is also on the Wasbank River, 0.12 km above the mine site **(Figure 11).**

Sampling Zone B

Sampling Zone B is considered to likely be already contaminated, before it reaches the defunct colliery mine site. It comprises of the Manzamnyama River that drains from the north part of the mine site. It drains the Northfield flatland, where there is also an abandoned coal mine that is not rehabilitated and managed, called Northfield Colliery. The Manzamnyama also flows adjacent to the second shaft of the defunct colliery before it joins the Wasbank River. The Manzamnyama River joins the Wasbank River directly adjacent to the mine site. The sampling zone comprises of one sampling point named sampling point 3. Sampling point 3 is on the Manzamnyama River before it joins the Wasbank River, at 0.5 km from the defunct colliery mine site **(Figure 11).** However, no samples were taken from this zone because it was dry throughout both wet and dry seasons.

Sampling Zone C

This is the zone that corresponds to the mine site **(Figure 11)**. This zone is at the confluence of the Wasbank River and the Manzamnyama River. It has one sampling point, named as sampling point 4. Sampling point 4 is 0.12 km from the mine site. This zone is expected to be highly contaminated since it is quite close to the mine site and also due to the observed discolored water within this site **(Figure 12).**

Sampling Zone D

Sampling zone D is at approximately 2 km below the mine site. It comprises of the Wasbank River, an unknown stream that joins the Wasbank River below the mine site, the contaminated water catchment dam that collects the contaminated water from the processing plant and the old residue dump site, and the catchment dam flow that eventually flows into the Wasbank River. There are four identified sampling points in this zone, which are sampling points 5, 6, 7 and 8 respectively. Sampling point 5 is on the mine site catchment dam outflow before it joins the

Wasbank River, at 1.19 km downstream of the mine site. Sampling point 6 is on the Wasbank River downstream of the mine site and below the old residue stockpiles, at 1.36 km downstream the mine site. Sampling point 7 is on an unknown stream at 1.2 km downstream of the mine site before it joins the Wasbank River and this stream is assumed to be clean. Sampling point 8 is on the Wasbank River below the confluence of the mine site catchment dam flow and the unknown stream, at 1.6 km downstream of the mine site **(Figure 11).** This sampling zone has an increased exposure to contamination from the overflow of the contaminated water catchment dam, and the pollution from the processing plant and the old residue stockpile, since there is dust generation during the coal wash blend process and the old residues can be eroded into the river by rainfall and wind.

These sample zones were selected in order to compare the trends and variations of water quality values upstream, adjacent, and downstream of the mine, and to determine the extent of impacts of the defunct colliery on this catchment area. Data was collected on a monthly basis for a period of eight months, from December 2017 to July 2018. Data was also analyzed as either dry or wet season, in order to also determine the role of seasons on the water quality. Therefore, data was separated for rainy season (December 2017 to March 2018) and dry season (April to July 2018). There were changes observed on the catchment area during the dry season as compared to the wet season. The water level in the streams decreased, water flow was slower, and water was clearer. At zone C, as the water level was very low, there was an observed decant coming from the ground, which was discolored and had a bad smell. Sampling was also done directly on the decant, and was added on the sampling design as sampling point C9 (**Figure 13**). Flow of an unknown stream where sampling point D7 is at was very minimal to an extent that it did not meet with D5 (catchment dam outflow) as it was during the wet season. Therefore, there was less dilution on sampling point D8, which is the point below the confluence of sampling points D5, D6 and D7. At sampling point D7 there was lots of algae observed, which was exposed due to water level drop in the Wasbank River.

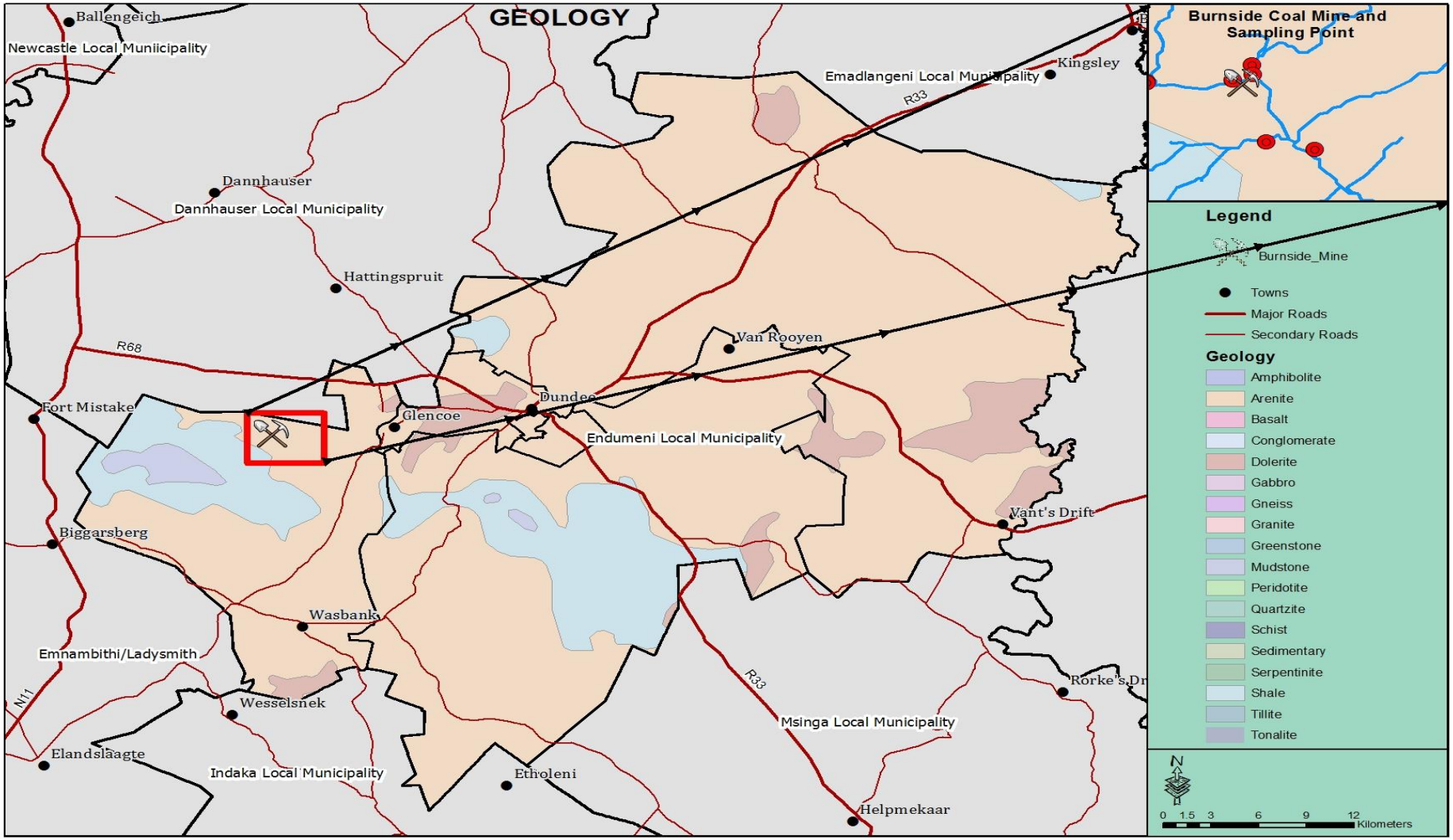


Figure 7: The Geology of the study area (Source: uMzinyathi District Municipality GIS Data)

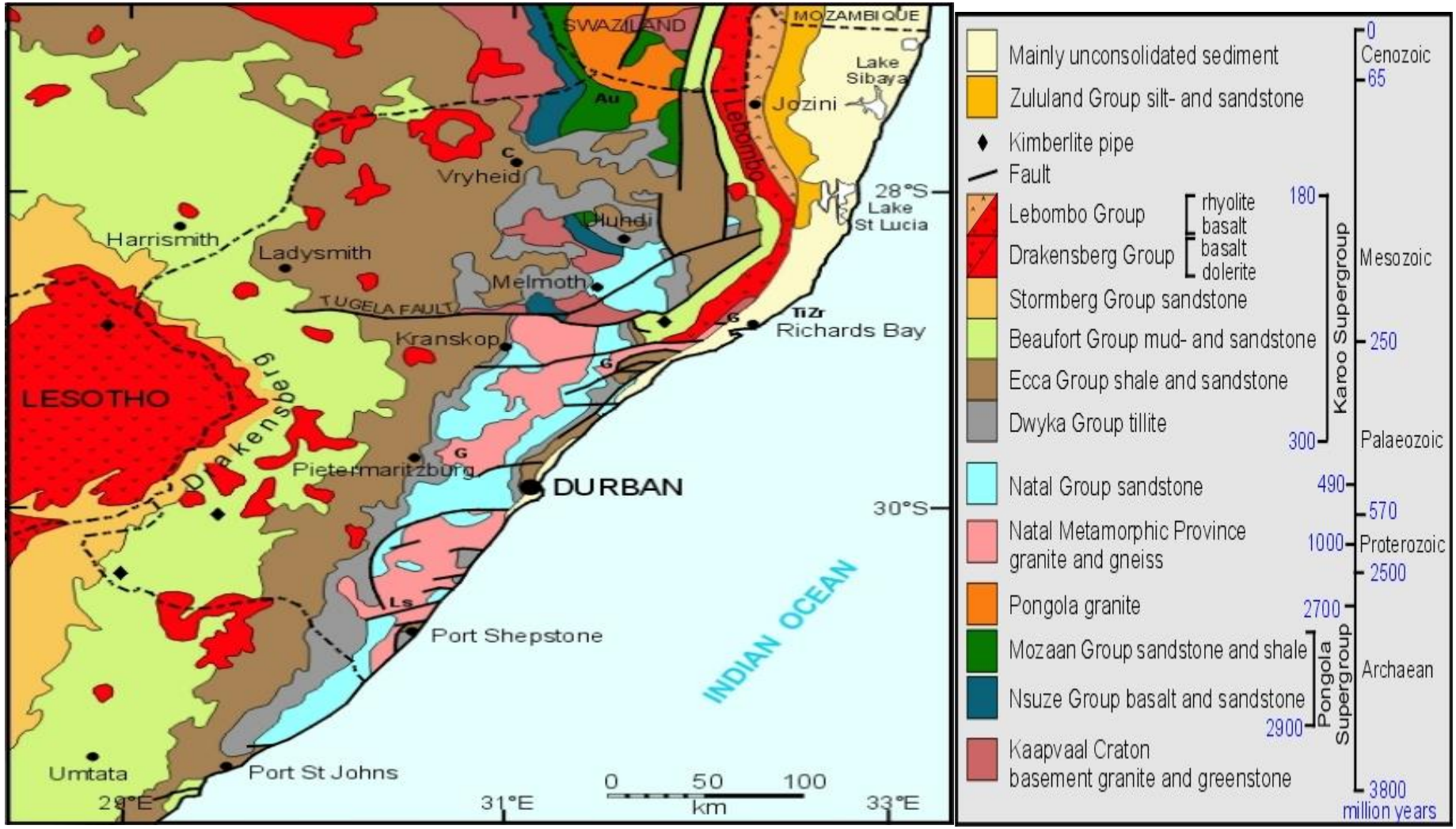


Figure 8: The Kwazulu-Natal Geology
(Source: http://stec.ukzn.ac.za/GeologyEducationMuseum/KZNGeology/KZNGeologyMap.aspx. Date: 19 April 2017)



Figure 9: The cattle of the Lot 209 farm drinking from the Wasbank River (Linah Nyathi (2017), Glencoe)



Figure 10: The contaminated mine site catchment dam below the processing plant (source: Linah Nyathi (2017), Glencoe)

