The effect of illegal dumping on surface water quality using diatoms as a bioindicator

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ABSTRACT

Aquatic ecosystems are vital for all life on earth as, without water, there would be no life. It is therefore important that this vital resource is protected, properly managed and that all measures are taken to ensure that it is used in a sustainable manner. As water moves through towns and cities of a region, the water resources are impacted by the anthropogenic activities within these regions. Poor waste management is one such example of an impact that pollutes water resources all over the world. The poor municipal waste management services and the challenges and gaps identified within the waste management legislation, has led to events of illegal dumping.

Illegal dumping has been identified as a global problem and not only a local environmental problem in South Africa. The effects caused by illegal dumping are not only limited to where the location of the dumping site is but extends rather to a much greater footprint. Some of the effects caused by illegal dumping include health, social, environmental and economic impacts. Studies have indicated that illegal dumping is more common in the rural communities where there is very limited access to basic services such as potable water, sanitation services and municipal waste collection.

This study aimed to assess the impact that illegal dumping has on water quality, through the use of diatoms as a bioindicator of the health of the aquatic ecosystem. Diatoms are known as primary producers that play a significant ecological role in the aquatic ecosystems with their dynamic position at the bottom of the trophic food web. Their specific environmental requirements make them sensitive to any changes within their environment and therefore they are regularly used in aquatic ecosystem studies to assess the anthropogenic impacts and the ecosystem health of aquatic ecosystems.

The study was conducted at several surface water bodies within the Ikageng and Promosa suburbs of Potchefstroom in the North-West Province of South Africa. These water bodies form part of a larger drainage system which drains into the Mooi River. The Mooi River is a very important water resource as it is the only source supplying water to the Potchefstroom city. Eight sampling sites were selected for the study at which once-off water and diatom samples were collected during the late summer rainfall month between 15 to 16 February 2019. These sites are located along the drainage lines/streams and dams which all eventually feed into the Mooi River system. The sites were selected as they were representative of the area and the water resources of the area during the time of sampling. Site 8 was used as a reference site to determine the anthropogenic impacts at the other sites and the effect of the illegal dumping on the water quality of those sites. In situ water quality variables were measured at each sampling site and water samples were collected to

measure the physicochemical variables of the water at each site. The samples were analysed for nitrites, nitrates, ammonium, phosphate, sulphate and chloride. The water quality results determined for each site was then compared to the South African water quality guidelines volume 7 specified for aquatic ecosystems to determine if the anthropogenic impacts such as illegal dumping affected the water quality at the different sites. During the diatom sampling, two sets of diatom samples were collected for the live and fixed diatom analysis. Diatoms were sampled from submerged aquatic vegetation stems at each site and prepared and analysed according to the prescribed method of Taylor *et al*. (2004).

The water quality results analysed for the sites raised concern as some of the variables far exceeded the specified concentration range within the water quality guidelines specified for aquatic ecosystems. The inorganic nitrogen (nitrate, ammonium and phosphate) concentrations measured for the sites were very high and indicated the sites to be of a eutrophic/hypertrophic ecological state. These eutrophic conditions at the sites are problematic as it can cause excessive growth of aquatic plants and blue-green algae blooms of which some species could be toxic and harmful to the livestock, humans and wildlife within the area. The chloride concentrations for all sites far exceeded the chronic and the acute effect value. The pH level measured at Site 3 was extremely low and indicated that the system was very acidic, with pH values within the recommended range measured for all the other sites.

From the diatom results analysed for the study area, a total of 56 diatom species were identified over the eight sampling sites. The dominant species identified at the sampling sites indicated that all the sites (except sites 1 and 8) are eutrophic as these are species that prefer nutrient-enriched waters and are commonly identified in waters known to be eutrophic and heavily to extremely polluted. The diatom results corresponded with the measured physicochemical water variables which also indicated these sites as nutrients enriched and affected by some sort of pollution. The diatom indices calculated (Specific Pollution sensitivity Index and Generic Diatom Index) also indicated that the sites had poor to bad water quality and was classified as eutrophic ecological state. The Percentage Pollutant Tolerant Valves scores for sites 2 and 3 (fixed) indicated that these sites were heavily contaminated with organic pollution which could be as a result of wastewater discharge from the surrounding areas causing organic pollution. The fixed and live diatom samples had a similar trend for some of the index scores for most of the sites while Site 3 had little resemblance in the index trend for the live and fixed samples.

These results, therefore, indicate that the ecosystem is enriched with nutrients which correlates with the water quality and dominant diatom species. The presence of the illegal dumping at these sites definitely contributed to the elevated nutrient concentrations as previous studies have indicated illegal dumping to be a contributing factor in certain elevated water quality variables such as nutrients. The hypothesis of the study is therefore supported as it can be concluded that the illegal dumping of waste near water sources does negatively influence the water quality of these water resources by altering the water quality parameters which has led to eutrophic polluted conditions. It was concluded that illegal dumping together with various other sources (such as waste water and agricultural runoff) does have an impact on the quality of the selected water resources within the Ikangeng and Promosa area.

Keywords: Illegal dumping, biomonitoring, water pollution, water quality, rural community, solid waste management, physicochemical analysis, diatoms

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List of Abbreviations

BC	Black Carbon
COD	Chemical Oxygen Demand
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DHEC	Department of Health and Environmental Control
DHSWS	Department of Human Settlements Water and Sanitation
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EPA	Environmental Protection Agency
FAII	Fish Assemblage Integrity Index
FRAI	Fish Response Assessment Index
GHG	Greenhouse gas
GPS	Global Positioning System
GWP	Global warming potential
HAI	Habitat Assessment Index
IDP's	Integrated Development Plans
IHAS	Invertebrate Habitat Assessment System
IHI	Index of Habitat Integrity
IP&WM	Integrated Pollution and Waste Management
IWMP	Integrated Waste Management Plan
MAR	Mean Annual Rainfall
MIRAI	Macro-Invertebrate Response Assessment Index
MO CARES	Missouri Department of Natural Resources for a Camera Assisted Remote Enforcement and Surveillance

NBPAE	National Biomonitoring Programme for Aquatic Ecosystems
NEMA	National Environmental Management Act
NEMWA	National Environmental Management Waste Act
NWMS	National Waste Management Strategy
PCBs	Polychlorinated biphenyls
PVC	Polyvinyl chloride
SASS	South African Scoring System
SDGs	Sustainable Development Goals
SW	Solid waste
VEGRAI	Vegetation Response Assessment Index
WEF	World Economic Forum
WRC	Water Research Commission

Chapter 1 - INTRODUCTION

Water is a crucial resource all over the world, however, in rural areas it is especially important as the people's livelihood are dependent on it (Hall *et al*., 2014). An important innovative change that was made in 2010 was the formal acknowledgement of the human right to have access to water, addressing the lack of access to water in developing countries, especially for women (Hall *et al.,* 2014). This access to water as a human right was established on a perspective of public health and prioritised the provision of clean and safe drinking water, hygiene, sanitation as well as the other necessary domestic activities (Hall *et al*., 2014).

An increasing amount of pressure has been placed on the world's water resources through anthropogenic activities such as urbanisation, increased standard of living, increasing competition for water, population growth and pollution (Hossain, 2015). Each of these anthropogenic activities has a direct impact on the ecosystem and thereby on the water resources (Hossain, 2015). These pressures are also worsened by changes within the natural conditions as well as climate change (Hossain, 2015). There are, however, some improvements being made as there are more officials that are assessing both the quality and quantity of water and water management efforts are being coordinated across the country (Hossain, 2015).

Activities that lead to water pollution can impact water quality and cause deterioration of the aquatic ecosystem (Hossain, 2015). Some of the main pollutants include fertilisers, metal concentrations released through industrial and mining activities, organic matter, run-off from agricultural lands, discharges from wastewater containing disease-carrying organisms and acid rain (Hossain, 2015).

Dumping sites can also have negative effects on the health of the environment and the people, regardless of their location (Hanfman, 2012). According to Rajpal (2002), it is not always perceived as convenient or affordable to properly dispose of waste and therefore people commonly dispose of it in unpermitted areas. This is done to avoid the charges with regards to disposal or the effort in terms of properly disposing of the waste at recycling centres or landfill sites (Hanfman, 2012). Other reasons for the illegal dumping of waste is due to the existing laws being portrayed as inadequate, the lack of understanding of the laws or the fact that the fees to properly dispose of the waste exceeds the potential fines for illegal waste disposal (Hanfman, 2012).

It is therefore important that all measures are taken to develop a common front in which the effects of illegal dumping can be reduced on a global scale while allowing for the environmental conditions to improve and sustainable development to be undertaken.

1.1 Research outcomes

1.1.1 Research question

What impact does illegal dumping sites have on the surface water resources in the Ikageng and Promosa areas?

1.1.2 Hypotheses

Illegal dumping of waste near water resources will negatively influence the water quality of these resources resulting in eutrophic conditions.

1.1.3 Aims and Objectives of the study

This study aim was to assess the impact that illegal dumping has on the surface water quality of selected water resources through the use of diatoms as a bioindicator.

The objectives of the study include:

- To review and identify the gaps within the waste management legislation regulating activities of illegal dumping.
- To sample the water quality and diatom communities at each site.
- To determine whether the diatom community (both live analysis and preserved analysis) differs between sites and what the dominant species at each site indicate.
- To assess whether the illegal dumping within Ikageng and Promosa area has an impact on the water quality of the aquatic ecosystems that the community depends on.

1.1.4 The layout of the dissertation

Chapter 1: Introduction

An introduction and motivation of the study together with the aims, objectives, hypotheses and layout of the dissertation.

Chapter 2: Background to the study area

Literature review detailing the problems faced with solid waste mismanagement and the current gaps and challenges identified within the legislation regulating these activities. The impact of illegal dumping on the water resources due to poor waste management and the use of diatoms as a bioindicator to determine the water quality.

Chapter 3: Research area in general

This chapter provides a background to the study area as well as a detailed description of each sampling site.

Chapter 4: Materials and methods

Discussion on how the different sampling sites were selected, and the methods followed to undertake the water and diatom samples as well as the statistical analysis used to interpret the results.

Chapter 5: Results

This chapter provides the water quality and diatom results determined for each site.

Chapter 6: Discussion

The water quality and diatom results presented in Chapter 4 is discussed in more detail and these results are related to the impact of illegal dumping on the water resources.

Chapter 7: Conclusion and Recommendations

This chapter concludes the findings of the study based on the results, hypothesis, and objectives of the study. Recommendations are made on similar studies that need to be conducted and some measures to address certain of the gaps identified within the waste management laws and legislation.

Chapter 8: References

This chapter includes the list of references used throughout the study.

Chapter 2 - BACKGROUND TO THE STUDY

2.1 Literature Review

2.1.1 Solid waste mismanagement as a worldwide problem

Solid waste (SW) mismanagement is a worldwide problem as it can result in environmental pollution, economic unsustainability, and social inclusion (Gupta *et al.,* 2015; de Souza Melaré *et al*., 2017). It is estimated that globally there is approximately 98,995,672 tons of waste that are currently being dumped illegally (Hanfman, 2012). Illegal dumping is often referred to as wildcat, midnight or fly dumping and mostly occurs in the early morning or during the night in poorly lit areas, on private or vacant properties along abandoned residential, commercial or industrial buildings, roadsides and in bushes (Hanfman, 2012).

The sustainable development principles were presented within the global sustainable development goals (SDGs), where 17 objectives were announced for decreasing environmental pollution, improving social equality, reducing poverty, and ameliorating city liveability (Ferronato and Torretta, 2019). The global waste management goals for improving sustainability worldwide include: *"to ensure, by 2020, access for all to adequate, safe and affordable SW collection services; to stop uncontrolled dumping and open burning; to achieve sustainable and environmentally sound management of all wastes, particularly hazardous ones, by 2030*" (Wilson and Velis, 2015).

Proper waste disposal is not always perceived as convenient or affordable and therefore people commonly dispose of it in areas that are unpermitted (Rajpal, 2002). This is done to avoid the charges with regards to disposal or the effort in terms of properly disposing of the waste at recycling centres or landfill sites (Hanfman, 2012). Other reasons for illegal dumping of waste are due to the existing laws being portrayed as inadequate, the lack of proper understanding of the laws or the fact that the fees to properly dispose of waste exceed the potential fines for illegal waste disposal (Hanfman, 2012).

In low-income areas, the refuse removal services are usually not present or very scarce and the residents of these areas are less likely to be able to afford the fees for pickup or disposal of their wastes (Medina, 2007). In certain cases, people will allow others to dump on their property for a fee or claim to operate a recycling centre or a transfer station and accept the waste for a fee and then abandon the unpermitted facility if it is at capacity (Hanfman, 2012). Materials are commonly dumped illegally due to the lack of waste disposal services or due to these materials being banned from landfills, such as tires, yard waste, car batteries and appliances that contain Freon (refrigerators, air conditioners, freezers and many more) (Hanfman, 2012).

Serious metal pollution due to uncontrolled disposal is present within the soil, water and plants and open burning pollute the atmosphere by causing pollutant emissions such as CO, CO_2, SO, NO, PM_{10} as well as several other pollutants (Gutberlet and Baeder 2008; UNEP, 2009; Wiedinmyer *et al*., 2014; Vongdala *et al.,* 2019). The SW that enter water bodies increases marine litter on a global scale and therefore, increases the environmental contamination (Gutberlet and Baeder, 2008; UNEP, 2009; Wiedinmyer *et al*., 2014; Vongdala *et al.,* 2019).

After illegal dumping has occurred at a site it is very difficult to stop it at the location and the spot can easily attract more illegal dumping to take place if it is not addressed effectively (Ferronato and Torretta, 2019). It is also common for people to continue dumping their waste at a landfill site after the closure of this site (Ferronato and Torretta, 2019). It was found that a neighbourhood with a high crime rate is more likely to be subjected to illegal dumping since the chances of catching and prosecuting the offenders are very slim due to the other criminal activities taking precedence in the area (Crofts *et al.,* 2010).