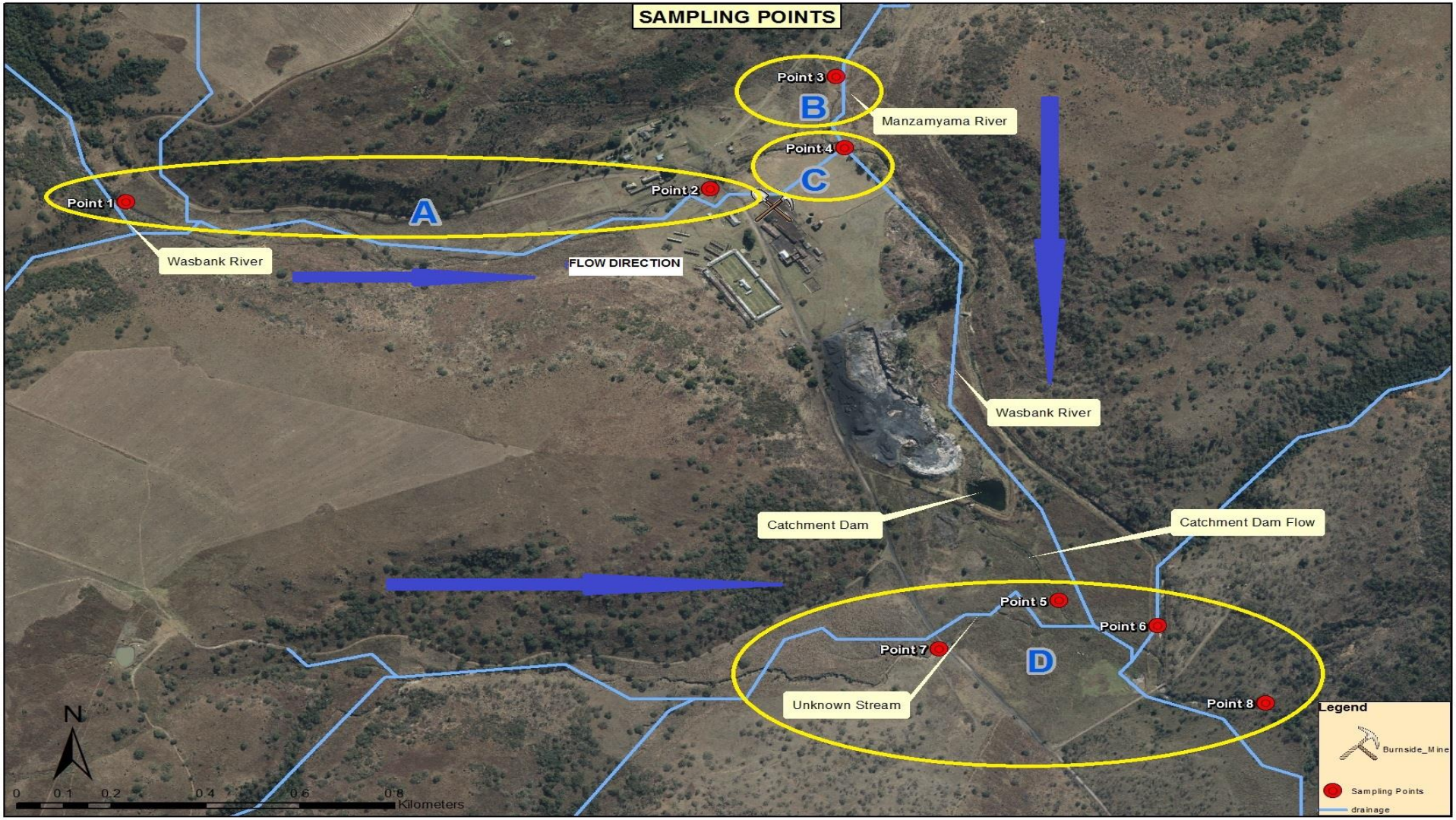


Figure 11: The streams surrounding defunct colliery and the identified sampling sites. (Source: uMzinyathi District Municipality GIS data)



Figure 12: Water discoloration in the Wasbank River, within Sampling Zone C (Source: Linah Nyathi (2017), Glencoe)

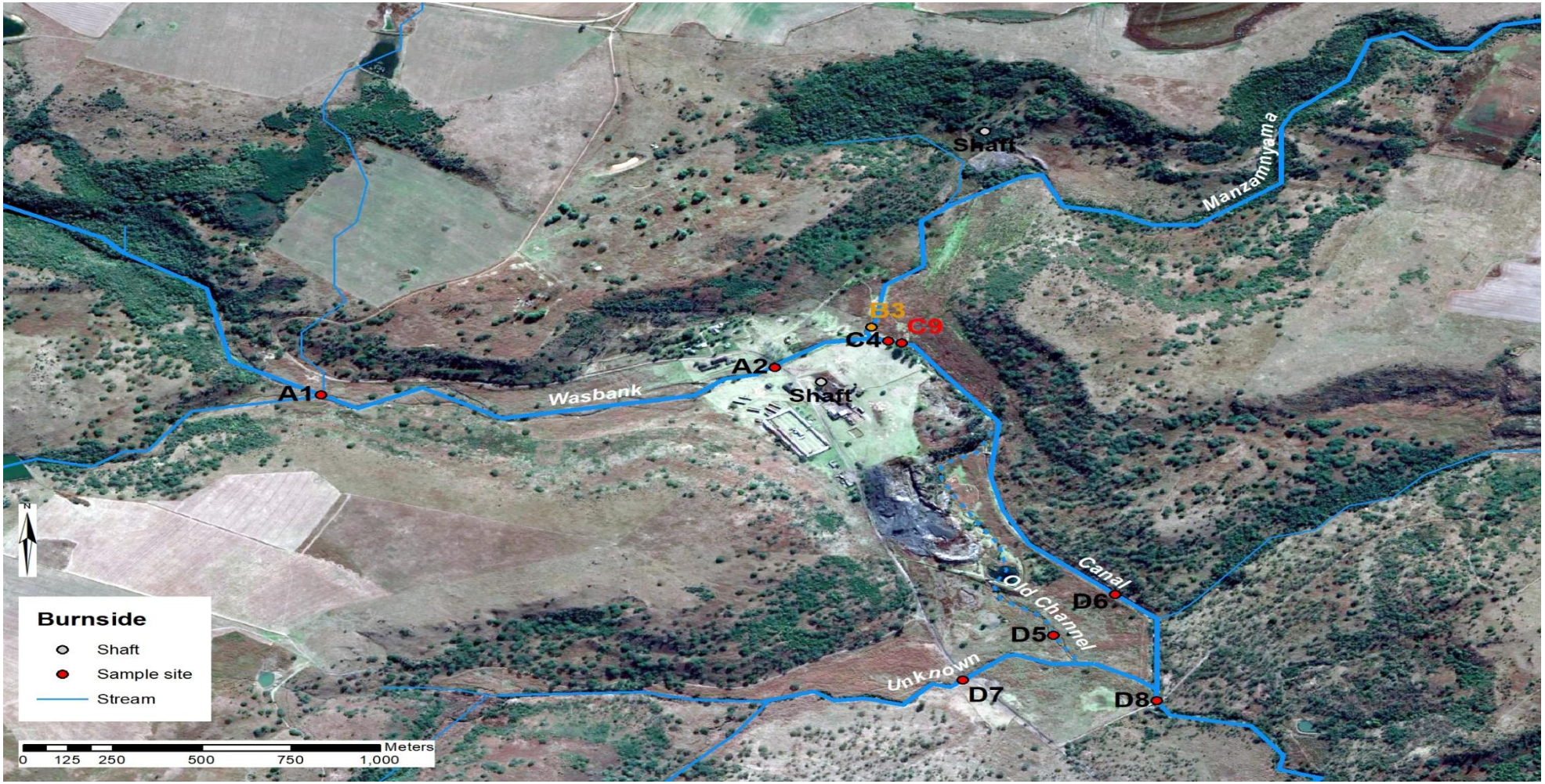


Figure 13: The identified sampling points and the new added point C9 in the dry season (Source: D. Furniss, 2018)

3 Results

3.1 Wet season data analysis

3.1.1 Description of trends in the wet season

Based on the pH data **(Table 3)** and **(Figure 14),** it shows that the pH value for the pristine zone has an average value of 7.62, which is a slightly alkaline. This value is referred to as a target value, assuming that if a zone within the old mine catchment area is not affected or contaminated, it should have a pH value that is approximate to 7.62. There was no flow on zone B throughout the wet season and therefore no pH was measured. There were no changes in the pH value of sampling zone C compared to the reference zone, therefore, there was no source of pollution that could decrease or increase the pH value for this zone. However, moving down to sampling zone D, which is downstream of the old mine, the pH increased to an average value of 8.1. Therefore, water in the downstream part of the old mine catchment area is more alkaline than water upstream of the mine. Furthermore, **Figure 14** shows that sampling point D7 of the unknown stream had a pH value almost similar to the pristine zone (zone A) and is assumed that it had a dilution effect on the Wasbank River below the confluence of the sampling points D5, D6 and D7.

The EC data on **Table 4** and on **Figure 15** reveal that an unaffected zone should have an EC value that is approximate to 89.59 µS/cm which is an EC value of the reference zone (zone A) and it was used as a target value (**Figure 15)**. EC values increased from sampling zone C to D. However, there was not much difference on sampling zone C from zone A and there was a much greater average EC value on sampling zone D as compared to sampling zone A. **Figure 15** shows that sampling point D5 (which is a sampling point from the catchment dam outflow) was the main contributor to the elevated EC value on sampling zone D.

A similar method of using sampling zone A as reference zone was used to establish the water quality trends of this catchment area using the water chemical results. The laboratory results of chemical analysis **(Table 5)** and **(Figure 16)** indicate that out of all water chemical variables that were tested, only five (5) parameters were markedly above the target values and those parameters were focused on in order to assess and analyze the possible cause of such a trend in this mine site catchment area. Those variables were calcium, potassium, magnesium, sulphur and sulfate. The results revealed a major increase in the concentration of the abovementioned five (5) variables, which was two to three times elevated, except for potassium, in sampling

zone D as compared to the reference zone. **Table 5** and **Figure 16** show that sampling point D5 is a major contributor to the elevated average concentrations in this zone.

The variables observed to be above the target value, were looked at individually per sampling point in order to properly assess and comprehend their trends. The range of values between sampling points A1 and A2 was used as a target value for each specific parameter. **Figure 17** shows that the target value for calcium concentration was 4.78 mg/l and it started to increase as from sampling point C4 (5.24 mg/l) to sampling point D8 (7.55 mg/l). However, sampling point D5 (20.48 mg/l), on the catchment dam flow, has a highly elevated calcium concentration which is approximately four times higher than the target value. The second-highest calcium concentration is at sampling point D7 (12.32 mg/l), of the unknown stream, which is three times higher than a target value. Sampling point D8 indicates that there was a dilution below the confluence of sampling D5, D6 and D7, which resulted in a decreased calcium concentration. However, the concentration at sampling point D8 (7.55 mg/l) is also still above the target value.

Figure 18 indicates that the potassium concentration was within the range of the target value (2.37 mg/l) in almost all sampling points, except for sampling point D5 (4.80 mg/l), which is much greater than the target value. **Figure 19** shows that the magnesium concentration in sampling points C4 (4.10 mg/l) and D6 (4.19 mg/l) was slightly above the target value (3.71 mg/l). There was a high increase in magnesium concentration at sampling point D5 (12.73 mg/l), which was approximately four times higher than the target value, and it was three times higher at sampling point D7 (9.68 mg/l). There was also an indication of dilution at sampling point D8, however still above the target value.