2.1.1.1 **Illegal Dumping**

All across Europe, waste companies are trying to find ways to avoid having to pay the increasing recycling and landfill charges (Hanfman, 2012). In 2004 an organization of waste inspectors, based in six different European countries, stated that up to 20 percent of the thousands of paper and plastic waste containers that are sent from Europe to China and Southeast Asia every year for recycling, may be illegal due to it not being authorised prior to being shipped (Hanfman, 2012). New evidence from the Netherlands has stated the 20 percent as an understatement stating that 70 percent of the waste being shipped from Europe to the other developing countries is not authorised and therefore illegal (Hanfman, 2012). Waste can easily be disguised by companies as recyclables by simply making it look like paper when baling it together and waste shipments can also be disguised as being "donations" (Hanfman, 2012).

The origin and ultimate destination of waste are also often disguised when intermediate storage sites are used (Hanfman, 2012). In 2005 in the Netherlands more than a 1,000 tons of household refuse was discovered to come from Britain disguised as waste paper to be shipped and recycled in China, the waste was then sent back to Britain where it had come from (Hanfman, 2012). It was identified by Europol that the illegal waste volumes being shipped across borders have increased and are impacted by globalization and economic growth (Hanfman, 2012). It is identified as the fastest growing areas in terms of organized crime due to the fairly low risk as well as a providing a good chance for making a profit (Hanfman, 2012).

In North-East Europe a large gravel pit was filled with approximately 134,000 tons of illegally dumped waste and the cost to remove and transport 1 ton of waste out of the pit cost 160 Euros (Hanfman, 2012). This added up to a total of 21 million Euros to remove and transport all of the waste out of the gravel pit. The cost to remove hazardous waste is even more costly and increases to approximately 300 Euros per ton (Hanfman, 2012).

There is a drastic increase in the number of factories in China which leads to an increase for the need for resources and for this reason China accepts a lot of the e-waste and recyclable materials from other countries (Hanfman, 2012). The items are sometimes melted down to extract the usable metals (Khaliq *et al.,* 2014). This is an illegal practise as the process gives off toxic fumes however, there are still people that continue to make use of this method at their homes (Hanfman, 2012).

Agbogbloshie, a slum within Ghana, had an area which consisted of only dumped old electronic equipment that the community burned to extract various metals and copper (Hanfman, 2012). The pollution from the waste of these dumping sites contaminated the lagoons, rivers and soil of the area, and in 2008 a study conducted by Green Peace on soil samples in this area identified high concentrations of mercury, lead, thallium, Polyvinyl chloride (PVC) and hydrogen cyanide (Hanfman, 2012).

In Banjul (Gambia) the local community's health is negatively influenced due to the smoke and odour from a nearby large dumpsite, where waste is burned (Ferronato and Torretta, 2019). During the rainy season, the nuisances worsen as the dumpsite are infested with insects and flies and run-off from the dumpsite contaminates the water bodies, soil and groundwater of the area (Ferronato and Torretta, 2019).

In the capital city of Cambodia (Phnom Penh) the management of SW is not regulated and therefore household waste is usually buried, burned or dumped (Seng *et al.,* 2018). According to Seng *et al.* (2018), it was identified in 2008 that there was approximately 361,000 tons of waste that was not properly disposed of and in 2015 it increased to 635,000 tons of waste not properly disposed of in Phnom Penh.

In Thailand, more than 60% of the final SW disposal was done by open dumping (Ferronato and Torretta, 2019). The number of disposal sites in 2004 totalled to approximately 425 of which 330 were classified as open dumpsites and every day most of these sites received approximately 25 tons of waste while the landfills within Bangkok received 4500 tons of waste per day (Chiemchaisri *et al.,* 2007).

Abuja, the capital city of Nigeria, generated more than 250,000 tons of waste in the year 2010 (Ferronato, and Torretta, 2019). In Abuja, four major waste disposal sites closed in 2005, due to air pollution, odours and the burning of waste at the sites that caused problems for the surrounding community (Ferronato, and Torretta, 2019). Especially during the rainy seasons, it was identified that the leachate that percolated down from the buried waste, contaminated the surface water bodies (Aderoju *et al.,* 2020).

In Mexico, of the total waste generated in the Huejulta Municipality, 24% is burned by the locals at their homes of which 90% is located within the rural areas where the municipal services are lacking and it was found that this activity contaminated the environment and also produced black carbon (BC) which contributed to the Global warming potential (GWP) (Reyna-Bensusan *et al.,* 2018). Results indicated that the open burning emitted BC which contained 15 times more CO_2 compared to the CH_4 which is released when equivalent amounts of combustible organic waste are decomposing at a dumpsite after it has been dumped (Reyna-Bensusan *et al.,* 2018).

In South Africa, in the township of Clermont (KwaZulu-Natal Province), the management of SW is problematic as the waste disposal is very similar to that of informal communities despite the township being a more formal residential area (Ngeleka, 2010). Clermont is characterized by mountains of SW that have been disposed of on open vacant spaces (Ngeleka, 2010). These heaps of SW pose a major health risk for the local communities, as it results in noxious odours from decomposing waste material as well as serve as a breeding ground for rodents, worms, insects and rats (Ngeleka, 2010).

According to Stats SA (2018), there were approximately 12.2 million households in South Africa in 2018 that received formal waste removal services, while approximately 323,478 of the households did not. It is estimated that approximately 12.7 million tonnes of domestic waste are generated each year by the households in South Africa, of which 3.67 million tonnes are not treated and collected through the formal waste collection services and ends up being illegally dumped (Rodseth *et al.,* 2020).

2.1.1.2 The perceptions of illegal dumping

Illegal dumping is a global problem which takes place across all different languages, cultures, and economies (developed and undeveloped) (Abel, 2014). To find the most appropriate way to stop illegal dumping from taking place, one needs to understand people's perceptions and attitudes towards the disposal of waste and also find the most effective way to communicate and create awareness under the different groups in terms of the importance of good waste management (Abel, 2014).

Findings from a study conducted by Abel (2014), in which other studies from America, Australia, Canada, Japan and Britain were reviewed, confirmed that people think that the responsibility falls on the government to clean up after them, that their actions won't result in the environment suffering any knock-on negative effects, and that the correct disposal of waste is inconvenient, unpleasant and expensive. According to Abel (2014), findings from the interviews held with communities that may be specific to the situations of South Africa indicated the apparent belief of people, "that one's vote is one's currency" and after you have voted for a specific political party, that political party is responsible for ensuring that you receive all you want or need, including cleaning up rubbish that has been dropped intentionally (Abel 2014).

Time and again, studies have revealed that people's perceptions and reasons behind illegal dumping are very similar across different parts of the world (Abel, 2014). These reasons include:

- For numerous people, littering or dumping on private or public land is not regarded as a major problem or as criminal behaviour, it is at most, regarded as a minor misdemeanour (Square Holes, 2007). According to Crofts *et al.* (2010), the connection between illegal dumping being a criminal activity is not always made, which could be a result of the delay in the consequences of the offence, such as contamination of the downstream water resources which in most cases are only picked up at a much later stage than when the offence took place. The people that dump illegally do not understand the cost involved to clean-up the waste that has been dumped as well as the negative knock-on effects that the illegal dumping has on the environment and the affected society (Abel, 2014). A survey conducted by Gomez Research in 2007, identified that half of the people that undertook the survey were aware of the well-known environmental issues such as air and water pollution/scarcity and global warming, but did not link these concerns to poor waste management and only 13% or the respondents had concerns with regards to waste and landfills. According to a study by Square Holes in 2007, more than half of the results from a survey indicated that people think it is the responsibility and obligation of the Council to clean up after them.
- One of the top reasons mentioned by 69% of respondents as to why they do not properly dispose of their waste at a landfill is due to the cost being too high (Curtis and Cowee, 2010). According to Reed and Yanke (2001), another reason for not

properly disposing of the waste is that building contractors and transporters can improve their profit outcomes and offer rates that are more competitive if they avoid the fees of disposing at a landfill.

- The distance to drive to the legal landfill sites is often too far with inconvenient operating hours at legal landfills. People are also not aware of the policies of the landfill with regards to disposing of large materials (Abel, 2014).
- Ignorance was another reason as people proclaimed to not know where the closest recycling centre, landfill or transfer station is (Abel, 2014). It is much more convenient, easier and cheaper for people to dump their unwanted goods along a sidewalk or down a bank of a quiet road than to travel and make arrangements to dispose of it at a landfill site (Abel, 2014). According to DEC (2004), there are very seldom consequences (no fines, much less jail time) to illegal dumping and because the waste is cleaned-up by the Council, there is a lack of accountability on the dumper.
- According to Reed and Yanke (2001), the law is poorly enforced as the regular dumpers already know the areas where the police patrols and what areas are of low risk of being caught. Often the law enforcement officers are not well trained in understanding the environmental local laws and therefore don’t treat dumping as an important offence (Abel, 2014). In the event where the case does go to court, it has been found that the judge or prosecutor does not regard it as a big issue as they sometimes do not properly understand the environmental law (Abel, 2014).
- For many, it has become a habit to dump illegally as they have not been caught before and their mess was cleaned up by someone else, so for them, it is worth it to take the risk and illegally dump their waste (Reed and Yanke, 2001). According to Reed and Yanke (2001), 81% of dumpers know of the fines which they can be issued with when caught but are willing to take the risk as the chance of being caught and convicted is far less likely.

2.1.1.3 **Combating Illegal Waste Dumping**

In every state in America, different laws regulate activities of illegal dumping (Hanfman, 2012). In California, it is considered littering if a person drops, throws or disregards their refuse on public or private land or within the surrounding watercourses (Hanfman, 2012). The fine for this criminal activity can reach up to $1,000 and could, depending on how serious the case is, include jail time for those found guilty (Hanfman, 2012).

In Connecticut (America), you are fined $219 when found guilty of dumping anything larger than one cubic foot of litter, and when a person is caught throwing refuse out of their vehicle, they can be arrested and fined and their vehicle may be confiscated (Hanfman, 2012). The offender can even be fined $25,000 per day for the clean-up costs involved to remove the material dumped (Hanfman, 2012).

In South Carolina, there are two acts under which illegal dumpers can be prosecuted which include Carolina Solid Waste Policy and Management Act of 1991 and the South Carolina Litter Control Act (Hanfman, 2012). There are specific criminal investigators within the state's Department of Health and Environmental Control (DHEC) which are specifically assigned to investigate cases of open dumping (Hanfman, 2012).

Four programmatic areas have been identified within the Environmental Protection Agency (EPA) for prevention of illegal dumping and these include community outreach and involvement, targeted enforcement, efforts to clean-up and lastly tracking and evaluation (Hanfman, 2012).

- Funding and resources are required for the **efforts to clean-up** and for the posting of signs to raise awareness of the penalties and fines associated with dumping as well as ways to report illegal dumping (which could therefore help avoid further dumping and improve the property values of the sites subject to the dumping) (Hanfman, 2012).
- Clean-up events can be held for **community outreach and involvement** that provide the communities with the required resources to dispose of illegally dumped material correctly (Hanfman, 2012). This provides the community with the opportunity to understand how certain materials need to be disposed of and how easily it can be done (Hanfman, 2012). Another measure to prevent dumping is to include policing programs in the community to increase the enforcement of the laws applicable to illegal dumping without the added cost of using separated resources (Hanfman, 2012). Effective communication with the citizens informing them of the heavy costs that illegal dumping has on the local taxes can also be implemented (Hanfman, 2012). Providing a hotline where citizens can report activities of illegal dumping will also be helpful (Hanfman, 2012).
- With **targeted enforcement** fines, permits for waste management, and penalties for recovering costs to clean-up are all enforced by legal ordinance to try to prevent illegal dumping and to implement waste management regulations (Hanfman, 2012). The fees that these ordinances collect can be used to reward those that report illegal dumping or used to fund programs that prevent illegal dumping. Other uses for the money can also include the hiring and training of staff to undertake inspections, conduct surveillance and write citations (Hanfman, 2012).

- **Tracking and evaluation** is the last programmatic area and can be used to determine just how effective the efforts for prevention are (Hanfman, 2012). Computer databases and mapping can be used to track and identify the locations where illegal dumping is dominant and therefore identify the occurrence patterns for illegal dumping sites to keep track of where and to whom the citations are issued (Hanfman, 2012). This will assist the officials to identify and target the areas where the resources are most needed (Hanfman, 2012).

The local authorities should inform the communities of the necessary information regarding where the closest waste services are located and how they can be used (Yoada *et al.,* 2014). Illegal dumping signs should also be placed at areas where illegal dumping occurs and the area should be well lit and landscaped to help to prevent it from happening and to make the residents aware that it is illegal and that if caught they can be prosecuted or fined (Hanfman, 2012). The type of enforcement to effectively help prevent illegal dumping is also dependent on the scale of the dumping (Shinkuma and Managi, 2012). The laws with regards to illegal dumping should be written in such a way that it can be easily understood by the public and the associated fines should be much larger than the cost to properly dispose of the waste (Hanfman, 2012).

There have been several campaigns and organisations that have been working to make a difference in preventing illegal dumping from taking place, these include (Hanfman, 2012):

- An organization called “Southwest Detroit Environmental Visions” funded a program named the “Tire Roundup Program” which involved paying the residents an incentive of 25 cents for every tire that they brought in that has been illegally dumped. During this program, 8,000 tires were brought in.
- In Philadelphia, an organization called “Keep Philadelphia Beautiful” surveyed the city to determine the extent of the illegal dumping and it was identified within the study that dumpsites measured having debris of half a ton or more. Most of the sites were found to be situated in North Philadelphia and the largest contributors were identified to be contractors form small private businesses that dumped the waste from their construction and demolition activities.
- A project in EPA region 7, called “Missouri Department of Natural Resources for a Camera Assisted Remote Enforcement and Surveillance” (MO CARES) was funded and entailed the placing of surveillance cameras at sites where illegal dumping occurs to monitor the dumping taking place and to further prevent it from happening.
- In the state of Washington, a foundation founded in 1996 called “Friends of Trail” removed, throughout eight-years, more than 100 vehicles, 400 appliances and more

than 900 tons of refuse and thousands of tires from hiking trails, public recreational areas and waterways (Rea, 2005).