Figure 20 shows a slight increase in sulphur concentration at sampling points C4 (7.30 mg/l), D6 (6.45 mg/l) and D7 (8.26 mg/l). Sampling point D5 shows to have a highly elevated sulphur concentration (39.50 mg/l) that is approximately nine times above the target value. Again, this figure shows a decrease in sulphur concentration at sampling point D8 (9.47 mg/l) which indicates a dilution as this point is downstream of the others. However, the sulphur concentration at sampling D8 is still outside the range of the target value. Sulfate trend, as indicated by **Figure 21**, shows a similar trend as the sulphur trend.

The variables that were identified to be above the target value, were also ranked on which parameter was above the target value (**Figure 22**). This rank suggested that sulfate and sulphur

concentrations were the chemical variables that were furthest above the target values of the reference zone due to the activities of the defunct colliery.

Table 2: Average Water temperature per month in both seasons

Average Water Temepartaure per Month								
Month	Dec-17	Jan-18	Feb-18	Mar-18	Apr- 18	May-18	Jun-18	Jul- 18
T (°C)	26.1	23.3	22.1	19.3	16.9	11.5	10.5	12.4

Table 3: Average pH values per Sampling Point in the wet season

Sampling Point	pH Value	Standard Deviation
A1	7.62	0.08
A2	7.62	0.07
B3	No Flow	No Flow
C4	7.62	0.07
D5	8.22	0.06
D6	8.24	0.05
D7	7.70	0.14
D8	8.22	0.22

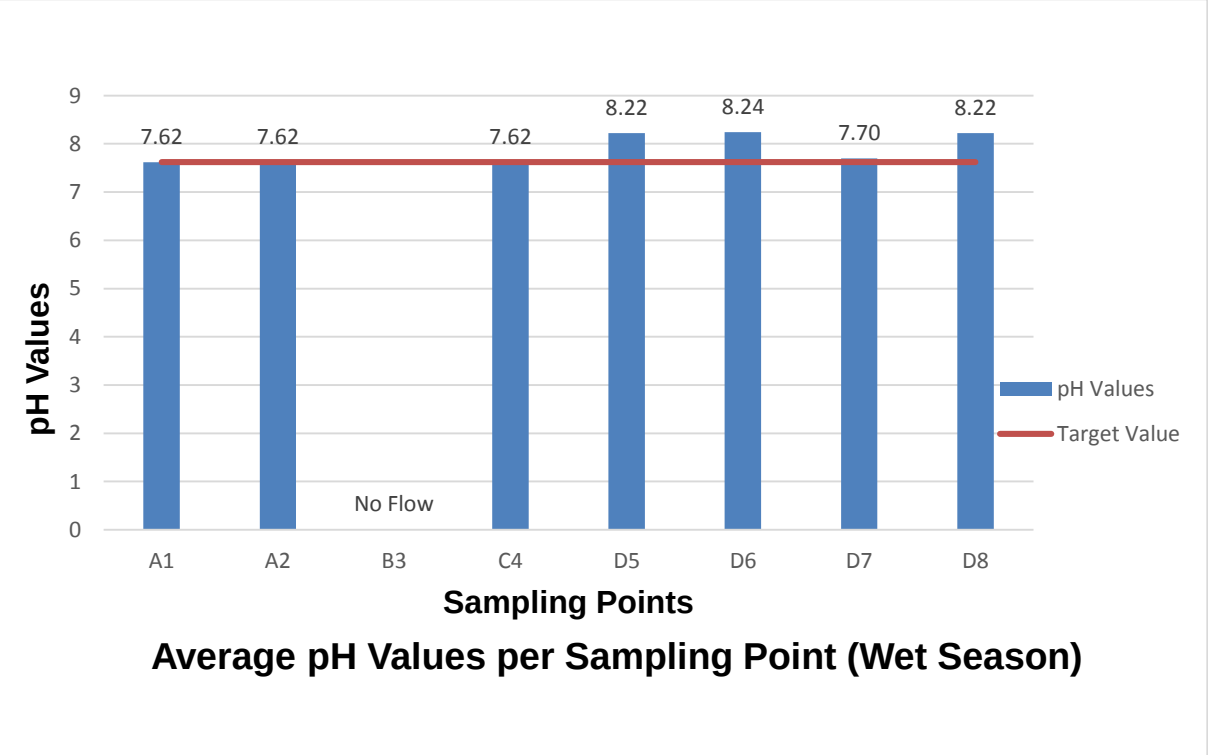


Figure 14: Average pH values per Sampling Point in the wet season

Table 4: Average EC values per Sampling Point in the wet season

Sampling Point	EC Value (µS/cm)	Standard Deviation
A1	89.55	19.10
A2	89.63	18.12
B3	No Flow	No Flow
C4	108.80	37.46
D5	1600.00	48.25
D6	174.40	47.52
D7	140.05	41.89
D8	211.68	94.13

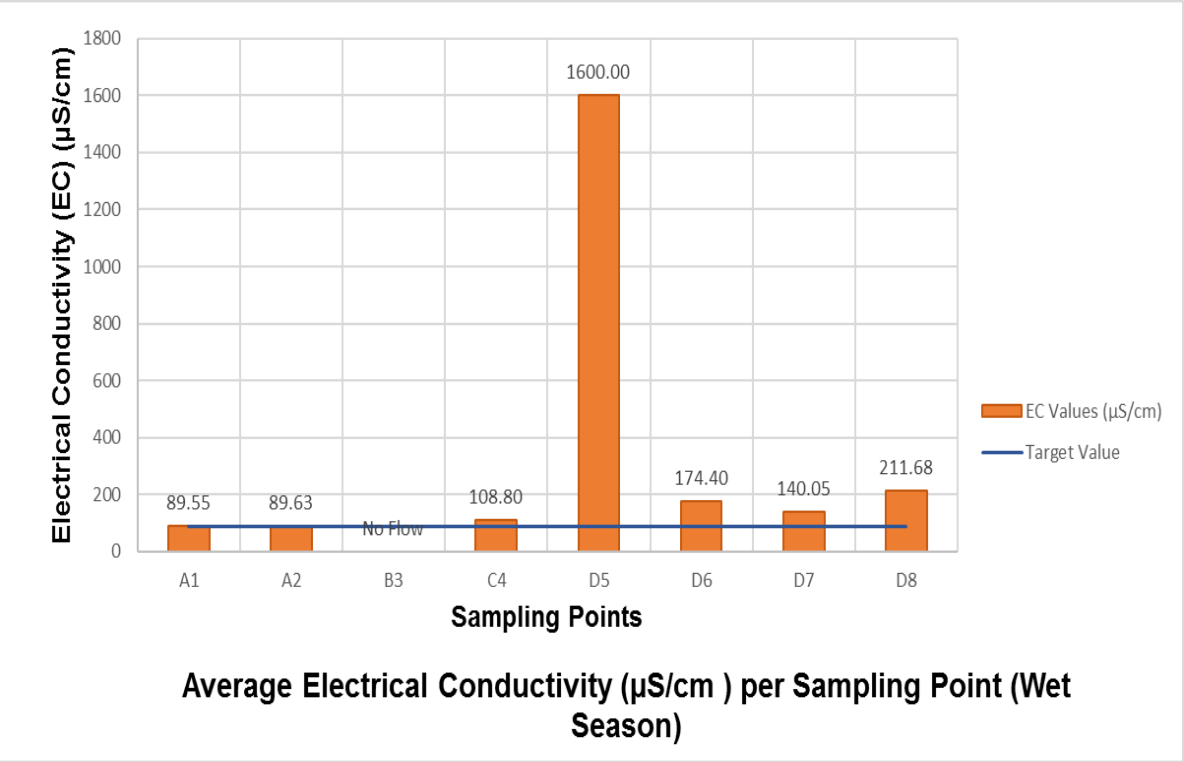


Figure 15: Average Electrical Conductivity per Sampling Point in the wet season

Table 5: Water chemical analysis laboratory results per Sampling Point in the wet season

Sampling Point	Calcium (Ca)	Potassium (K)	Magnesium (Mg)	Manganese (Mn)	Sodium (Na)	Aluminium (Al)	Iron (Fe)	Sulphur (S)	Arsenic (As)	Sulfate (SO4)	Chlorine (Cl)	Flouride (F)	Nitrates (NO3) as N	Orthophosphate (PO4 3–)
	(Concentration in mg/l)													
A1	4.745	2.38	3.67	0.03	<0.024	0.61	0.685	4.65	0.105	10	0.07	0	0.006	0.08
A2	4.8	2.35	3.745	0.025	0.05	0.79	0.705	4.51	0.115	11	0.1	0	0.007	0.06
B3	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow
C4	5.244	2.334	4.098	0.03	0.091	0.807	0.882	7.302	0.144	21	0.09	0	0.009	0.18
D5	20.48	4.8	12.73	0.04	0.212	0.047	0.026	39.5	0.26	80	0.04	0	0.006	0.43
D6	6.048	2.622	4.194	0.03	0.124	0.786	0.654	6.45	0.144	16	0.04	0	0.006	0.04
D7	12.32	0.946	9.681	0.004	<0.03	0.04	0.014	8.26	0.168	19	0	0	0.04	0.03
D8	7.548	2.946	5.148	0.03	0.354	0.522	0.456	9.474	0.156	22	0.05	0	0.007	0.08

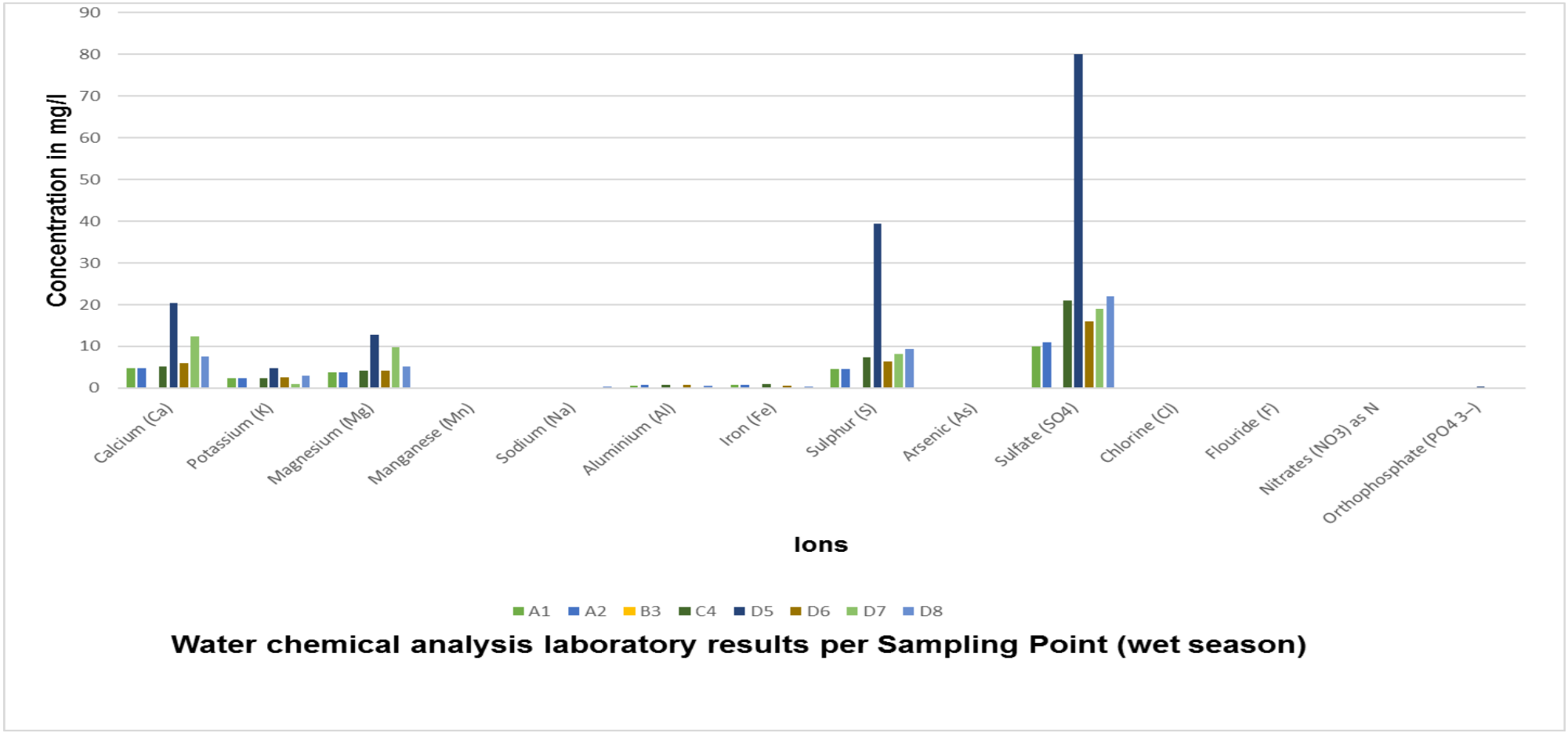


Figure 16: Laboratory results for chemical analysis per sampling point in the wet season

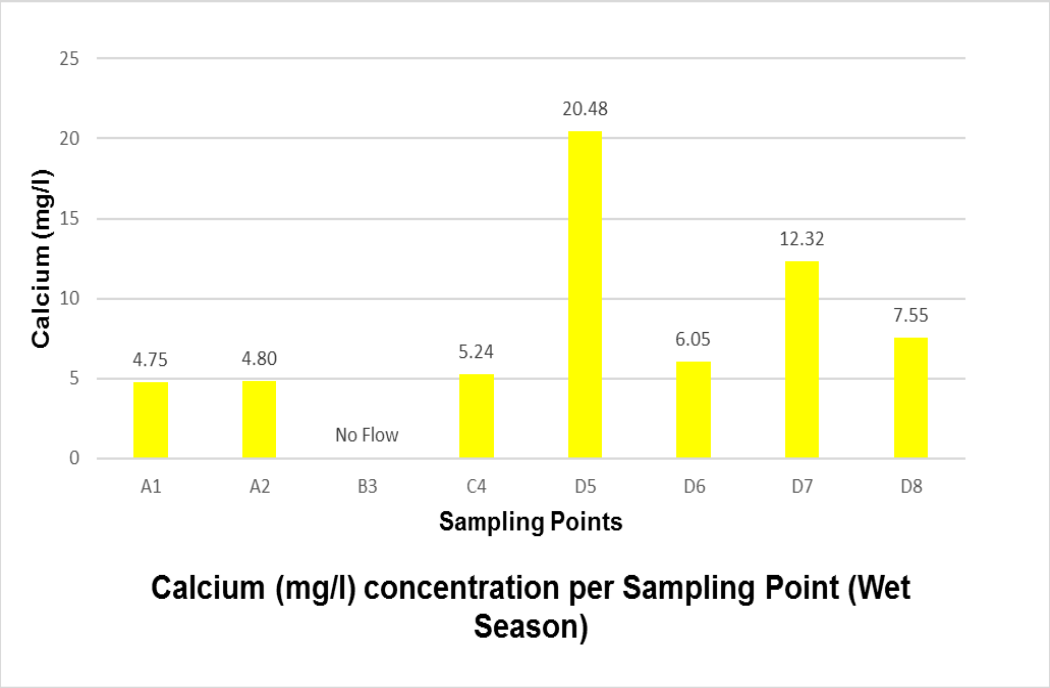


Figure 17: Calcium concentration per sampling point in the wet season

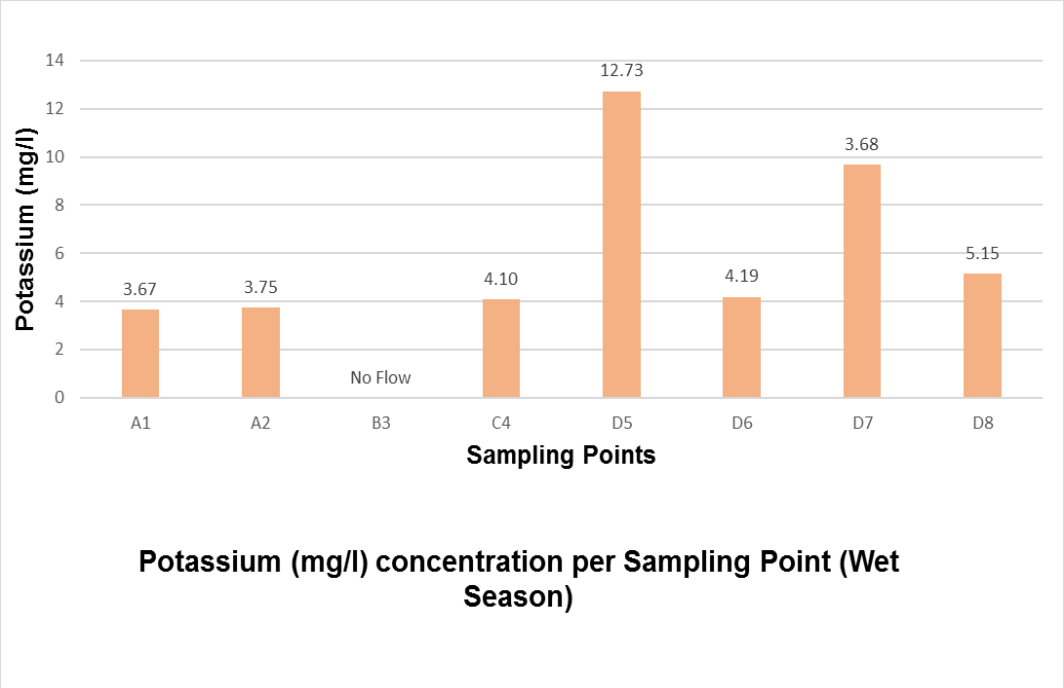


Figure 18: Potassium concentration per sampling point in the wet season

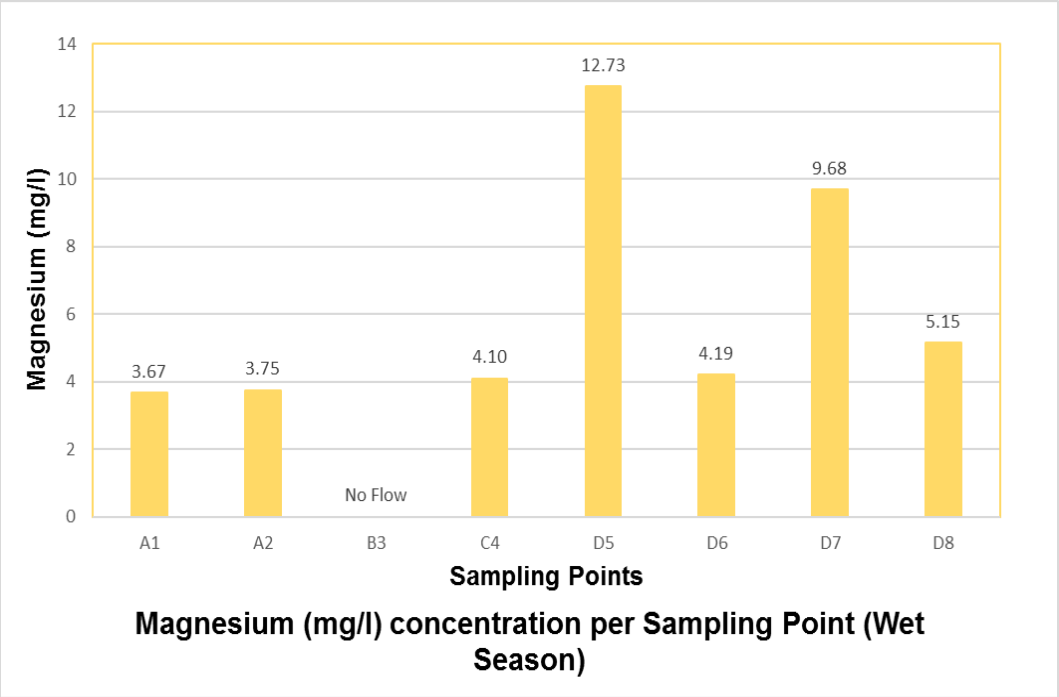


Figure 19: Magnesium concentration per sampling point in the wet season

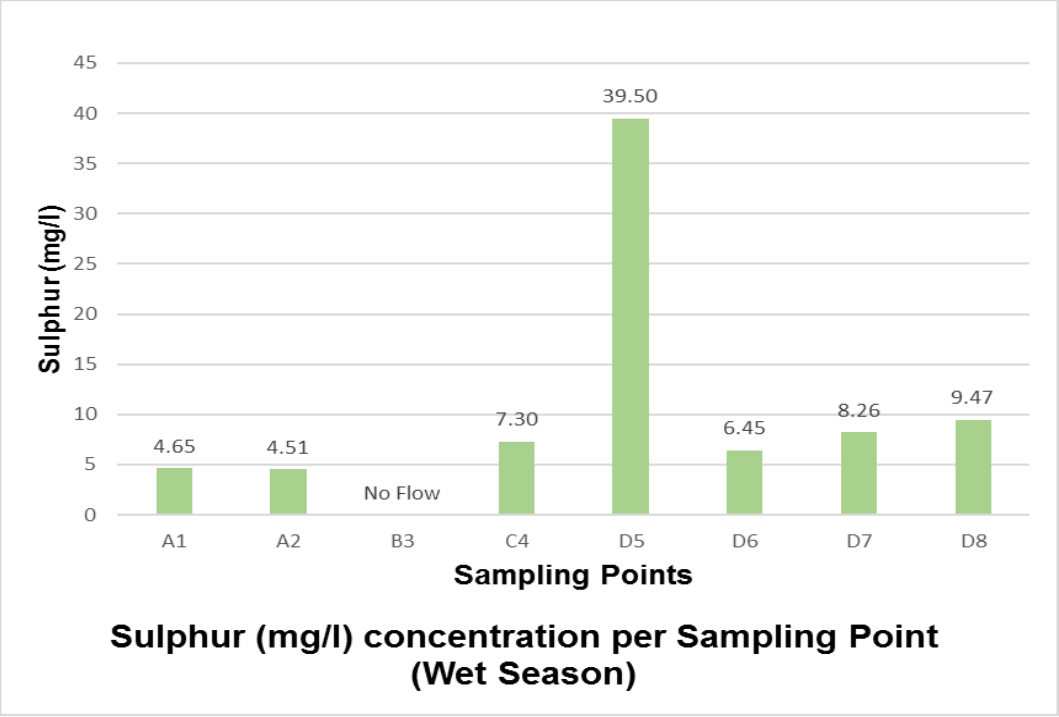


Figure 20: Sulphur concentration per sampling point in the wet season

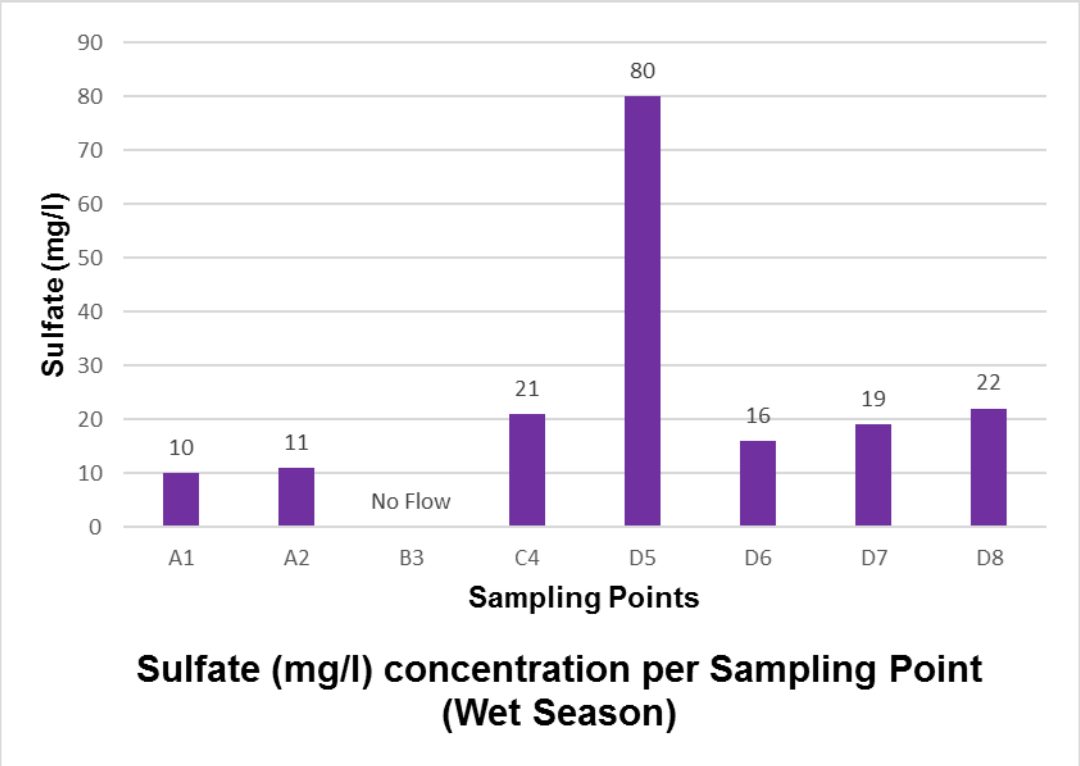


Figure 21: Sulfate concentration per sampling point in the wet season

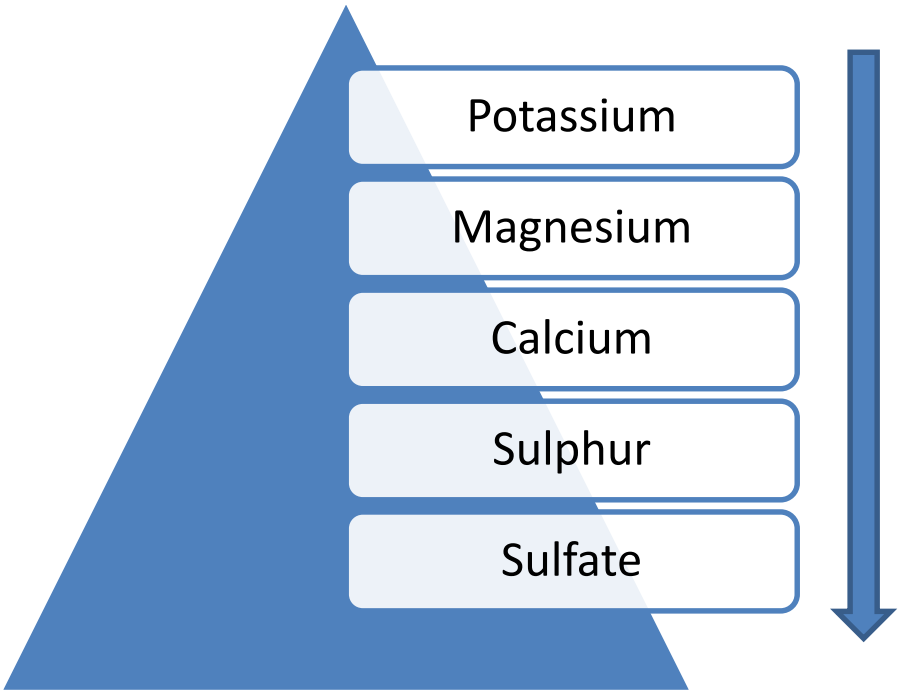


Figure 22: The ranking of water quality parameters that were above the target value, increasing downwards

3.2 Dry season data analysis

3.2.1 Description of trends in the dry season

The pH data on **Table 6** and **Figure 23** shows that the average pH value at the reference zone was 8.06, which is quite alkaline as compared to the wet season pH results. The pH data further shows that the pH values at all other sampling points were either within or very slightly above the target value.

The EC data on **Tables 7** and **Figure 24** shows that the average EC value on the pristine zone was 89 µS/cm, which is quite similar to the average EC value of the pristine zone during the wet season. There is an observed slight increase of EC value at the sampling point C4 (104 µS/cm). Data shows that the EC value in the Wasbank River was considerably greater than the target value, where sampling points C9 (the decant) (1703.00 µS/cm) and D5 (the catchment dam flow) (1686.00 µS/cm) were the major contributors to the elevated EC at the sampling zone D which is a zone in the Wasbank River, downstream the mine site, where their values were approximately eighteen to nineteen times higher than the target value. There was a decrease in the EC value at sampling point D8 (858.33 µS/cm), which suggests a slight dilution below the confluence of sampling points D5, D6, and D7. However, the EC value at D8 was still much greater than the target value by approximately 9 times.

The laboratory results for the chemical analysis (**Table 8**) and (**Figure 25**) indicate that out of all the water chemical variables that were tested, six parameters had a much greater concentration than the target value and those parameters were focused on in order to assess and analyze the possible cause of such a trend in this mine site catchment area. Those variables were calcium, potassium, magnesium, sodium, calcium carbonate and sulfate. Similar methods that were used to analyze the wet season results was carried out, parameters were assessed individually per sampling point in order to analyze their trends.

Figure 26 shows that the calcium concentration doubled between sampling zone A (7.08 mg/l) to sampling point C4 (14.43 mg/l) to D8 (19.72 mg/l), except for sampling point D7 (5.53 mg/l). Results show that sampling point C9 (the decant) had the highest calcium concentration (21.13 mg/l), followed by sampling point D8 (19.72 mg/l), which is a combination of flow from sampling points C4, C9, D5, D6 and D7.