- In Estonia (Europe), there was a campaign called “Let's do it 2008” that involved people using their GPS setting on their cell phone to map illegal dumping sites across the country and take photos thereof. In the end, there were over 3,000 sites that were mapped and in 2008, more than 50,000 people in Estonia worked together to remove the waste and clean up the sites. The goal of the project was to shift people’s mindset in becoming more conscious of the environment and the important role that it plays. This project inspired a website whereby illegal dumping sites can be mapped by people all over around the world.

Possible solutions have been reported in many studies to improve SW mismanagement in developing countries through implementing measures such as:

- Buyback programs for organic waste for the production of biogas or compost (Hettiarachchi *et al.*, 2018).
- Implementing technologies and plans to convert waste-to-energy (Ouda *et al.,* 2016).
- Waste-to-energy as well as recycling of metals, glass and other recyclable materials (Sadef *et al.,* 2016).
- Production of energy by producing briquettes from biomass waste (Sawadogo *et al.,* 2018).
- Providing legal incentives for waste pickers (Ghisolfi *et al.,* 2017).

The main aspects that are important to finding any solution include, the implementation of effective waste management practices for the collection and disposal of waste, involving all sectors within the production chain starting at the manufactures and changing people’s behaviour (Ferronato and Torretta, 2019). The changes in improving SW management is reduced by the lack of resources for transportation, collection, treatment, final disposal, financial requirements, raising awareness and public attitudes (Ferronato and Torretta, 2019). The generation of SW can also nevertheless, be viewed as a basis for opportunities such as new employment, renewable energy production, private investments, new advantages for the economic sector and improvement of environmental awareness and the main challenges (Ferronato and Torretta, 2019).

It is clear after reviewing several studies that these projects to prohibit illegal dumping should be introduced at an international level to reduce the health issues and environmental contamination that is associated with illegal dumping and open burning of waste (Ferronato and Torretta, 2019). The different parties and authorities that are involved in waste management should know about the problems that are affecting sustainable development all over the world, and they should inform the public about these problems as well as raise awareness for recycling and prevention activities (Ferronato and Torretta, 2019).

2.1.1.4 **The effect of illegal dumping**

Illegal dumping in low-income countries is common as it is the cheapest cost option, the waste is disposed of in an inadequate and uncontrolled manner and can easily be accessible to animals and waste pickers and the pollutants that are generated by the dumping is not monitored (Zhu *et al.,* 2008).

Illegal dumping can threaten aquatic and wildlife habitats (Ejaz *et al.,* 2010). Animals and birds can ingest or become entangled in the waste, causing them to suffocate or become stranded and die (Kühn *et al.,* 2015). In aquatic systems, the aquatic species and fish can die from the litter and waste that enters the system as it clogs the fish's spawning areas and depletes the oxygen levels in the water when food waste decomposes (Hanfman, 2012). Human health can also be affected by illegal waste dumping in several ways (Triassi *et al.,* 2015). When people can easily access the sites, they are in danger of stepping on sharp edges and nails and getting injured (Triassi *et al.,* 2015). Children that play at these sites are also at risk of becoming trapped inside of old or broken appliances that have been thrown away (Rajpal, 2002).

People that are within proximity to these dumpsites are also at risk as they could be exposed to hazardous chemicals through dust or toxic fluids (Jerie, 2016). Appliances which were manufactured before the year 1979 also pose a risk of leaking polychlorinated biphenyls (PCBs), which has been identified to be linked to reproductive failure, cancer and an imbalance in hormones in humans and animals (Hanfman, 2012).

Dumpsites are known to be a breeding place for rodents, insects and other animals which results in increased spread of infectious diseases, particularly through mosquitoes (Cointreau, 2006). Tires have been found at illegal waste sites to be the common item dumped, and research has indicated that tires offer the ideal breeding place for mosquitoes as they can reproduce at a ratio of 100 times faster in the stagnant warm water that accumulates within the tire compared to normal breeding circumstances (Hanfman, 2012). The mosquitoes that breed within these tires contribute to the spread of diseases such as yellow fever, dengue fever and encephalitis (Braack *et al.,* 2018).

There are millions of cases of Dengue that occurs every year and more than 2.5 billion people reside in areas where they are at risk of this disease (Yevtushenko and Tolstoj-Sienkiewicz, 2006). A study was conducted in Tamilnadu (India) in which the dengue vector was tested for in different items where the mosquito larvae usually breed (Ferronato and

Torretta, 2019). Of the 118 water containers (mud pots, cement cistern, used tires and many more) that were tested, 38 of them had the dengue vector (Ferronato and Torretta, 2019). All different types of containers were inspected and those positive of containing the mosquito larvae included mud pots, tires and cement items (Yevtushenko and Tolstoj-Sienkiewicz, 2006). As tires are a quite common item found at the illegal dumpsites and are favourable breeding items for these mosquito larvae, actions should be taken to avoid the final disposal of the waste tires at dumpsites to reduce the spread of Dengue disease.

Waste from illegal dumpsites is burned, in some cases by the surrounding residents, to reduce the amount of waste and create space for more waste to be dumped. This has detrimental effects on the surrounding community as the emissions released from the burning can cause health and respiratory problems due to the contaminants being released and breathed in by the surrounding community (Jerie, 2016). Illegal dumpsites are common areas where fires occur either through arson or spontaneous combustion as there may be old gas cans or aerosols that can cause explosions and chemicals from farms or households can emit a cloud of toxic smoke (Jerie, 2016) or other toxic emissions such as PCDD/F (Hossain *et al.,* 2011). The burning that occurs at these sites can also result in knock-on effects such as forest fires, initiate erosion and therefore increase the sediment load that enters nearby streams (Hanfman, 2012). The property values of the neighbourhood can also decrease due to the presence of illegal dump sites and can therefore affect the local tax assets (Tunnell, 2008).

These areas are viewed by residential and commercial developers as unattractive which limits the future economic potential of the area (Hanfman, 2012). To clean up these illegal dumpsites cost millions of dollars and the cost to dispose or transport the waste then falls on the residents that pay higher property taxes or service fees (Hanfman, 2012).

In developing countries, medical waste is commonly disposed of at open dumps (Ali and Kuroiwa, 2009; Manga *et al.,* 2011; and Ali *et al.,* 2016) which causes infectious pathogenic micro-organisms to be transmitted into the environment through either ingestion, inhalation, direct contact or indirectly through the food chain (Ziraba *et al.*, 2016). At the illegal dumpsites, the waste pickers neglect the necessary hygienic and technical considerations as they were observed picking up and gathering all the health waste to recycle the waste and sell the materials and pass it on to innocent patients within the low-income areas (Ferronato and Torretta, 2019).

Waste mismanagement such as illegal dumping has a specific impact at three different levels (Ferronato and Torretta, 2019):

- Local or municipal impacts – pollution of the groundwater, air and soil, the spread of dangerous diseases through various animal vectors (rodents, mosquitos) and many more.
- Regional impacts – the watercourses are polluted which are used for household and agricultural purposes.
- Global impacts – including marine littering and global warming

Most of the waste material that is illegally dumped include demolition and construction material (Mihai, 2019). The building industry is greatly affected by this as the contractors and builders that illegally dispose of their waste can quote much lower prices than those that dispose of their waste in the correct manner, which makes it difficult and not fair for those disposing of their waste in the proper manner (Ferronato and Torretta, 2019).

The groundwater and runoff contamination data from eight different case studies undertaken in India, Cuba, Nigeria, Thailand, Mexico, Malaysia and Egypt were compared to the standards for drinking water since the groundwater in low to middle-income areas are mostly used for drinking water without proper water treatments (Ferronato and Torretta, 2019). It was identified that the metals within the samples were 10 times higher than the World Health Organisation (WHO) limits suggested and the chemical oxygen demand (COD) concentrations were also very high compared to the WHO limits (Ferronato and Torretta, 2019). These results also prove that the surrounding population's health is at serious risk due to the impact of these open dumping sites (Ferronato and Torretta, 2019). Global warming potential due to illegal dumping of organic waste is another concerning environmental issue, due to the degradation of anaerobic waste (Ferronato and Torretta, 2019). A by-product of municipal SW landfill sites is Methane gas, which is directly released into the atmosphere (Ferronato and Torretta, 2019). Experimental studies have indicated that the anaerobic biodegradation of the organic waste found within municipal SW produces approximately 200 Nm^3 of methane for each dry ton of biomass (Themelis and Ulloa, 2007). Methane gas is identified to be one of the gasses that greatly increases the GWP at a rate 25 times more than the potential of CO^2 (Boucher *et al.,* 2009). Illegal dumping sites and mismanaged landfills are therefore a direct source contributing to the greenhouse gas (GHG) emissions (Ferronato and Torretta, 2019).

Marine litter has also been a big problem in affecting the ocean on a global scale and is mostly caused by the daily plastic waste (Derraik, 2002 and Iñiguez *et al.,* 2016). Marine litter can be defined as any processed or manufactured SW that somehow enters the marine environment (Ferronato and Torretta, 2019). Approximately 80% of the marine litter that enters the ocean is generated inland and then ends up in the rivers and streams which flows into the ocean (Jambeck *et al.,* 2015).

Illegal dumping can therefore be regarded as the main cause of polluting the marine environment (Ferronato and Torretta, 2019). The generation of the so-called “micro-plastics” is even more hazardous according to Ferronato and Torretta, (2019). These plastics are formed at the surface of the ocean where biological, photochemical and mechanical processes break the larger plastic items into <5 mm smaller items which are then considered as microplastics (Andrady, 2011). Microplastics tend to float on the surface of the sea and are actively or passively ingested by the marine organisms (do Sul and Costa, 2014). A more recent study conducted by Anela *et al.* (2019), in the greater Monterey Bay pelagic ecosystem of the central California coast indicated microplastics to be present in all depths of the water column both offshore and nearshore. Marine litter results in a diverse range of impacts which include (Cheshire *et al.,* 2009):

- Environmental – ingestion problems, blocking of filters, poisoning of organisms, causing physical damage to the mangroves and the reefs and many more.
- Social - visual impacts, indigenous values are decreasing or being lost and risks to human safety and health.
- Economic – the income from tourism sector decreases due to decrease in tourists, cost to vessel operators, the fishery sector also loses income, fees are required to clean-up the litter, operations need to be implemented to rescue affected animals, the cost to recovery and dispose of the waste.
- Public safety – hazards to divers and swimmers, navigational hazards, risk of getting cuts, stick and abrasion injuries, the hazard of poisonous chemicals leaching out, explosive risk.

A big environmental concern is an inappropriate way in which some industries dispose of their industrial waste, which greatly affects and contaminates the environment as these wastes are usually hazardous. The different types of industrial waste causing environmental contamination, if not properly managed, includes residues due to coal mining, carbide slag, mine tailings, waste from chemical production (e.g. phosphoric acid), fly ash, acidic waste rock and many more (Torretta *et al.,* 2015). The presence of metals are usually linked to the leaching of industrial waste and impacts the quality of the surface and groundwater resources as well as the soil, this, in turn, affects the health of the citizens that are dependent on these resources (Ferronato and Torretta, 2019).

Studies have indicated that the management of industrial waste is an underestimated issue and requires improvement strategies through the implementation of appropriate technologies and methodologies (Ferronato and Torretta, 2019).

2.1.2 South Africa's waste management legislation

In South Africa, the previous implementation of governance from the period of 1948 until the early 1990s has to a large extent worsened the environmental problems that the country faces (Ngeleka, 2010). The refusal of education, land ownership and certain important services have resulted in the affected communities feeling a sense of unworthiness which has greatly contributed to the levels of degradation of the natural resources within these areas where the affected communities reside (Ngeleka, 2010). However, the severity of the natural resources being deteriorated is not only limited to the areas where there was a lack of basic services but also extends to established and more formal areas such as the African townships (Ngeleka, 2010).

South Africa faces several important concerns regarding waste management including (Fiehn and Ball, 2005):

- The lack of communication and information on waste management to all sectors,
- The occurrence of illegal dumping and dumping sites that are illegal,
- People and animals salvaging at waste dumping facilities,
- Municipalities using unpermitted landfills,
- Limited availability of landfill airspace that is environmentally acceptable,
- For much of the population, the waste collection services are not consistent and not reliable,
- The municipalities do not do the necessary recycling activities or give encouragement to the general public,
- The waste minimalization goal is mostly only practised by industries and there is a lack of databases within the government departments' containing the required waste information,
- There is a lack of enforcement and regulation of the existing waste legislation.

There are several government laws regulating waste within South Africa. These include:

- The South African Constitution (Act 108 of 1996)
- Hazardous Substances Act (Act 5 of 1973)
- Health Act (Act 63 of 1977)
- Environment Conservation Act (Act 73 of 1989)

- Occupational Health and Safety Act (Act 85 of 1993)
- National Water Act (Act 36 of 1998)
- The National Environmental Management Act (Act 107 of 1998)
- Municipal Structures Act (Act 117 of 1998)
- Municipal Systems Act (Act 32 of 2000)
- Mineral and Petroleum Resources Development Act (Act 28 of 2002)
- Air Quality Act (Act 39 of 2004)
- National Environmental Management: Waste Act, 2008 (Act 59 of 2008)
- National Environmental Management: Waste Amendment Act, 2014 (Act 26 of 2014)

A lot of transformation and change was brought into the communities of South Africa during the constitutional era in 1996, for instance, the right to a clean environment created the basis for waste management frameworks that are effective and sustainable (Zhakata *et al.,* 2016). One of the key components of sustainable development is waste management because sustainability is greatly supported by sound waste management practices (Kidd, 2011).

Section 24 (b) of the Constitution states that:

"Everyone has the right – (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that – (i) prevent pollution and ecological degradation;"

The different governmental spheres should therefore ensure that this provision is met by establishing effective legislative frameworks that manage and control waste to ensure that the environment is not contaminated (Zhakata *et al.,* 2016). Waste management in South Africa is closely linked to the environment and for this reason the National Environmental Management Act (NEMA) provides specific environmental protection principles to ensure proper waste management (Zhakata *et al.,* 2016).

There have been several additional guiding principles introduced by NEMA into the environmental legislation of South Africa, as well as the waste management life cycle approach, the responsibilities of the producer, the principle of taking precaution and the polluter pay principle (Zhakata *et al.,* 2016). NEMA (Act 107 of 1998) also places a duty of care on anyone that causes the environment to be polluted or degraded and requires them to take the necessary measurements to either try avoiding pollution events or to rectify and minimise the degradation or pollution in the event where it cannot be prevented (Zhakata *et al.,* 2016). This duty of care is also provided for in the Waste Act as the act obliges waste holders to take the required measures to ensure that the waste hierarchy is implemented while protecting the health of the public and the environment (Zhakata *et al.,* 2016). There are several good waste management policies, standards and acts that have been established for South Africa, however, it is still a challenge for most of the municipalities to effectively implement these strategies for waste management (NWMS, 2011).

The National Environmental Management: Waste Act, 2008 (Act No. 59 of 2008) (NEMWA) was then introduced to address these challenges, and according to the Department of Environmental Affairs (DEA) (2012), the Act provides an improved licencing system for managing the waste activities to ensure that these activities are controlled and not impacting the health of the people or the environment (Zhakata *et al.,* 2016). The Act also requires anyone that causes the environment to be polluted or contaminated to take the necessary measurements to rectify and pay for the area impacted to be cleaned and rehabilitated (Zhakata *et al.,* 2016). This provision is a new measure that has been included in the country's waste legislation. The Waste Act also addresses some of the common problems identified in the sector of waste management that was usually not implemented due to it not being compulsory, for instance, reporting the necessary data to the waste information system, developing plans for integrated waste management and developing the National Waste Management Strategy (NWMS) (Zhakata *et al.,* 2016).

NEMWA promotes waste minimisation, cleaner production, recycling, re-use and the treatment of waste with the last resort being disposal in terms of waste management (Ngeleka, 2010). The National Waste legislation of South Africa does not only serve a purpose in protecting the health of the citizens and the environment by regulating waste management, but it also highlights the specific measures that should be implemented by companies to prevent ecological degradation and pollution (Ngeleka, 2010). The NWMS is a legislative requirement of the "Waste Act" and all organs of state and citizens are therefore required to ensure effective implementation and adherence thereof (Ngeleka, 2010). The main purpose of the NWMS is to ensure that the objectives of the Waste Act are achieved as well as to address the current challenges that South Africa faces in terms of waste Management (Ngeleka, 2010). One of the main challenges is the increase in the population and economic growth which results in the generated waste volumes to increase and therefore increases the pressure on the existing waste management facilities which are already limited (Ngeleka, 2010).

There is a framework of eight goals around which the NWMS is structured, which are to (NWMS, 2011):

- "promote waste minimisation, re-use, recycling and recovery of waste,
- ensure the effective and efficient delivery of waste services,
- grow the contribution of the waste sector to the green economy,

- ensure that people are aware of the impact of waste on their health, well-being and the environment,
- achieve integrated waste management planning,
- ensure sound budgeting and financial management for waste services,
- provide measures to remediate contaminated land,
- establish effective compliance with and enforcement of the Waste Act.”

The White Paper on Integrated Pollution and Waste Management (IP&WM) proposed “a holistic and integrated system and process of management aimed at pollution prevention and minimisation at source, managing the impact of pollution and waste on the receiving environment, and remediating damaged environments” (DEAT, 2000). The management of waste is defined from the start till the end of its life cycle, for instance from where waste material is generated, stored, collected, transported, treated and then lastly to where final disposal of the waste takes place. The primary goal of the White Paper is therefore to ensure that pollution and waste are managed in an integrated manner (DEAT, 2000). The new legislation is deliberately trying to shift from the previous uncoordinated and fragmented waste management and pollution control measures to integrated pollution and waste management and minimisation. There is a poor existing integrated approach taken in terms of waste management between the implementation of the act on a local scale and the NEMWA (NWMS, 2011). This was supported by evidence of some of the community areas having limited education on proper waste management. Some residences lack services such as waste recycling facilities, the collection of waste is not sufficient or done on an irregular basis, and there is among some of the formal residents and most of the informal residents a lack of compliance in paying the required tariffs (NWMS, 2011).

There are also differences in the waste management strategies that exist in the informal and formal areas of the municipality which are mainly as a result of most of the informal settlements being considered as illegal and not planned (Tembon, 2012). According to a study conducted by Tembon (2012) in the Ekurhuleni Municipality, it was identified that residents of informal settlements are not billed for the delivery of the waste management service and therefore most of the residents in these areas do not pay for this service. For this reason, the waste is not properly managed as a result of the financial constraints within the municipality.

The management practices in South Africa should be focused and measured mainly through the use of the NEMWA and the other related standards and policies (Tembon, 2012). Waste management requires corporative governance across all the different governmental spheres, to ensure that all the sectors within the republic implements and enforces the law since one of the main reasons resulting in poor waste management is the lack of proper or even any enforcement (Tembon, 2012). Waste management practises has been challenging in many parts of South Africa as they are not supportive to a healthy environment and the poor communities are those that are most impacted by the effects of poor waste management practices (Tembon, 2012). The challenges associated with waste management and disposal is therefore mostly felt by the local governmental spheres (Tembon, 2012).

It is the responsibility of the local authority to properly dispose of and remove medical waste and if the local authority is not able to carry out these responsibilities, the provincial government must take action to create and ensure a co-operative government (Tembon, 2012). It is also very important that the councils within the municipality do not judge themselves on the functions that they do but that an independent institution is used to control the checks and balances required (Tembon, 2012). The South African strategy for sanitation services for Informal settlements (2007) discloses that the waste disposal activities must be assessed in the informal settlements to ensure that any unsafe practices are identified and that appropriate measures are implemented to prevent the occurrence of such practices that causes environmental pollution and diseases (Tembon, 2012).

2.1.2.1 **The gaps and challenges within the implementation and enforcement of the NEMWA**

2.1.2.1.1 **Interpretation and Principles**

The Act does not specify the required information on the management of the different types of waste, for instance building waste, agricultural waste, garden waste, e-waste, batteries, and many more (Zhakata *et al.,* 2016). There is a long list of terms used in the Waste Act for which the dictionary definition of these terms will not be sufficient (Zhakata *et al*., 2016). To ensure that these terms are properly implemented they need to be contextually interpreted in the Act (Zhakata *et al*., 2016). One of the main terms defined in the Act is “waste” and has been defined as “*any substance irrespective whether it has a potential to be reduced, reused, recycled or recovered; that is surplus or the owner or generator does not need it anymore”* (RSA, 2009). This definition, therefore, exposes the fact that not all of the different types of waste are included in the definition, for example, medical waste which is not allowed to be recycled (Zhakata *et al.,* 2016).

This results in many challenges in court cases involving the waste types that are not included (Zhakata *et al.,* 2016). There are certain areas to which the Waste Act does not apply as other sectoral legislation regulates these areas, such as the disposing or stockpiling of radioactive waste residue and the disposal of explosives and animal carcasses (DEA, 2012). Although other empowering provisions regulate these aspects, it is still an issue as the waste Act is supposed to supersede any other legislation in which waste is managed and governed (Zhakata *et al.,* 2016).

2.1.2.1.2 **Inadequate Waste Disposal Services**

In 2007 approximately 61% of households in South Africa had access to waste collection services, however, this access remains highly biased as these services are only available in the urban and wealthier communities (Zhakata *et al.,* 2016). Inadequate waste services result in unpleasant, unhealthy and environmentally polluted living conditions (DEA, 2012).

This problem mostly occurs in disadvantaged areas where the people residing in these areas were negatively affected during the apartheid era (Zhakata *et al*., 2016). It is, therefore, necessary that the local government ensures proper waste management services in these areas by allocating more resources to the required areas (Zhakata *et al*., 2016). According to an e-news report (June 2011), local municipalities find it very difficult to provide proper waste management services to the people living within the squatter and rural settlements due to the lack of proper facilities and infrastructure such as roads required for the trucks to collect the waste (Tembon, 2012).

Illegal dumping sites are also a big problem in South Africa. In 2011, approximately 1,149 landfill sites were established countrywide since 2007, of which only 568 of these sites were permitted, and the rest of the sites were created illegally (IWMSA, 2011). These illegal dumping sites occur mostly due to the municipality not providing the necessary waste storage facilities to the residents that are not able to afford to pay for such receptacles (IWMSA, 2011). Another problem is the proximity of some of these landfill sites to the residential areas, which create not only environmental problems for the residents but also health problems (Tembon, 2012), as previously stated. Other challenges in regards to the municipal collection services, is the inconsistent collection of waste from the neighbourhoods, which is not collected on the scheduled collection days, with the municipalities changing these dates without informing the public (Tembon, 2012). Some of the residents complain that the weekly waste collection frequency is to low, however according to NEMWA, the once a week collection of waste is the ideal frequency as there are certain areas where the collection of waste only occurs once in every two weeks or only once a month (Tembon, 2012). This could be a result of the municipality having limited resources available (Tembon, 2012). On rainy days there is also no waste collection. This results in many households needing to either keep their refuse until the next collection date or cause some households to deal with their waste in other alternative ways such as burning or illegal dumping (Tembon, 2012). The waste receptacle sizes provided by the municipality are too small which results in the containers becoming too full and overflowing causing accidental littering and dogs scavenging through the litter (Tembon, 2012).

During the collection of the waste, the collection personnel are sometimes guilty of accidentally littering when handling the waste due to refuse falling out of the truck, which causes aesthetic disturbances and pollution (Tembon, 2012). The recycling systems are underdeveloped as some of the municipalities do not have proper recycling facilities or programs (Tembon, 2012). There are for instance no separation bins provided to the public to sort their waste. This is mainly due to the municipality not having the resources to provide these additional bins. There are also quite a few towns and communities where no bins are provided, and the refuse trucks collect black plastic bags. This results in low recycling rates within the municipalities and the recyclable waste volumes that reach the landfills being high and increasing with population growth (Tembon, 2012).

The NEMWA act states that levies can be charged for waste collection services. However, a case study undertaken in the Ekurhuleni Municipality revealed that these fees are not properly enforced by the municipality as some residents within the formal areas only pay the fees at certain times while others do not pay at all (Tembon, 2012). In the informal settlements, the residents do not pay any waste collection tariffs (Tembon, 2012). This causes the financial resources for waste collection within the municipality to become limited and therefore challenging to collect all of the generated waste within the municipal boundaries (Tembon, 2012). There is also a lack of awareness within the waste management sector and a case study conducted within the Ekurhuleni Municipality by Tembon (2012) revealed that most of the community members do not know the basics of how to sort the waste in terms of the waste management process.

2.1.2.1.3 Lack of Corporative Governance

It is important that the municipality as well as other state organs promote the fundamental rights as stated under section 24 of the Constitution (Zhakata *et al.,* 2016). This means that waste collection services must be carried out sustainably and be compliant with Section 24(b)(i) of the Constitution, which requires measures to be enforced by the municipality and relevant organs of state that will reduce ecological degradation and pollution (Zhakata *et al.,* 2016).

Most of the challenges faced within the waste management sector are evidence of the lack of corporative governance between the different governmental spheres, as the local spheres are supposed to be supported by the national and provincial spheres in terms of waste disposal especially with certain types of waste, such as medical waste (Zhakata *et al.,* 2016).

An increase in cases of medical waste being illegally dumped have increased all over South Africa (Zhakata *et al.,* 2016). The illegal disposal of medical waste has been identified to have devastating impacts on the wellbeing and health of the community and is contradictory to Section 24 of the Constitution. Therefore, there is a call for the government to take action in ensuring that all measures are taken to ensure that such dangerous waste is properly disposed of (Zhakata *et al.,* 2016).

In terms of NEMWA, municipalities are expected to implement new ways in which waste can be minimised to ensure that there is no waste going to landfills. The municipalities, however, are not taking the necessary steps to ensure this and according to a study conducted by Luitel *et al.* (2008), most of the municipalities only focus on the collection and dumping of the waste without taking the required actions to try and minimise the waste generated (Tembon, 2012).

NEMWA has emphasized the fact that integrated waste management plans need to be developed by municipalities and included in the Integrated Development Plans (IDP's) (Tembon, 2012). In Gauteng, the waste generated per-capita is very high, causing the waste management sector of the province to be under pressure. These pressure sources have been recurring since the year 1998 (Tembon, 2012).

Unmaintained municipal parks are used by local communities for illegally disposing of their waste (Tembon, 2012). The existing landfill sites are also identified as being poorly maintained with no measures or monitoring being conducted (Tembon, 2012).

2.1.2.1.4 . Addressing the Challenges

There are several solutions suggested within the NWMS to address the waste problems faced within South Africa (Zhakata, *et al.,* 2016). These solutions, however, call for the civil society, the private sector, and government to work cooperatively to ensure the implementation of the waste hierarchy of reducing, recycling and reusing the waste (Zhakata, *et al.,* 2016).

These problems can only be resolved if all the sectors in society work together, especially as it was stated by the Centre for Environmental Management that the illegal dumping of waste is increasing (Zhakata *et al.,* 2016). An investigation undertaken in the Limpopo province revealed that the province was experiencing problems of illegal dumping at sites meant for different purposes such as development or public open spaces (Zhakata *et al.,* 2016). Tenders to remove and dispose of the waste were then awarded to companies by the Department of Health and Social Development (Zhakata *et al.,* 2016). This is an effective solution as the local government usually does not consist of the required manpower and resources to properly remove such waste.

Integrated Waste Management Plans (IWMP's), standards, regulations and legislation must be drafted by the government to ensure that the current existing waste laws are implemented and fulfilled (DEA, 2011). These plans and standards would therefore ensure that the general public and companies take charge in terms of waste management and that the gaps within the waste management Act are addressed (Zhakata *et al.,* 2016).

The Municipalities need to implement integrated waste management plans and produce an annual report on how they plan to dispose of and regulate the waste (Zhakata *et al.,* 2016). Since it is very expensive to dispose of certain waste, the government must provide new comprehensive ways to assist the waste disposal process (Zhakata *et al.,* 2016).