The potassium concentration for all sampling points on the Wasbank river, was much greater than the target value (0.27 mg/l) of the reference zone (zone A) and it is only sampling points D5 (0.12 mg/l) and D7 (0.22 mg/l) that had a potassium concentration within the target value. (**Figure 27**). The highest concentration of magnesium is found at sampling point D5 (the catchment dam flow) (19.30 mg/l), then followed by sampling point C9 (the decant) (13.70 mg/l) (**Figure 28**). The concentration at sampling point D6 (6.50 mg/l), was low and hence the results suggest that there was a dilution caused by D6 at sampling point D8 (10.80 mg/l). Sampling point D7 also had low magnesium concentration (3.70 mg/l), however, it had no influence to the Wasbank River because it had a minimal flow which did not reach its confluence with the catchment dam flow.

A trend similar to of the potassium concentration is shown by the results of the sodium concentration. Sodium concentration was greatly elevated at all the sampling points of the Wasbank River, which are sampling points C4 (312.50 mg/l), C9 (282.70 mg/l), D6 (176.20 mg/l) and D8 (222.40 mg/l), relative to the reference zone (6.67 mg/l) (**Figure 29**). The reference zone shows that the target value for sulfate concentration was 3.00 mg/l, and results show that the concentration was three times higher at sampling point C4 (9.00 mg/l), and further shows a significant increase in concentration at sampling points C9 (96.00 mg/l), D5 (56.00 mg/l) and D8 (62.00 mg/l) (**Figure 30**). The sulfate concentration at sampling point D6 (16.00 mg/l), also suggests some form of dilution, even though the source of dilution could not be verified.

Figure 31 shows the calcium carbonate concentration trend in the mine site catchment area during the dry season. It shows that there was no calcium carbonate concentration at sampling points A1, C4, D5, and D7. However, sampling point A2, which is part of the reference zone, had a concentration of 7.90 mg/l, which was used as a target value. Sampling points situated in the Wasbank River which are sampling points C9 (30.00 mg/l), D6 (40.00 mg/l) and D8 (30.00), except for C4 (0.00 mg/l), had much greater calcium carbonate concentration than the target value.

Table 6: Average pH values per sampling Point in the dry season

Sampling Point	pH value	Standard Deviation
A1	8.14	0.39
A2	7.98	0.11
B3	NO FLOW	NO FLOW
C4	8.02	0.46
Decant	7.44	N/A
D5	8.64	0.14
D6	8.85	0.4
D7	8.31	0.28
D8	8.82	0.19

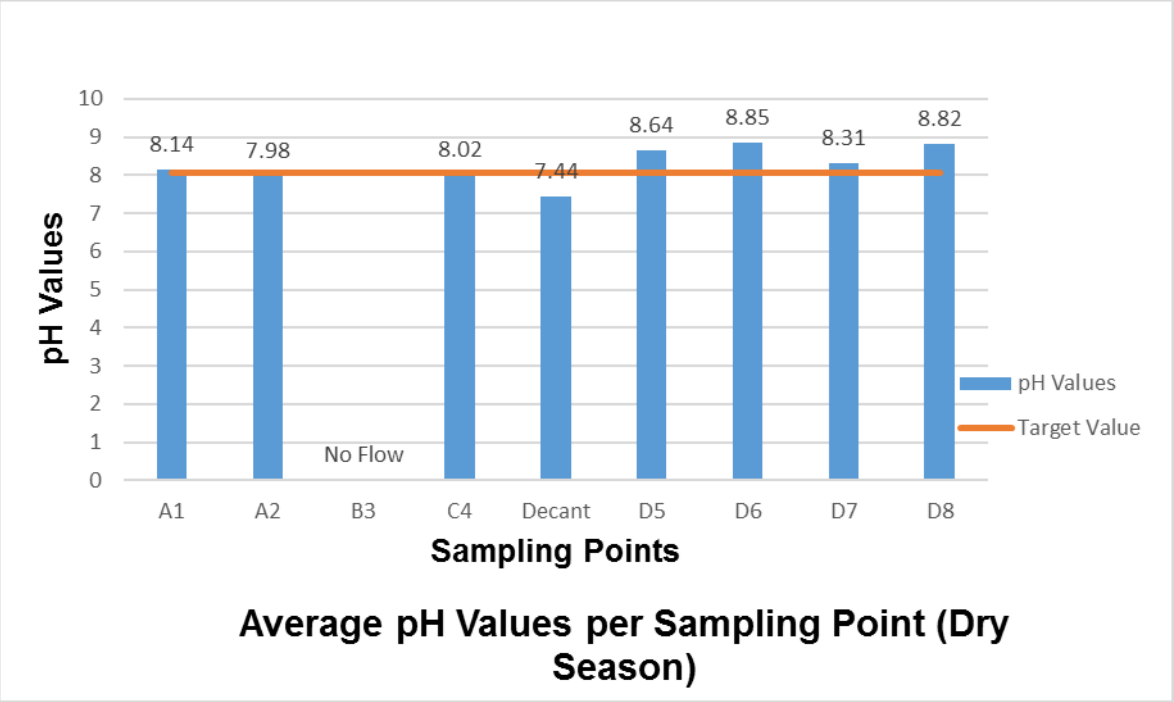


Figure 23: Average pH values per Sampling Point in the dry season

Table 7: Average EC values per Sampling Point in the dry season

Sampling Point	EC Value(µS/cm)	Standard Deviation
A1	87.2	10.61
A2	90.8	11.33
B3	NO FLOW	NO FLOW
C4	104.43	11.09
Decant	1703	N/A
D5	1686	120.01
D6	585.3	527.82
D7	200.33	52.44
D8	858.33	556.73