As revealed in the current waste management problems, it is clear that not enough is being done by the government with regards to waste management. The basic level of access to the waste services must be expanded time and again and ensure proper disposal of waste, at a licenced landfill site, if it cannot be recycled, reused or recovered (Zhakata *et al.,* 2016).

By implementing this goal, the inequality and historical backlog of access to waste services will be addressed and the community's quality of life will therefore be improved by providing a cleaner living and workplace (Zhakata *et al.,* 2016). More jobs will be created through the expanded provision of waste services which will increase the socio-economic growth of the area (Zhakata *et al.,* 2016). It is clear given the extent of littering that, across the different communities, there is an uneven awareness of waste management and the impacts of waste on the community's well-being, health and the environmental impact (Zhakata *et al.,* 2016). It is important that awareness is raised of all the problems with waste management and that the basic curriculum used within schools includes practical waste projects to educate the youth of these critical problems (Zhakata *et al.,* 2016).

Educational campaigns should be arranged as they might be the most effective measure in raising awareness of waste activities, anti-littering and insight to the extended waste services and available recycling infrastructure (Zhakata *et al.,* 2016). Such campaigns could be important to inform the people on how waste should be separated at their homes to be recycled (Zhakata *et al.,* 2016). Municipal campaigns can form the foundation of a plan to raise awareness of waste as these campaigns should be implemented and designed with the collaboration of NGOs, local stakeholders, including the industry, labour and civil society (Zhakata *et al.,* 2016). Long-term waste management awareness campaigns are planned by the DEA, which will be implemented incrementally and sustainably with the main goal of achieving changes in the behaviour of people (Zhakata *et al.,* 2016).

There should be a trade-off available to industries on the long- and short-term between protecting the environment and recycling, re-using and recovery of materials (Zhakata *et al.,* 2016). For such a trade-off to be implemented and achieved in South Africa, the criteria for the 'End-of-Waste' needs to be re-evaluated and re-considered in terms of getting a clearer indication of what constitutes waste as well as establish a better clear defined definition of "waste" (Zhakata *et al.,* 2016). This process of re-evaluation should be done through a public participation process whereby all the relevant stakeholders are invited (Zhakata *et al.,* 2016). It is also important to note that although a comprehensive legal framework is provided through the Waste Act to manage waste, its conditions will be pointless if there are no measures taken to monitor and when required, enforce compliance (Zhakata *et al.,* 2016).

This cannot be done by government alone, civil society and businesses also play an important role in reporting cases of non-compliance and establishing a society of compliance (Zhakata *et al.,* 2016). Compliance should be monitored by the government through the use of the Waste Act, as well as published regulations with regards to the Act, integrated waste management plans, licences, and waste management plans of industries (Zhakata *et al.,* 2016). A study undertaken by CSIR (2011), investigated waste management within the municipalities of South Africa and found some municipalities offering improved services of waste management. Findings from the study indicated that the City of Johannesburg offered black refuse bags to informal settlement households to contain their waste (CSIR, 2011).

A budget is allocated through the SA Treasury for municipalities to implement such waste management measures within the informal residential sector (CSIR, 2011). According to the CSIR (2011), the informal settlements within the Johannesburg Municipality are cleaned daily by the municipality and a closed landfill site is currently in the process of being transformed into a drop-off centre for waste. The United Nations Environment Programme (UNEP, 2009), focuses on helping developing countries to rather use practices and policies that are environmentally sound, as "prevention is better than cure" (Tembon, 2012).

It is stated in the NEMWA document that for waste management, an IWMP is crucial and that Municipalities must apply an integrated approach to managing waste (Tembon, 2012). The use of an integrated approach to waste management can only be successful if the involved relevant stakeholders have been educated in the correct manner and benefits of implementing this approach (Tembon, 2012). It is the responsibility of each citizen within South Africa to manage their waste sustainably, to reduce their amount of waste produced, and to improve on measures of recycling and re-using of their waste and therefore reduce the use and impact of the natural resources (Tembon, 2012). According to Tembon (2012), many people have described waste to be a ticking bomb in South Arica. In the North-West province, the airspace currently available will soon likely reach its limits at the current rates of waste generation (Tembon, 2012). With the ever-increasing cost of waste removal services as well as the struggle in securing space for waste disposal, opportunities should be considered to transform waste into a resource and it should be implemented in a coordinated approach by the authorities and the main stakeholders (Tembon, 2012).

The hierarchy of waste management is supported by the NWMS and it plays an important role in the Government policy to ensure that the environment is protected (Tembon, 2012). In 2008, the first generation of the Provincial Integrated Waste Management Plan (PIWMP) was developed. The second-generation focus on the gaps, priorities the changes in the profile of waste management as well as the activities currently taking place within the North-West province (Tembon, 2012). The amended legislative framework is also addressed in this second generation as well as the new legislative requirements (Tembon, 2012). The development and implementation of the PIWMP were mainly to ensure that the province is in line with the plan and that the necessary resources are efficiently allocated to ensure effective management of the waste (Tembon, 2012).

2.1.3 **Water resources**

2.1.3.1 **Worldwide**

The most important and abundant resource on Earth is water, extensively covering over 70% of the Earth’s surface (Hossain, 2015). Water is vital for all living forms on Earth and is the only natural substance commonly present in all three of its different forms of matter (solid, liquid, and gas) (Hossain, 2015). Without water, there would be no life.

According to the World Health Organization (WHO) (2010), a person requires 50-100 litres of water every day, to meet their basic human needs which includes preparing food and personal hygiene (Ramulongo *et al.,* 2017). The volume of water required by industries to manufacture goods and generate electricity and for the transportation of goods and people is much more (Hossain, 2015).

Research has revealed that the volume of water required for the production of one egg is approximately 454 litres, 98 litres for one ear of corn, 9,4 litres of water for a pound (0.45 kg) of beef, 1,136 litres of water for one loaf of bread and approximately 45,425 litres of water for 60 pounds (27.22 kg) of wheat (Hossain, 2015). Humans also make use of water for recreational activities such as swimming, sailing, fishing, boating, canoeing, rafting as well as many other water dependant activities (Hossain, 2015). Over the last decades, there has been an improvement almost all over the world in the provision of safe drinking water for humans, however, there is still approximately 768 million people internationally that do not have access to save drinking water of which 80% reside in rural community areas (WHO and UNICEF, 2013). According to Hall *et al.* (2014), poor access to water is linked to various water-related diseases and poor school attendance.

According to Hossain (2015), there is a strong correlation between "access to safe water and gross domestic product per capita". It is estimated that by 2025 the water use sectors (industrial, domestic and agriculture) would have increased their water use by at least 50 percent (Rosegrant *et al.,* 2002). According to Hossain (2015), a report was issued in November 2009 which stated that in some of the world's developing countries, the water demand will exceed the rate of supply by the year 2030 by 50%. The world's economy is strongly influenced and dependant on the water as water plays an important role in the manufacturing everything produced (Cosgrove and Loucks, 2015).

The world's available water resources are constantly under pressure and reduced through natural forces (evapotranspiration, weathering of rocks, leaching from soil and many more) and anthropogenic activities (landscape changes, deforestation, irrigation and agricultural activities, water extractions) (Hossain, 2015). Over the last decade, there has been an increase in public awareness on safeguarding water resources, however, water policy still tends to be driven at all levels by political considerations and economic criteria (Hossain, 2015). Best practice and science is rarely given enough consideration (Hossain, 2015).

If the water resources of a country are used unsustainably and the quality of the water is in a poor condition then the economic development will be limited and the people's livelihoods and health will be affected (Hossain, 2015). The rising water demand was usually addressed by measures such as using reservoirs to store surface water, extracting groundwater, and changing the flow patterns of rivers to reach drier regions (Hossain, 2015). However, these measures have been increasingly supported by methods such as desalination, reuse of water and the harvesting of rainfall (Hossain, 2015). There is immense pressure placed on the worlds' water resources and a great need for more reliable water data of the quantity and quality available as well as the variabilities that occur geographically and over time (Hossain, 2015).

According to the Global Water Partnership (GWP) (2010), water is strongly linked to food security, economic growth, reduction in poverty, human health and energy production among others. It is important to have access to clean safe water daily to meet the basic needs (drinking, bathing, and washing as well as the other required domestic water uses) of humans (Hall *et al*., 2014). Water is especially crucial in rural areas as the people's livelihood activities are dependent on it, for the making of bricks, horticulture, livestock farming, irrigation, and commercial small-scale activities (Hall *et al*., 2014). Through these activities, a family can increase its food security and income (Hall *et al*., 2014).

2.1.3.2 **Water resources within South-Africa**

According to the economic and population growth forecast, it is predicted that South Africa could, by 2030, have a 17% gap between the demand and supply of water (Reddick and Kruger, 2019). Not all the provinces will be affected equally, the main industrial areas are expected to have severe shortages, such as KwaZulu-Natal, Mpumalanga, Gauteng, and the Western Cape (Reddick and Kruger, 2019). In South Africa, water scarcity is the main concern that also represents a significant opportunity for businesses and investors within the water sector (Reddick and Kruger, 2019).

In 2017, the World Economic Forum (WEF) ranked the “water crises” challenge in South Africa as the third highest risk for conducting business, and it is globally also ranked as one of the highest risks according to WEF (2017). According to Luo *et al.* (2015), South Africa is an extremely water-stressed country and is ranked globally as the 30th driest country in the world. The country’s water scarcity can be attributed to severe climate as well as variations in rainfall (Luo *et al.,* 2015).

According to the Department of Water and Sanitation (DWS) (2017), it is estimated that over the next 10 years an approximately R90 billion is required each year for investments in water and sanitation infrastructure to address the water scarcity challenge in South Africa and provide the people, industries and businesses with reliable sources of water and sanitation (Reddick and Kruger, 2019). This includes upgrading and refurbishing of the current infrastructure and installation of new infrastructure that will be able to support the growth of the economy and population (Reddick and Kruger, 2019).

The water resources (inclusive of surface water and groundwater) are regulated and protected under the National Water Act, Act No 36 of 1998 (NWA) and ownership to the water has been effectively transferred to the state. The main authority in South Africa responsible for regulating of water is the DWS (Reddick and Kruger, 2019), which has recently been renamed to Department of Human Settlements Water and Sanitation (DHSWS) to include the human settlements sector.

In South Africa, water is possibly the most valuable natural resource (Pitman, 2011). South Africa’s climate can be described as semi-arid with a yearly rainfall average of 465 mm, which is low compared to the 860 mm world average (Pitman, 2011). The mean annual runoff (MAR) is approximately 50 x 109 m^3 for South Africa (including Swaziland and Lesotho) which comprises of only 50% of the Zambezi River’s average flow and only 3% of the flow of the Congo River (Pitman, 2011). Even though South Africa is characterised as being a water-scarce country, the water consumption level for South Africa is approximately 233 litres/capita/day (l/c/d), which is much higher than the consumption benchmark globally, which is about 180 l/c/d (DWS, 2017). According to the DWS (2017), the yield (i.e. supply received from current infrastructure) of South Africa is reliable at approximately 15 billion kl/year (with a 98% supply assurance or a 2% failure of supply probability each year) of which the surface water resources (68%) and the supporting return flows (13%) contribute the most.

In South Africa, the largest sector of water use is agriculture (62%), with the municipalities being the second largest (27%) and includes industrial, residential and commercial users whom the municipalities supply (DWS, 2017). Water is at the core of sustainable development and is crucial for human survival, healthy ecosystems and socio-economic development (Yildiz, 2017). It is therefore important that this valuable resource is effectively managed for sustainable development and growth (Yildiz, 2017).

2.1.4 The use of bioindicators to determine the quality of the water resources

Traditionally, water quality has been monitored through the use of physicochemical analysis, however, the use of biomonitoring dates back to the 20th century in Europe (Cairns and Pratt, 1993). Although the physicochemical analysis is very accurate, the results only indicate the conditions of the water when the sampling was conducted (Matlala, 2010). There are so many pollutants that might be present in the water which could cause this analysis to become very time consuming and expensive (Matlala, 2010). There is no standard method available that screen for the possible occurrence of all pollutants and therefore several tests need to be conducted to determine the pollutants present (Matlala, 2010). According to the Department of Water Affairs and Forestry (DWAF) (1996), some of the most toxic substances are identified to occur in water resources in such minute quantities, that even the most advanced analytical techniques are not able to detect them as they are often below the limits of detection.

For these reasons, the Water Research Commission (WRC), DWAF and the Department of Environmental Affairs and Tourism (DEAT) developed the National Biomonitoring Programme for Aquatic Ecosystems (NBPAE) in 1996 (Matlala, 2010). Through the NBPAE, biological indicators are included in determining the health and ecological state of aquatic ecosystems and these include indicators such as riparian vegetation, fish- and aquatic invertebrate communities (Kleynhans, 1999). The purpose of the programme was to develop a program in which the health of all the different aquatic ecosystems will be monitored all over the country, to provide a database that can be used to better manage the aquatic ecosystems and water resources (Matlala, 2010). This biological approach had the main advantage as it analyses organisms (i.e. aquatic macro-invertebrates and fish) which are continuously exposed to water as well as the pollutants that enter these water resources, and therefore reflect the direct impacts (short- and long-term) that these pollutants have on the ecosystems, which might have been overlooked through physicochemical analyses (Pan *et al.,* 1996; De la Rey *et al.,* 2004). In 2016 the NBPAE was replaced with the program known as the National Aquatic Ecosystem Health Monitoring Programme (NAEHMP).

The approach used in these programs is based on the fact that after disturbances (human impacts, animal impact or pollutants) impact the water resources, the community structure is influenced and changed, which is the result of the competitive selection of the most tolerant species (Li *et al.,* 2010). The tolerance and sensitivity of indicator assemblages to different environmental attributes, for instance, metals, organic pollution, eutrophication, pH and pesticides are known to be different between the species, as some are more tolerant or sensitive compared to other species (Li *et al.,* 2010). Therefore, biomonitoring is based on the physiological and behavioural response of the organisms to the water quality variables in their specific environment over a short and long term (Matlala, 2010). The river health programme (RHP) makes use of the biological communities (e.g. invertebrates, fish and vegetation) instream and on the riparian edge to monitor the response of these organisms to disturbances that take place within their environment (DWAF, 2008). The reason for this is because the health of these organisms is a direct reflection of the river ecosystem in which they live and therefore can also be used as a measure of the river's health as a whole over a period of time (DWAF, 2008). In 2016 the River Eco-status Monitoring Programme (REMP) replaced the RHP and is a component of the NAEHMP (DWAF 2016).