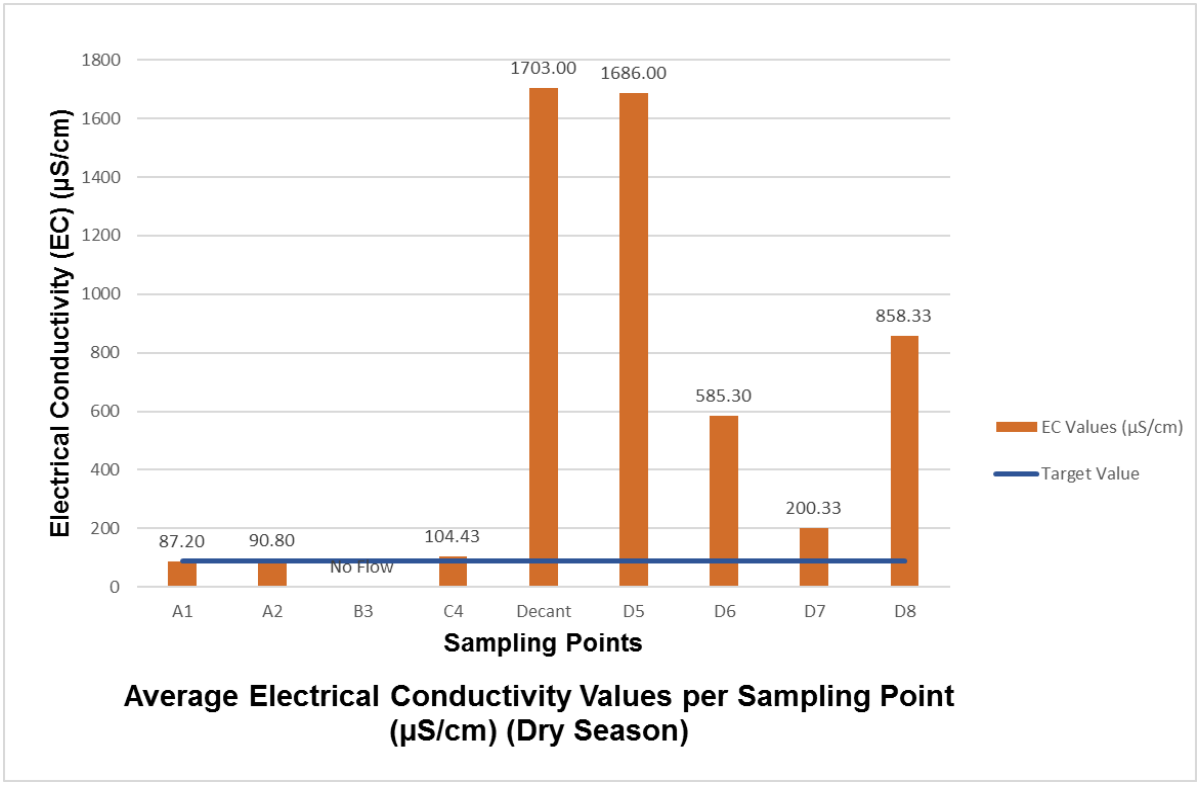


Figure 24: Average EC values per sampling points during the dry season

Table 8: Water chemical analysis laboratory results for a dry season

Sampling Point	Calcium (Ca)	Potassium (K)	Magnesium (Mg)	Manganese (Mn)	Sodium (Na)	Aluminium (Al)	Iron (Fe)	Sulfate (SO4)	Chlorine (Cl)	Nitrates (NO3) as N	Orthophosphate (PO43-)	Boron (B)	Calcium Carbonate (CaCO3)	Nickel (Ni)	Silicon (Si)
						mg/l									
A1	7.577	0.287	4.877	0.01	6.429	0.108	0.136	3	0.01	1.8	0.02	2.879	0	0.421	0.335
A2	6.575	0.239	4.401	0.01	6.896	0.141	6.757	0.03	0.03	1.7	0.02	2.609	7.94	0.436	0.33
B3	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow	No Flow
C4	14.43	10.57	4.799	0.51	312.5	0	0.027	9	0.02	1.9	1.13	4.027	0	0.669	0.63
C9 (Decant)	21.13	13.79	13.75	0.013	282.7	0.05	0.013	3	0.02	2	0.91	3.08	30	0.489	0.341
D5	17.63	0.118	19.35	0.009	10.83	0	0.001	56	0.01	1.8	0.04	2.53	0	0.132	0.468
D6	14.74	7.371	6.506	0.011	176.2	0.021	0.025	16	0.02	1.7	0.56	2.671	40	0.482	0.325
D7	5.531	0.222	3.749	0.013	7.696	0.046	0.155	1	0.01	1.5	0.04	2.284	0	0.448	0.285
D8	19.72	10.17	10.88	0.014	222.4	0	0.028	64	0.03	2.1	0.58	2.542	30	0.426	0.244