According to Dallas (2005), fish are useful long-term bioindicators on the ecological state of the aquatic ecosystem as they are mobile and long-lived (several years), whereas macro-invertebrates are good short-term indicators of disturbances on the aquatic ecosystem due to their shorter life span. The life cycles for the different aquatic macroinvertebrates differ depending on the taxa, for instance, multivoltine and bivoltine have life cycles of half a year or less (blackflies, midges and mayflies), univoltine have life cycles of one year (stoneflies, caddisflies and mayflies) while semivoltine have lifecycles of more than one year (crabs, mussels and dragonflies) (Teels, 2002).

When aquatic invertebrate communities are used as a bioindicator for determining the integrity of an aquatic ecosystem, indices such as the Invertebrate Habitat Assessment System (IHAS), Macro-Invertebrate Response Assessment Index (MIRAI), and the South African Scoring System (SASS) are used (Matlala, 2010). When analysing the integrity of an aquatic ecosystem through use of the fish community the Fish Response Assessment Index (FRAI) and the Fish Assemblage Integrity Index (FAII) indices are normally used (Matlala, 2010). The health or integrity of aquatic ecosystems is also based on the riparian vegetation. This is completed by monitoring the functional and structural changes of the vegetation through the use of the Vegetation Response Assessment Index (VEGRAI) (Dallas, 2005). The important factor in using aquatic organisms as indicators to the changes in the condition of the aquatic ecosystem is understanding the integrated information between the environment and species assemblages of that environment (Pan *et al.*, 1996).

Due to the shortcomings identified within the physicochemical assessments, the use of biomonitoring techniques in aquatic ecosystems has increased in the health management programmes (De la Rey *et al.,* 2004). The use of fish and macroinvertebrates as bioindicators can become limited in heavily impacted systems as these species become sensitive and absent in these conditions, whereas diatoms occur in a wider variety of waters of almost any condition (Potapova and Charles, 2007). The use of diatoms in aquatic health assessments has increased due to the major improvements in the diatom assessment technologies and the limitations associated with bioindicators such as macroinvertebrates and fish (Potapova and Charles, 2007).

2.1.4.1 **The use of diatoms as a bioindicator**

In South Africa, Cholnoky, Archibald and Schoeman were the first, in the early 1950s to the late 1980s, to study the use of diatoms as bioindicators to determine water quality; along with many other species identified throughout the rivers of South Africa (Taylor, 2004). Diatoms have thereafter been extensively studied throughout South African rivers, with the intent of establishing a diatom index that could, as an addition, be incorporated into the NBPAE with the other established biomonitoring techniques (DWAF, 2008).

Diatoms form part of the microphytobenthos as one of its major components and is present in the aquatic ecosystem as one of the primary producers in the food web (Dalu *et al*., 2014) According to Round *et al.* (2007), diatoms fall within the *Bacillariophyceae* class and consist of a ubiquitous, highly distinctive and successful group of unicellular algae, with their siliceous cell walls being their most distinguishing characteristic (Dalu and Froneman, 2016). Diatoms are found in the shallow aquatic habitats attached to submerged surfaces that receive sufficient light penetration (Matlala, 2010). Diatoms are the most used bioindicators to detect the physicochemical and integrity conditions of the aquatic ecosystems due to their rapid growth rate, their extensive dispersal rate and because they respond rapidly to changes within their environment due to their short life span (approximately 2 weeks) (Kwandrans *et al.,* 1998; Stevenson *et al.,* 2002).

Diatom communities respond rapidly and very specifically to any changes that occur in their environment, such as organic enrichment, eutrophication, salinization and especially changes within the pH as diatoms are very sensitive indicators to pH fluctuations (Battarbee *et al*., 1997; Rott *et al.,* 1998). Their short life span makes them useful indicators in experiments for manipulating the environmental conditions to identify the cause-effect relationship between the different environmental stressors and the response that the diatoms communities have to each stressor (Stevenson *et al.,* 2002).

Diatoms are primary producers and can be found in all aquatic ecosystems and they actively incorporate the different components and nutrients of water quality (Morales *et al.,* 2001). The use of diatoms as a bioindicator within the biomonitoring methods has also been facilitated through the designing of software programmes in which the diatom indices are calculated (Matlala, 2010). One of the programs that have been designed to calculate the diatom indices is the OMNIDIA program (Lecointe *et al.,* 1993). Diatoms have more recently been used across the African continent to access the environmental change as well as water quality for short- and long-term periods (De la Rey *et al.,* 2004; Taylor *et al.,* 2007b; De la Rey *et al.,* 2008; Bere and Tundisi, 2011).

The sampling of diatoms is very easy and cost-effective. They can be sampled from natural submerged surfaces, such as stones, sediments and marginal vegetation, as well as from artificial substrates present within the aquatic ecosystem (De la Rey *et al.,* 2004; Taylor *et al.,* 2007a; Bere and Tundisi, 2011; Dalu and Froneman, 2014; Dalu *et al.,* 2014). The benefits of using diatoms as a bioindicator in biomonitoring programs include it being cost-effective, the collection of the data is rapid and accurate, and non-specialist with a biological background can, with the help of illustration guides, carry out the diatom identifications and counts (De la Rey *et al.,* 2004; Round *et al.,* 2007).

According to Hirst *et al.* (2004) and Lacoursière *et al.* (2011), using artificial substrates has played an important role in the formulation of the stress-response models for diatoms. These models directly monitor the response of the microorganisms to the stresses (for instance nutrient deficiency or other environmental stressors) within their environments (Shi *et al.,* 2013). Microorganisms have protective response mechanisms that they use to survive when exposed to adverse conditions (Shi *et al.,* 2013).

The current legislation within many of the African countries (e.g. South Africa, Zambia, Botswana, Zimbabwe Kenya) governing the management of water resources requires that the health of the aquatic ecosystem and rivers be assessed to determine what the environmental impacts of new developments would be and also to provide strategies for water consumption (Harding *et al.,* 2004). This diatom-biomonitoring approach has been included in South Africa's national river health programme and is part of the NAEHMP (DWS, 2016).

During this study, diatoms were used as a bioindicator to assess whether the illegal dumping within Ikageng and Promosa area has an impact on the water quality of the aquatic ecosystems that the community depends on. According to Ololade *et al*. (2019), the leachate of solid waste dumping sites can cause the surface water and groundwater quality to be negatively impacted and cause severe consequences for ecosystem and human health. It has been identified that leachate from poor SW disposal contaminate the ground- and surface water resources as it increases metals, nutrients, organic contaminants, and pathogens of the affected waters (Khatri and Tyagi, 2015). Diatoms are sensitive to changes within their environment, and after disturbances (human impacts, animal impact or pollutants) impact the water resources, the community structure is influenced and changed, which is the result of the competitive selection of the most tolerant species (Li *et al.,* 2010).

According to Battarbee *et al*. (1997) and Rott *et al.* (1998), the diatom communities respond rapidly and very specifically to any changes such as organic enrichment, eutrophication, salinization and especially pH which will be altered when disturbances causes the water quality to be impacted. The sensitive diatom species would be the first to die-off while the more tolerant diatom species would be able to survive and become more dominant within the system (Battarbee *et al.,* 1997; Rott *et al.,* 1998; Martín and de los Reyes Fernández, 2012). Therefore, the dominant diatom species can be used to interpret the short-term changes in their environment. As the leachate from the solid waste causes the water quality to be impacted, the dominant diatom species would be those species usually present in surface water that is impacted and consists of poor water.

Chapter 3 RESEARCH AREA IN GENERAL

The study was conducted in two suburbs of Potchefstroom in the North-West Province of South Africa. According to Bezuidenhout *et al.* (2011), the North-West Province (NWP) is known as the platinum province because of the underground metal wealth that it contains. It is the fourth-smallest province in the country, comprising of only 8.7% of the country's surface area and a population of 3.4 million people (Bezuidenhout *et al.,* 2011). The population of the NWP is predominantly rural, however, there is an urban population situated in the bigger cities and towns such as Potchefstroom, Rustenburg, Klerksdorp, Brits, Vryburg, Lichtenburg and the capital, Mafikeng (Bezuidenhout *et al.,* 2011).
The province's rainfall is unevenly spread with the eastern regions receiving more rainfall than the western regions (Bezuidenhout *et al.,* 2011). Both the surface and groundwater sources of the province is utilised by activities such as mining (chrome, platinum and gold), agriculture, and domestic use (Bezuidenhout *et al.,* 2011). The surface waters of the province are mainly non-perennial and comprise inland pans, lakes and rivers (Bezuidenhout *et al.,* 2011).

Information sources available for the NWP indicates that majority of the province's water quality is classified in a poor ecological state and may be deteriorating further (NWP-SOER, 2002; Van der Walt *et al.,* 2002; Kalule-Sabiti and Heath, 2008; Kwenamore and Bezuidenhout, 2008). Mining activities, agricultural activities, poor sanitation practices and other anthropogenic activities are the main areas contributing to the pollution (nitrates, metals, microbiological and elevated organic substances) of the province's water resources (Van der Walt *et al.,* 2002; Kalule-Sabiti and Heath, 2008).

Most of the poorer communities of the province living in the rural areas do not have the financial funds to contribute to the local management agencies and only have access to poorer water quality while treated drinking water is provided to the residents within the major towns and cities of the province, such as Potchefstroom (Kalule-Sabiti and Heath, 2008).

The potable water for Potchefstroom is obtained from groundwater and surface water resources situated in the Mooi River Catchment (Annandale and Nealer, 2011). Water from the catchment area is collected in Boskop Dam where it is stored and then released into an open-on-top cement canal and transported on a 12 km route to Potchefstroom's water purification works (Annandale and Nealer, 2011). The Mooi River flows from Boskop Dam to Potchefstroom Dam and the surface water is influenced by various anthropogenic activities located along the river, which includes agricultural activities and effluents from the industrial, urban and informal settlement areas (Pelser, 2015; Koekemoer, 2019). The population of

Potchefstroom consists of 162,762 people (StatsSA, 2011) and the city supports a university as well as several large industries such as a South African Breweries depot, Nestlé, several fertilizing manufacturers and an abattoir (Pelser, 2015).

The Promosa and Ikageng semi-informal and informal settlements contribute to stormwater and urban runoff, and sewage entering the Wasgoed Spruit tributary which causes the ammonia concentrations in the system to increase (Koekemoer, 2019). The Wasgoed Spruit is a canalised tributary of the Mooi River that is influenced by the industrial effluent from these industries mentioned above (Pelser, 2015). All the storm and urban water runoff flow directly into the Mooi River without being treated (Pelser, 2015). The city's wastewater treatment works are located on the southern edge of the city and from there the treated sewerage is released back into the Mooi River (Pelser, 2015). Potchefstroom experiences a mean annual rainfall of 620 mm with heavy rainfall in the summer months that may cause the wastewater treatment plant to overflow and cause the semi treated and raw untreated sewage to overflow into the Mooi River (Pelser, 2015). Just downstream of Potchefstroom, the Mooi River is joined by a large tributary known as the Loopspruit, which is mainly used for crop irrigation by the surrounding community as well as drinking water for livestock (Pelser, 2015). Three main pollution sources are located along the Loopspruit, which include the Kokosi informal settlement and two gold mines (van der Walt *et al.,* 2002). This has resulted in elevated nutrient levels within the river which has been identified to move from the Loopspruit into the Mooi River (van der Walt *et al.,* 2002).

Potchefstroom supports a large industrial area, and there are several semi-formal and informal community areas such as Promosa and Ikageng that surrounds the town (Koekemoer, 2019). The activities within the Promosa and Ikageng communities do contribute to polluting the river ecosystem and was therefore chosen for the study (Koekemoer, 2019). The Mooi River is characterised by its dolomitic lithology (Labuschagne, 2017). The Mooi River is also directly impacted by the Poortjie Dam and Spitskop Spruit as these water sources contribute to the stream of Wasgoed Spruit (Koekemoer, 2019). The Spitskop Spruit stream drains the north-western section of Ikageng (Koekemoer, 2019). Poortjie Dam which is located just downstream of Spitskop Spruit (Wyma, 2012) is regularly identified to be polluted by sewage as a result of pump stations that are blocked (Nel, 2011). This causes the dam to regularly experience serious blooms of cyanobacteria which could potentially be toxic (Koekemoer, 2019).

3.1 Study Area

The study areas selected for the present study include the rural suburbs of Ikageng and Promosa near Potchefstroom which falls within the JB Marks Local Municipality and the quaternary catchment C23H and C23L.

The geology identified within the quaternary catchments includes geology from the Ventersdorp, Transvaal and Witwatersrand Supergroup (Daemane *et al.,* 2010). The geology within the supergroups includes dolomite, subordinate chert, chert, carbonaceous shale, subequal shale, shale limestone, quartzite, tuff rocks, conglomerate, mudrock, diamictite, andesitic lava, subordinate pyroclastic rocks, alluvium and diabase andesitic lava (Manzi *et al.,* 2013).

The Ikageng and Promosa areas are poorer communities that live in poor conditions where not all of the residents have access to basic services (Taruza, 2016). Some of the residents in Ikageng do not have direct access to water or access to a stand pipe within 200 m from their house which according to the handbook of the Council for Scientific and Industrial Research (CSIR) is the prescribed maximum distance requirement (Taruza, 2016). For this reason, some of the children and women need to walk far distances to fetch the required water for their daily needs (Taruza, 2016). According to Taruza (2016), the water collected from the stand pipes is not necessarily access to adequate and improved water and the residents often need to stand in long queues at the communal stand pipes to be able to get water.

The study was conducted to determine the water quality of the natural water resources that the community are exposed to and when necessary, makes use of. Eight sampling sites were selected for the study. These sites were located along the drainage lines/streams and dams of the selected areas and all of them feed into the Mooi River system. The study sites were selected as they are representative of the area and the water resources of the area. The location of each sampling site is shown in Figure 3-1 below and a detailed description of each sampling site is discussed in the section below with a summary of each site in Table 2-1.

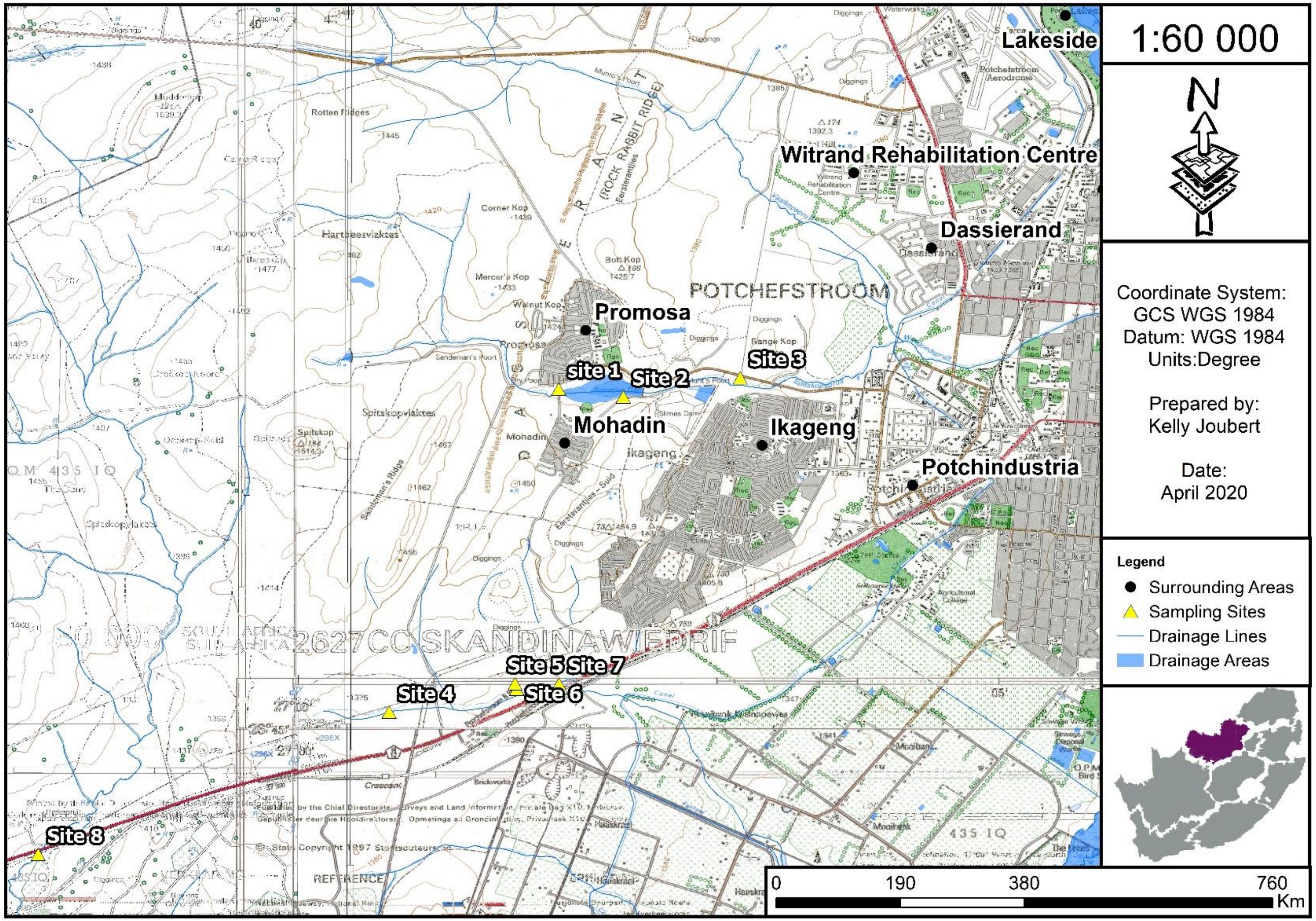

Figure 3-1. A topographic map showing the locations of the sampling sites which were chosen for this study as well as the areas surrounding these sampling sites.

3.1.1 **Sampling sites**

The different sites described below were selected as they are representative of the study area, their ease of accessibility and the presence of illegal dumping at these sites. Eight sampling sites were selected, of which sites 1-7 were subject to illegal dumping. There were no pollutants observed leading to and at Site 8. Therefore, Site 8 was chosen to see if the system recovers when there are no impacts and whether the influence of illegal dumping decreases when there is no illegal dumping for approximately 21 km. The GPS coordinates, environmental setting (disturbed, natural, instream habitat characteristics), and any surrounding anthropogenic disturbances that could impact the water quality was captured for each site at the time of sampling.

3.1.1.1 **Site 1**

Site 1 is located in Promosa just 50 m upstream of Poortjie Dam, on the eastern side of the gravel road known as Robert Avenue where the water flows through a culvert underneath the bridge of the street and flows into Poortjie Dam. This system is known as the Spitskopspruit which flows into Poortjie Dam on the west. This site was chosen as a sampling site to determine the quality of the water that is flowing into Poortjie Dam. The inflowing water at the site had a brown cloudy colouration, which could be a result of the reddish underlying soil as can be seen in Figure 3-2 (A). Factors identified on-site that may influence the water quality was litter found to be dumped and accumulated in the water channel, as well an illegal dumping site located along the stream just upstream of the sampling point (Figure 3-2(B)).

A) **B)**

Figure 3-2. A photo of the stream at sampling Site 1 in which the water and diatom samples were collected (A). A photo of one the illegal dumping sites located just upstream of the sampling point at sampling Site 1(B).

3.1.1.2 **Site 2**

The site is located in Ikageng at Poortjie Dam with the sample for the site collected near the south-eastern edge of the dam (Figure 3-3 (A)). The dam is used by the surrounding communities as a recreational area for fishing or relaxing with friends and family. During sampling at the site, the water of Poortjie Dam was clear to light brown. There were no visible pollution factors at the sampling site itself, however, there were scattered heaps of waste found to be illegally dumped near the drainage channels that flow into Poortjie Dam (Figure 3-3 (B)), and some of these channels were filled with litter form runoff from these dumping sites.

A) **B)**

Figure 3-3. A photo of sampling Site 2 at Poortjie Dam at which the sampling took place (A) and a photo of one of the drainage lines upstream draining into Poortjie Dam (B).

3.1.1.3 **Site 3**

Site 3 (Figure 3-4) is located at a point along the Spitskopspruit in Ikageng approximately 1.18 km downstream of Poortjie Dam. The water at the site had a milky brown colouration with an unbearable stench. Some of the impacts observed at the site include the presence of building rubble and litter that was illegally dumped and scattered along the stream. The unbearable stench also made it clear that there was raw sewerage from the surrounding communities flowing into this stream.

Just upstream of Site 3 is the Kynoch Gypsum Tailings Dump of the Kynoch Fertilizer Factory which has been identified as the single biggest threat in the area when it comes to the formation of sinkholes (Smit, 2017). During a study conducted by Smit (2017), the seepage from the sides of the tailings were measured and resulted in an extremely low pH of 1.8 which could cause the underlying dolomite to dissolve and cause the formation of sinkholes. The presence of this tailings facility just upstream of Site 3 should also be considered when interpreting the water quality results measured for the site, as it could influence the water quality of the stream.

Figure 3-4. A photo of sampling Site 3 along the Spitskopspruit stream.

3.1.1.4 **Site 4**

This sampling site is located next to a bridge at Kopanong Street in Ikageng just 500 m north from the N12 highway. The water of this stream was identified to be a milky brown colour. The impacts observed at the site were on the south-western side of the bridge as there was a large illegal dumping site, where the surrounding community has been dumping all of their waste, as can be seen in Figure 3-5. Other impacts that will influence the water quality at the site include the surface runoff from the bridge and surrounding community area.

A) B)

Figure 3-5. Sampling site 4 and the illegal dumping that has taken place over the years along the bridge (A) and at the edge of the stream (B).

3.1.1.5 **Site 5**

Site 5 (Figure 3-6) is located at the beginning of a stream near Mokwepa Street in Ikageng, just 260 m north from the N12 highway. The samples were taken in the stream just downstream from the culvert. The water was identified to be milky brown. The pollution factors observed were illegal dumping from the surrounding community that has been dumped along the houses and within the streets which enters the surrounding water resources through surface run-off.

Figure 3-6. A photo of where the sampling for Site 5 took place.

3.1.1.6 **Site 6**

Site 6 is (Figure 3-7) located approximately 30 m downstream of Site 5 just 180 m north from the N12 highway. The water was also identified to be milky brown and the pollution factors observed was the overflowing manhole (Figure 3-7 (B)) just upstream of the sampling site that was spilling dark brown to black wastewater into the channel. Illegal dumping from the surrounding community was observed at the site that has been dumped along the houses and within the streets which enters the surrounding water resources through surface run-off.

(A) **(B)**

Figure 3-7. A photo of the sampling site (A) where the sampling was undertaken for Site 6 and a photo (B) of the overflowing manhole that is contaminating the water in the stream.

3.1.1.7 **Site 7**

Site 7 (Figure 3-8) is located at the eastern side of the bridge of Sisulu Street just before turning left onto the N12 highway. The surrounding land uses include community houses and small-scale agricultural activities. The water of this site is milky brown. The impacts observed at the site include illegal dumping along the side of the bridge as well as within the drainage lines that drain into this stream. There was also the discharge of wastewater into the stream, near the houses just upstream of the site, which could potentially impact the quality of the water in the stream.

A)

B)

Figure 3-8. A photo of Site 7 where the sampling took place at the bridge of Sisulu Street (A) and a photo of the wastewater upstream that the surrounding community is discharging into the stream (B).

3.1.1.8 **Site 8**

Site 8 (Figure 3-9) is located just 21.1 km South-West of Ikageng, at the bridge along the highway (N12). There were no pollutants observed leading to and at the site. This site was chosen as a reference site as the site is located far from any residential areas with no signs of anthropogenic activities such as illegal dumping observed at or near the site. This site was therefore selected to serve as a good reference site to determine the anthropogenic impacts at the other sites and the effect of the illegal dumping on the water quality of those sites impacted.

Figure 3-9. A photo of reference site (Site 8) at which the sampling took place.

At each of the eight sites, water and diatom samples were collected during the late summer rainfall month (15 to 16 February 2019). A summary of the site attributes of the different sites is detailed in Table 3-1 below.

Table 3-1 A summary of the attributes of each sampling site

Site name	Description	Possible sources of pollution observed	Co-ordinates	Elevation
Site 1	Located approximately 50 m upstream of Poortjie Dam in Spitskopspruit on the eastern side of the gravel road known as Robert Avenue.	• Illegal dumping.	26°42'37.10"S 27° 1'51.50"E	1386 m
Site 2	Located at Poortjie Dam near the south-	• Drainage channels containing surface run-off and litter from the illegal	26°42'40.40"S 27° 2'19.00"E	1385 m

Site name	Description	Possible sources of pollution observed	Co-ordinates	Elevation
	eastern edge of the Dam just 22 m north from Sooliman Street.	dumping sites upstream.		
Site 3	Located along the Spitskopspruit approximately 1.18 km downstream from Poortjie Dam, just 9 m south from Promosa Road.	• Dumping of building rubble and litter • Sewerage discharge • Kynoch Gypsum Tailings Dump	26°42'32.30"S 27° 3'8.70"E	1367 m
Site 4	Located underneath the bridge of Kopanong Street in Ikageng just 500 m north from the N12 highway.	• Illegal dumping. • Surface run-off from the surrounding areas	26°44'54.62"S 27° 0'39.35"E	1372 m
Site 5	Located at the culvert near Mokwepa street just 260 m north from the N12.	• Illegal dumping. • Surface water run-off	26°44'42.50"S 27° 1'32.90"E	1361 m
Site 6	Located approximately 30 m downstream of Site 5 just 180 m	• Overflowing manhole that is spilling wastewater into the channel. • Illegal dumping • Surface run-off from the	26°44'44.80"S 27° 1'33.60"E	1361 m

Site name	Description	Possible sources of pollution observed	Co-ordinates	Elevation
	north from the N12 highway.	surrounding areas.		
Site 7	Located at the eastern side of the bridge of Sisulu Street just before turning left onto the N12 highway	• Illegal dumping • Discharge of wastewater upstream	26°44'42.66"S 27° 1'51.63"E	1360 m
Site 8	Located just 21.1 km South-West of Ikageng, at the bridge along the highway (N12). This site was chosen to be used as a reference site.	• No sources of pollution observed leading to and at the site	26°45'55.13"S 26°58'10.08"E	1362 m

Figure 3-10 indicates the locations of the different sampling sites within the Ikageng and Promosa area as well as the illegal dumping identified near the sites. From the map in Figure 3-10 it can be seen that there are three different river systems at which the sampling took place. Sites 1 - 3 form part of the same river system as the water from Site 1 flows through the sampling sites at sites 2 and 3 while the water at sites 4 – 7 form part of a different river system where the water at sampling Site 4 flows through sampling sites 6 - 7. Sampling Site 5 forms part of a small tributary that flows into the river system at Site 6. There is however another tributary that connects to the river system after sampling site 4 and just before sites 5 - 7.

Sampling Site 8, which was used as a reference site, forms part of a different river system and is not linked to the two systems mentioned above. There are numerous illegal dumping sites located around sampling sites 1 – 7 as well as along the drainage lines that drain into these river systems, which ultimately impacts the water quality of these river systems.

These dumping sites differ in size and composition as anything and everything unwanted by the surrounding community is dumped at these sites. Some of the most common items observed at these dumping sites included solid waste such as all sorts of plastic waste, empty dirty containers from cleaning products, food products (canned food, glass and plastic bottles and plastic containers) and household products, used disposable diapers, building rubble, pieces of old torn clothing, used clothes and broken shoes, cardboard boxes, rubber from broken tyres, old batteries, and old food items. The most dominant item observed at these sites was plastic waste. There were no visible illegal dumping sites or other pollutants observed at Site 8, except for a highway close by, and the site runs through no urban areas.