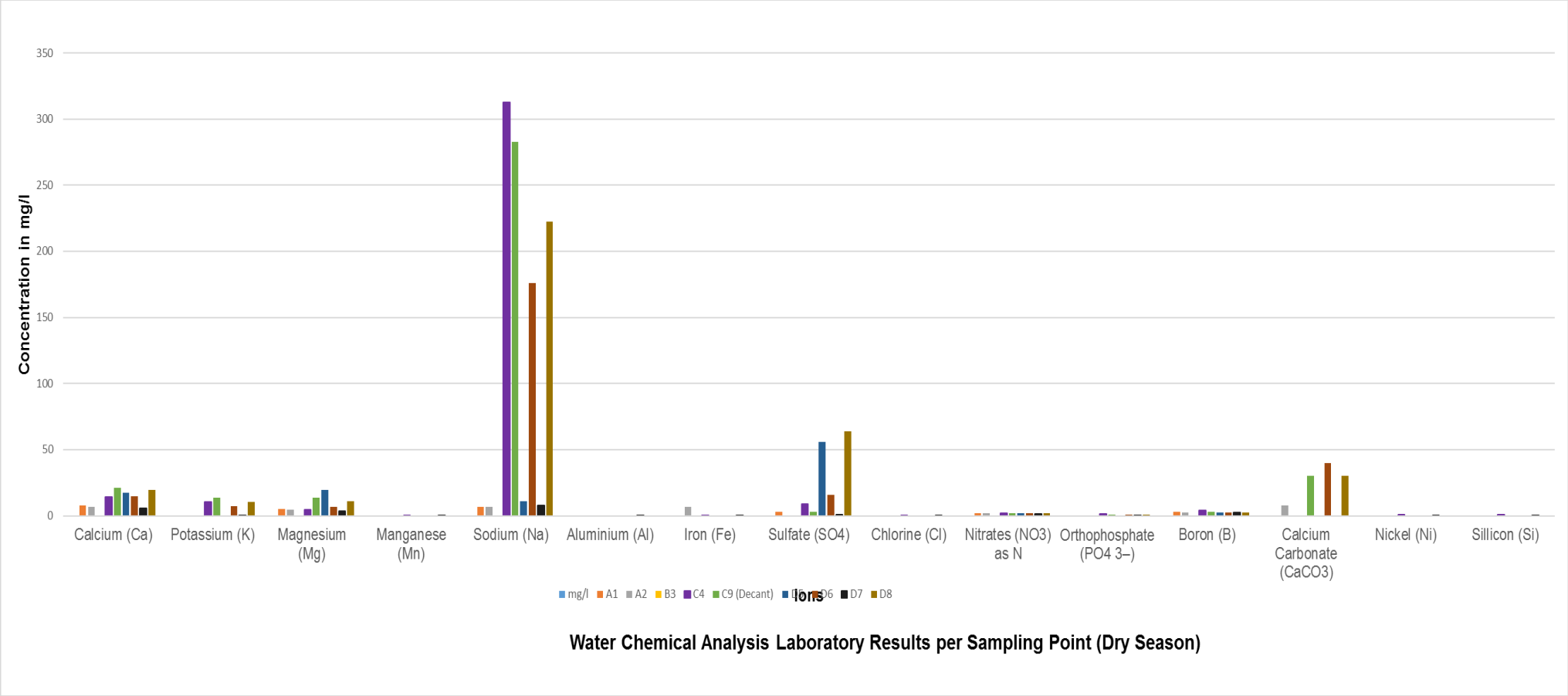


Figure 25: Water chemical analysis laboratory results for a dry season

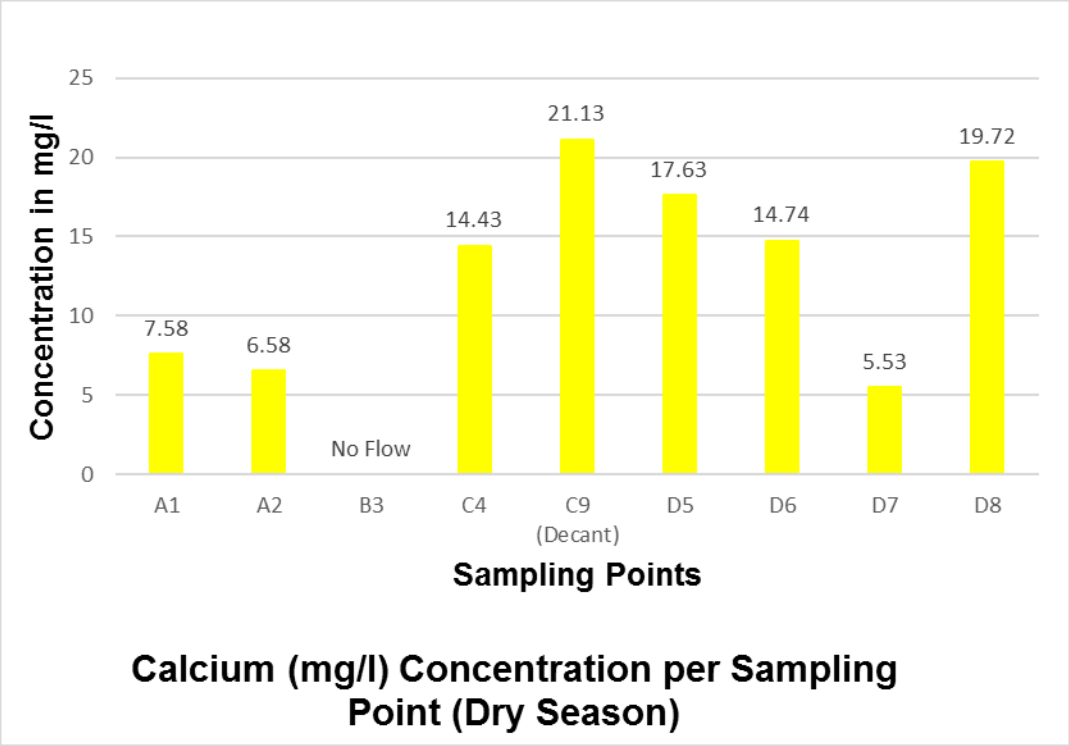


Figure 26: Calcium concentration per sampling point in the dry season

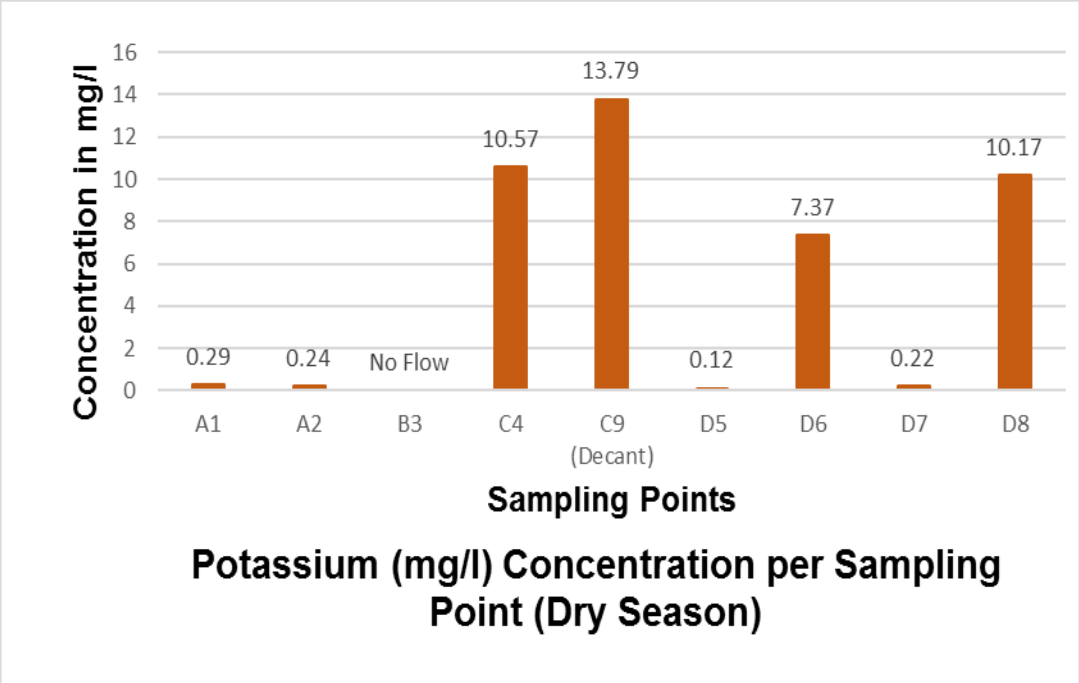


Figure 27: Potassium concentration per sampling point in the dry season

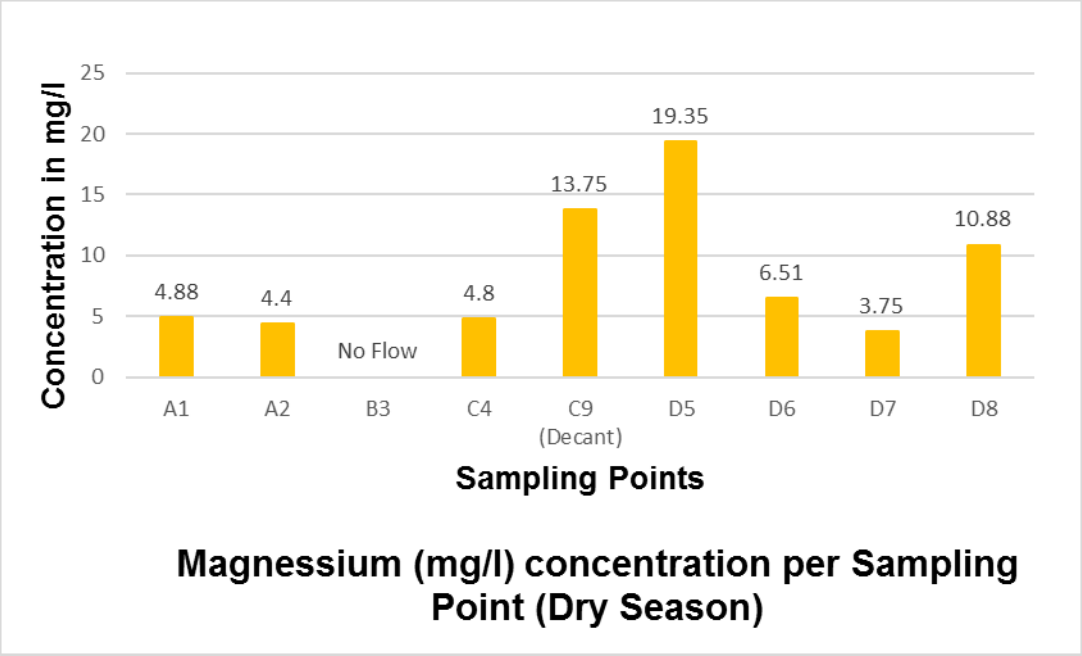


Figure 28: Magnesium concentration per sampling point during the dry season

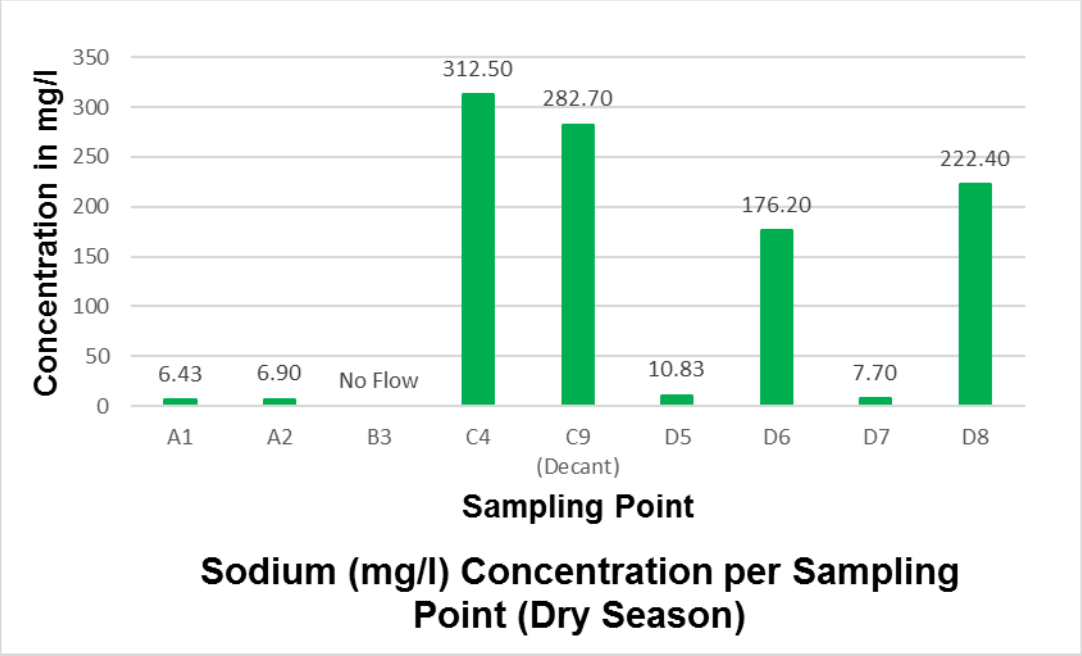


Figure 29: Sodium concentration per sampling point during the dry season

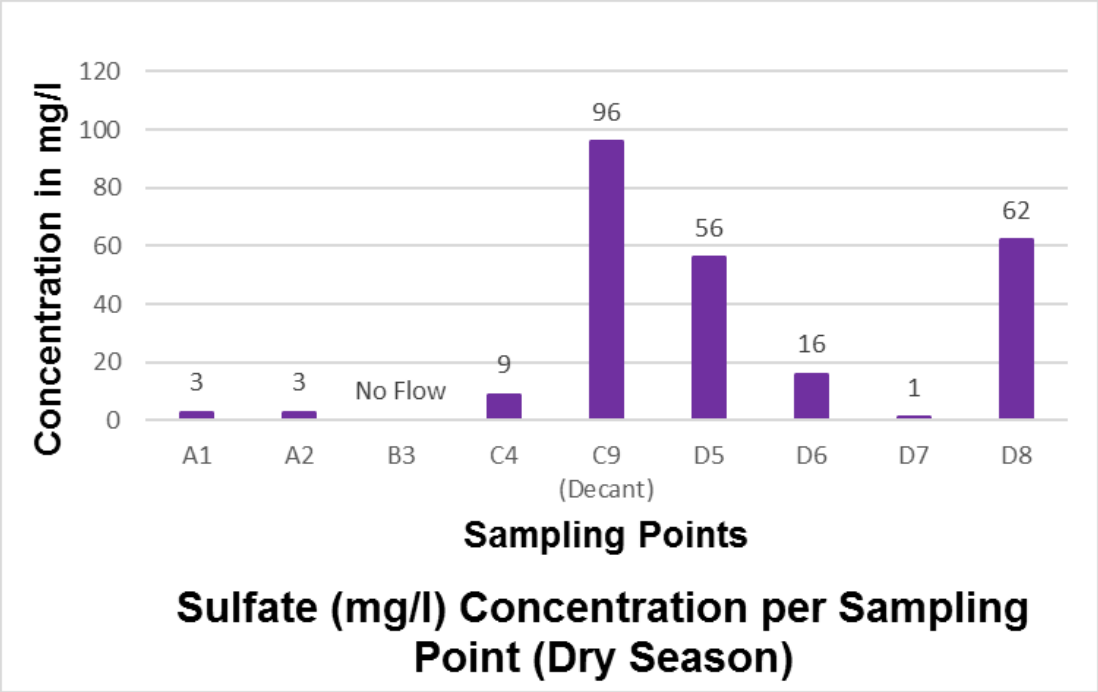


Figure 30: Sulfate concentration per sampling point in the dry season

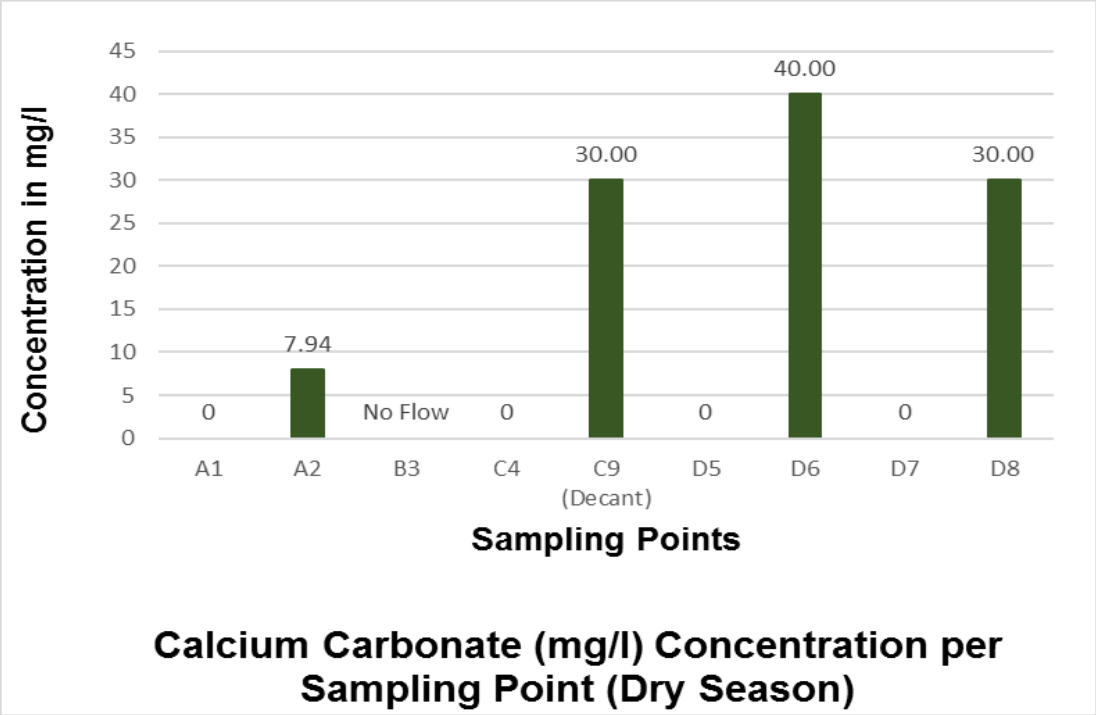


Figure 31: Calcium Carbonate concentration per sampling point in the dry season

3.3 Water quality analysis based on National Water Quality Guidelines: Domestic Use and Agricultural Use (Livestock watering)

Based on the South African Water Quality Guidelines (SAWQG) for domestic use, it shows that most ions are within the acceptable range for domestic use (Tables 9 and 10). The acceptable EC range for domestic use is 0-700 µS/cm. However, the EC value of water coming from the catchment dam flow (sampling point D5) (1600.00 µS/cm in the wet season and 1686.00 µS/cm in the dry season), and Wasbank River from the decant (sampling point C9) (1703.00 µS/cm) and downstream of the mine site, sampling point D8 (858.33 µS/cm) was above the acceptable range for domestic use (DWAF, 1996). Secondly, dry season results (**Table 10**) also reveal that the sodium concentration was above the acceptable range (0-100 mg/l) for domestic use on all of the Wasbank River sampling points as from sampling point C4 (312.50 mg/l), C9 (282.70 mg/l) and D8 (222.40 mg/l) (DWAF, 1996). Furthermore, the SAWQG for livestock farming shows that all ions are within the acceptable range, in both seasons of analysis.

Table 9: Water quality analysis for domestic use in the wet season (DWAF, 1996)

	Target Water Quality	A1	A2	B3	C4	D5	D6	D7	D8
pH	6-9	7.62	7.62	No Flow	7.62	8.33	8.24	7.7	8.22
EC	0-700 µS/cm	89.55	89.63	No Flow	108.8	1600	174.4	140.05	211.68
Calcium	0-32 mg/L	4.75	4.8	No Flow	5.24	20.48	6.05	12.32	7.55
Potassium	0-50 mg/L	2.38	2.35	No Flow	2.33	4.8	2.62	0.95	2.95
Magnesium	0-30 mg/L	3.67	3.75	No Flow	4.1	12.73	4.19	9.68	5.15
Sulfate	0-200 mg/L	10	11	No Flow	21	80	16	19	22
Sulphur	0-200 mg/L	4.65	4.51	No Flow	7.3	39.5	6.45	8.26	9.47

KEYS

	Above Target Value

Table 10: Water quality analysis for domestic use in the dry season (DWAF, 1996)

	Target Water Quality	A1	A2	B3	C4	C9	D5	D6	D7	D8
pH	6-9	8.14	7.98	No Flow	8.02	7.44	8.64	8.85	8.31	8.82
EC	0-700 µS/cm	87.2	90.8	No Flow	104.43	1703	1686	585.3	200.33	858.33
Calcium	0-32 mg/L	7.58	6.58	No Flow	14.43	21.13	17.63	14.74	5.53	19.72
Potassium	0-50 mg/L	0.29	0.24	No Flow	10.57	13.79	0.12	7.37	0.22	10.17
Magnesium	0-30 mg/L	4.88	4.4	No Flow	4.8	13.75	19.35	6.51	3.75	10.88
Sodium	0-100 mg/L	6.43	6.9	No Flow	312.5	282.7	10.83	176.2	7.7	222.4
Sulfate	0-200 mg/L	3	3	No Flow	9	96	56	16	1	62
Calcium Carbonate	0-80 mg/L	0	7.94	No Flow	0	30	0	40	0	30

KEYS

	Above Target Value

4. Discussion

According to Du Plessis (2017), the usual impacts caused by coal mining in the receiving catchment areas include increased acidity, and increased concentration of sulfates and TDS. However, the water quality results of the defunct colliery show the unusual trend of increasing alkalinity in the immediate surrounding catchment area. Based on the pH results of the upper Wasbank catchment area collected in both wet and dry seasons, it reveals that this catchment area is neutral to alkaline, as the pH trend shows an increase from the reference zone to the sampling zone below the mine shaft. There is an indication of increasing alkalinity, with the pH values above 8 in the Wasbank River, at the sampling points that are adjacent and below the mine shaft.

Alkaline water is normally found in mine catchment areas where an excessive amount of alkaline chemicals was used to treat mine water which results in alkaline receiving water bodies (Wolkersdorfer, 2008). Another common source of alkalinity in water resources is a dissolution of limestone ($CaCO_3$) which tends to give relatively high pH values that are greater than seven and high TDS (Brezonik and Arnold, 2011). Holland *et al.* (2005) explains that coal mine effluents can either be acidic or alkaline depending on the host rock geology. Alkaline water is also referred to as hard water because hardness is derived from the similar source as alkalinity. The primary hardness cations are calcium and magnesium (Brezonik and Arnold, 2011). Movement of water through soil and aquifers of calceous regions that are dominated by limestone and dolomite causes alkalinity in the receiving water systems, therefore precipitation, rock dominance, temperature and evaporative crystallization have an impact on alkalinity of water in these areas (Brezonik and Arnold, 2011).

MacDonald *et al.* (1994) defines Electrical Conductivity (EC) as a function of water temperature and the concentration of dissolved ions, which is a useful indicator to assess water quality for various purposes. The EC trend in the defunct colliery catchment area suggests that there is an increasing concentration of dissolved ions in the Wasbank River adjacent and below the mine shaft compared to the upstream reference zone. Wet season EC results indicate that there were more dissolved ions concentrated in a catchment dam as compared to entire mine catchment area, however, dry season results show that there was more ion concentration coming from underground in the Wasbank River adjacent to the mine shaft and there was a slight dilution towards the zone below the mine shaft. A study conducted by Konecny (2005) suggests that a possible cause of EC value change in different seasons is the effect of rainfall

rate on water level and water flow rate of a catchment. High water level and high water flow of streams can decrease the EC value of a catchment as it dilutes the current salinity concentration (Konecny, 2005). Therefore, the reason why the upper Wasbank catchment area had lower EC values in wet season compared to dry season is because there was high water level and heavy water flow in the streams and therefore it resulted in dilution (Konecny, 2005). Jacobs *et al.* (2014) explains that EC estimates the amount of dissolved solids in water and contaminated water usually gives an elevated EC value as compared to uncontaminated water. Therefore, there is contamination of water caused by the abandoned coal mine to the immediate receiving catchment area. However, EC measurements do not automatically indicate the toxicity of ions in water (Jacobs *et al.*, 2014).

The chemical analysis results for both seasons revealed that calcium, potassium, magnesium, sodium, calcium carbonate, sulphur and sulfate are the main dissolved ions that have affected the EC trend for this catchment area. The large difference in sulphur and sulfate concentration between the reference zone and the sampling points in the Wasbank River adjacent and below the mine site, and also in the outflow of the contaminated catchment dam, reveals that the defunct colliery has AMD impacts on this catchment area (Du Plessis, 2017). However, there is also a significant trend of high concentrations of alkali metals such as calcium, calcium carbonates, magnesium, potassium and sodium in the Wasbank River, in an almost similar pattern as the sulfur and sulfate trend stated above. The U.S Geological Survey (2009) states that geological environments have a significant influence on the chemical character of the stream draining the terrain. Large amounts of water tend to have high pH values, hardness, calcium carbonates and dissolved solids where the underlying geological terrain has limestone and dolomite (U.S Geological Survey, 2009). The U.S Geological Survey (2009) further explains that shales and sandstones also have a potential to produce small amounts of calcium, magnesium-calcium-carbonate water, but does not give a significant high pH values and alkalinity. Increased concentration of calcium, magnesium and sulfate generally result from the interaction of the acidic water with the basic minerals of the underlying aquifer (Azapagic *et al.*, 2004).

The geology of this area only reveals the occurrence of dolerite intrusions, as discussed in section 2.4, however, the pH, EC and chemical concentration trends suggest the possibility of the presence of limestone and dolomite (Geological Survey, 2009). Based on the findings of the study conducted by Campaner *et al.* (2014) in Brazil, which resembled the almost similar trends and characteristics as the results of this study, there is an assumption that the previous

owners of the defunct colliery implemented measures to neutralize AMD by means of either limestone, hydrated lime, ammonia or fly ash, which increases the pH values and reduces the solubility of metals. Campaner *et al.*, (2014) further explained that AMD reduction can also occur naturally when carbonates rocks are present in the local stratigraphic sequence.

There are two different categories of AMD treatment that can be implemented in order to reduce acidity in a mine catchment area: active and passive treatments (Skousen *et al.*, 2018). Active AMD treatment includes adding of alkaline chemicals such as calcium, hydroxide, calcium oxide, sodium hydroxide, sodium carbonate, and ammonia (Skousen *et al.*, 2018). An active AMD treatment system is considered to be the most expensive (Skousen *et al*, 2018). Passive AMD treatment includes aerobic and anaerobic wetlands, anoxic limestone drains, vertical flow wetlands, open limestone channels and alkaline leach beds (Skousen *et al.*, 2018). Based on the observations and information ascertained from the farm owner, Mr. Wessels, the most likely AMD treatment system that was probably used to treat the impacts of this abandoned mine on this catchment area, is the engineering of limestone drains (pers. comm., Wessels, 2017). Limestone drains generate alkalinity when water moves through a limestone bed in a semi-closed system, with as little dissolved oxygen as possible (Skousen *et al.*, 2018).

The pH, EC trend and laboratory results for chemical concentration analysis suggest that this catchment area is affected by AMD, however, due to passive neutralization, the catchment has become more alkaline, and therefore categorized as alkaline mine drainage (Dahrazma and Kharghani, 2012). Alkaline mine drainage is generally characterized by pH values greater than neutral, high sulfate levels, significant concentrations of calcium, potassium and magnesium, and a low concentration of aluminium (Dahrazma and Kharghani, 2012). Therefore, the results from defunct colliery catchment area conform to the characteristics of an Alkaline Mine Drainage.

Furthermore, after the assessment of whether the abandoned colliery had impacts on this catchment area or not, using the reference zone comparison, it was also assessed against the SAWQG for domestic use and livestock farming, to determine whether water from this catchment area can be consumable by both humans and livestock. According to the standards (SAWQG) for livestock, water from the defunct colliery catchment area can be consumed by livestock, since it is within the acceptable ion concentration range, and therefore there are no potential negative impacts that can result from its consumption by the livestock (DWAF, 1996). Moreover, according to the standards (SAWQG) for domestic use, pH and other dissolved ions

of this catchment area are within the acceptable range for domestic use. However, in the Wasbank River, as from adjacent and below the mine shaft, the results of the study show that the EC values and the sodium concentrations are above the acceptable range for domestic use (DWAF, 1996). According to the SAWQG, water with EC values above 700 µS/cm tends to have a salty taste and would probably not be used on aesthetic grounds if alternative supplies are available. Some effects on plumbing and appliances, such as increased corrosion or scaling, may be expected. However, consumption of water does not appear to produce adverse health effects in the short term (DWAF, 1996). According to the SAWQG, water with sodium concentration above 200 mg/l, has a slightly salty taste and it is undesirable for consumption by people on a sodium- restricted diet (DWAF, 1996).

5. Conclusion

This study revealed that the post-mine decant from the defunct colliery have effects on the water quality of this catchment area. The pH, EC, and dissolved ion concentrations show a large difference below the mine in comparison to the reference zone. However, the values and trends of water quality in this catchment area resemble the characteristics of an engineered AMD treatment strategy, where the water decanting from the old mine site into the Wasbank River is alkaline, despite the high sulphate concentrations of this water. Furthermore, laboratory analysis of water samples from this catchment area is within stipulated limits for livestock consumption, and can be used for domestic purposes with certain slight restrictions (DWAF, 1996). Alkaline mine drainage effects are normally not as severe as acid mine drainage and are not easy to identify (Diane Publishing Company, 1995). Therefore, this study concludes that this catchment area is contaminated by the abandoned colliery. However, the AMD impacts have been lessened by limestone drain treatments which have further attenuated the severity of impacts on this catchment area for livestock farming and domestic use (Scott *et al.*, 2007). Furthermore, taking into consideration the state of the water quality of this catchment area and the land uses that are dependent on this catchment area, this defunct mine can be treated as low priority in terms of rehabilitation interventions by the Department of Water and Sanitation. However, as much as this study concludes that this defunct mine is low priority, there is a need for continuous water quality monitoring to be conducted by the state. Continuous monitoring would ensure that there are not any changes that can cause significant impacts on this catchment area which can further affect where this defunct mine stands in the

hierarchy of rehabilitation priorities and the results of this study can be used by the state as a base-line study for continuous monitoring.

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