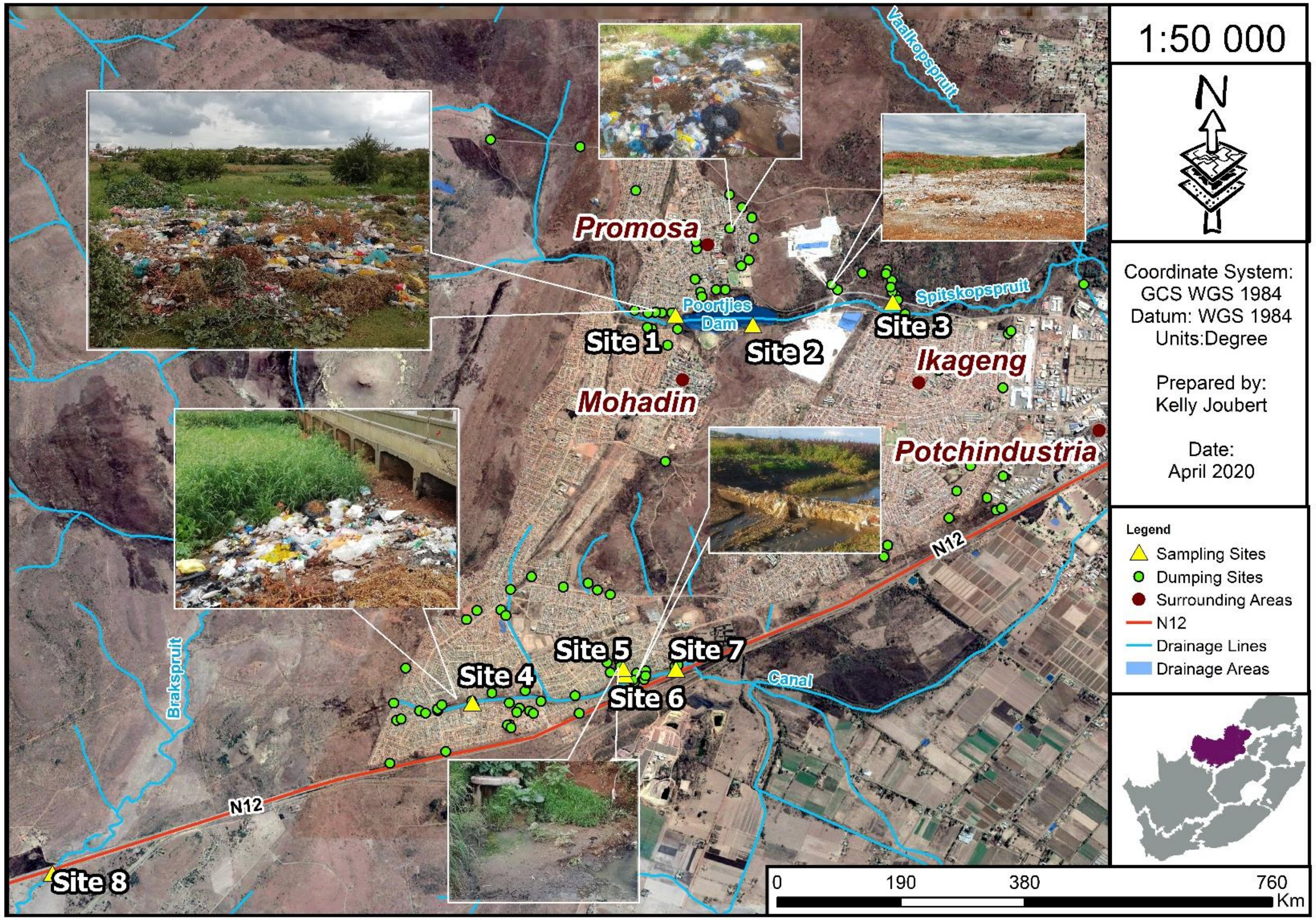

Figure 3-10 A map indicating the sampling sites and locations of all the dumping sites located in the surrounding areas. The images of the illegal dumping sites illustrated in the map were captured during the site visits that were undertaken on the 15th and 16th of February 2019.

Chapter 4 - MATERIALS AND METHODS

4.1 Water quality

4.1.1 Water sampling

In situ water quality variables (electrical conductivity, pH, salinity, total dissolved solids, temperature, dissolved oxygen) were measured using a handheld Extech DO610 and Extech EC610 (Extech Instruments, A FLIR Company USA) water quality meters at each sampling site. Water samples were collected at each site to measure the physicochemical variables of the water. The water samples were collected in 500 ml sterile sampling bottles and immediately frozen for further analysis in the laboratory. In the laboratory, the frozen water samples were defrosted and analysed in terms of their nutrients and ion concentrations using the relevant test kits and a Spectroquant (Merck Spectroquant Pharo 300 UV-VIS Spectrophotometer) for each parameter. According to Khatri and Tyagi (2015), the leachate from poor SW disposal contaminates the ground- and surface water resources as it increases metals, nutrients, organic contaminants, inorganic nitrogen and pathogens of the affected waters as well as contribute to elevated levels of ammonium in the water which can be harmful to aquatic organisms and can also cause negative effects for the people consuming the water (Kamal *et al.,* 2015). According to Deshmukh and Aher (2016), the leachate from dumping sites could also cause the total salts in the water to increase and thereby cause a spike in the EC and TDS concentrations of the water. The samples taken at each sampling site were therefore analysed for most of the parameters mentioned above such as nitrites, nitrates, ammonium, phosphate, sulphate and chloride.

The water quality results determined for each site was then compared to the South African water quality guidelines (WQG) volume 7 specified for aquatic ecosystems (DWAF, 1996) to determine if the anthropogenic impacts such as illegal dumping affected the water quality at the different sites.

4.2 Diatom sampling and analysis

The diatom sampling, preparation and analysis were completed according to the prescribed method of Taylor *et al.* (2004). Two sets of diatom samples were collected for the live and fixed diatom analysis. Diatoms were sampled from submerged aquatic vegetation stems at each site. Ten stems (approximately 10-15 cm and indicating diatom growth) from submerged vegetation were retrieved from the main channel of the river or stream or near the edge of the impoundment. The sampled stems were then placed in a resealable plastic bag (zip-line bag) with 50 mL of site water and vigorously rubbed and shaken to detach the diatoms from the plant stems. The sample water containing the detach diatoms were transferred into sampling bottles. The samples for the fixed diatom sample preparation were preserved with 70% ethanol and transported back to the laboratory for further analysis.

4.2.1 **Live diatom samples**

Live diatom samples were analysed under the microscope within 24 hours of sampling. Microscope slides for the live samples were prepared for each site as follows:

1. A clean microscope slide, coverslip as well as a pipette was used.
2. The sampling bottle was gently shaken to disperse the diatoms present within the sampling bottle.
3. The pipette was then used to draw up a small amount of the sample containing the diatoms and one drop was placed in the middle of the microscope slide with the coverslip being placed gently over the drop.
4. The prepared microscope slide was then ready to be placed under the compound light microscope at 40x magnification for diatom identification and counts.

4.2.1.1 **Diatom species identification**

The Rapid Diatom Riverine Assessment Method (R-DRAM) described by Koekemoer and Taylor (2007) was used for this part of the study. Each slide was analysed at the 40x magnification and a minimum of 200 diatom valves, where possible, was counted for each site. The results are a list of the different diatom species present at each site as well as their abundance and the OMNIDIA software program was used to calculate the diatom indices based on these results.

4.2.2 **Fixed diatom slide preparation**

The hot hydrochloric acid (HCl) and potassium permanganate ($KMnO_4$) method described by Taylor *et al.* (2004), was used for the preparation of fixed slides. This method was used as it is the recommended method of use in South Africa as the samples usually contain a high concentration of organic matter. The steps that were followed include the following:

1. After sampling, samples were left to stand for at least 24 hours to allow the diatoms to settle, after which the clear supernatant was carefully decanted, being careful not to decant any diatom material.
2. After properly shaking the sample, 5-10 mL of the diatom containing suspension was decanted into a heat resistant test tube.
3. The $KMnO_4$ (approximately 10 mL) was added to the test tube and the sample was left to stand overnight.

4. Hydrochloric acid (32%) was added to the samples (5-10 mL), in a fume cabinet, and heated to 90 °C on a hot plate using a watch glass to cover the test tubes for approximately 1-2 hours or until the solution cooked clear (oxidation completed). A drop of hydrogen peroxide was added to the samples to ensure that there is no organic matter left in the samples.
5. Once the oxidation process was completed, the sample was left to cool to room temperature and washed through four wash cycles with distilled water.
6. For the washing process, 10 mL sample was transferred to centrifuge tubes and centrifuged for 10 minutes at 2500 rpm. Approximately 7 mL of the clear supernatant was decanted, and the tube filled to 10 mL with distilled water and placed in the centrifuge for 10 more minutes. The washing of the sample was then repeated 4 more times.
7. Thereafter 7 mL of the supernatant was poured out in one swift movement and 1 drop of ammonium chloride was added to the remainder of the sample and vortexed to resuspend the diatom samples.
8. Samples were then pipetted onto pre-cleaned coverslips and left to dry overnight.
9. Lastly, the coverslips were mounted onto pre-cleaned microscope slides using Pleurax (Refraction index, 1.73) (Taylor *et al.,* 2004).

4.2.2.1 **Diatom species identification**

Each prepared microscope slide was analysed using a Zeiss Primo Star iLED compound light microscope at 100x magnification and the diatom valves were counted until a total of ~400 diatom valves or the entire microscope slide. The results are a list of the different diatom species present at each site as well as their abundance.

The R-DRAM manual was used for this study and has listed a total of 20 key species that are indicators of certain parameters within the water. The guideline by Taylor *et al*. (2007c), "*An illustrated guide to some common diatom species from South Africa"* was also used to identify the diatom species. The results of the diatom species present at each site were analysed based on the presence of those indicator species to determine the quality of the water and whether the illegal dumping affects the water quality and therefore the diatom communities present.

4.2.3 **Statistical analysis**

4.2.3.1 **Univariate Analyses**

4.2.3.1.1 **OMNIDIA**

Omnidia version 5.3 software (Lecointe *et al.*, 1993) was used to determine the diatom indices based on the species identified and their abundances. The four indices used in this study included (Kelly and Whitton, 1995).

Specific Pollution sensitivity Index (SPI)

- This index has the broadest spectrum of diatom species, including more than 1400 species in its database and takes factors such as eutrophication, salinity and organic pollution into account (Holmes and Taylor, 2015).

Generic Diatom Index (GDI)

- The final score for this index is calculated based on the diatom taxon's tolerance to pollution at genus level (Coste and Ayphassorho, 1991).

Trophic Diatom Index

- With this index, diatoms are classified into five different categories of sensitivity to nutrient concentrations (Kelly and Whitton, 1995).

Percentage Pollutant Tolerant Valves (%PTV)

- This index provides an illustration of the degree of eutrophication vs organic pollution as it indicates the diatoms in the sampled community that are tolerant to pollution (Kelly and Whitton, 1995).

The SPI and GDI are all assigned scores that range from 1 - 20 with a lower score indicating a eutrophic ecosystem (Table 4-1). The scores are based on Zelinka (1961), weighted average formula (Taylor *et al.,* 2007b). The TDI provides a score ranging from 0 - 100 with a lower score indicating an oligotrophic ecosystem and vice versa (Table 4-2). The %PTV has scores range from 0 - 100 and the lower the score the less organic pollution is present (Table 4-3) (Holmes and Taylor, 2015).

Table 4-1 Interpretation of diatom index scores for Specific Pollution sensitivity Index (SPI) and the Generic Diatom Index (GDI) to determine the ecosystem quality as well as the ecosystem trophic level.

Index Score (up to 20)	Ecosystem quality	Trophic level
>17	High Quality	Oligotrophic
15-17	Good Quality	Oligo-mesotrophic
12-15	Moderate Quality	Mesotrophic
9-12	Poor Quality	Meso-eutrophic
<9	Bad Quality	Eutrophic

Table 4-2. Interpretation of diatom index scores for Trophic Diatom Index (TDI) to determine the ecosystem trophic level.

Index Score	Trophic level
0-20	Oligotrophic
21-40	Oligo-mesotrophic
41-60	Mesotrophic
61-80	Meso-eutrophic
>80	Eutrophic

Table 4-3 Interpretation of diatom index scores for percentage Pollution Tolerant Valves (%PTV) to determine the ecological status of the ecosystem.

Index Score	Ecological Status
<20	Site free from organic pollution
21-40	Some evidence of organic pollution
41-60	Organic pollution likely to contribute to eutrophication
>61	Heavily contaminated with organic pollution

4.2.3.1.2 **Univariate analyses**

GraphPad Prism Version 5 were used to graphically illustrate the water quality results, the univariate diversity indices as well as the diatom index scores of the live and fixed diatom samples for the different sites. Primer software version 7 (Clarke and Gorley, 2015) was used to determine the diatom diversity indices (Margalef species richness, Total species, Shannon diversity index and Pielou’s evenness index) for the live and fixed diatom samples for the different sampling sites. A two-tailed Pearson correlation coefficient ($p < 0.05$) was also used between the environmental variables and the diatom indices while a one-way ANOVA test was used to determine how the diatom indices respond to the different environmental variables determined for each site.

4.2.3.2 **Multivariate analyses**

Canoco software version 5 was used to determine the unconstrained principle components analysis (PCA) and constrained redundancy analysis (RDA) (Morris, 2015). The principle components analysis (PCA) was used to indicate the relationship between the water quality variables and the sampling sites. Redundancy analysis (RDA) was used to indicate the correlation between the water quality and the diatom indices results determined for the different sites. A nonmetric multidimensional scaling (nMDS) plot and a Bray Curtis similarity matrix (in Primer Version 7) were used to determine the differences and similarities of the diatom results. A hierarchical cluster analysis (Clarke and Gorley, 2015) was also performed in Primer Version 7, to determine the similarities between the different sites sampled. A Simper multivariate analysis (Clarke and Gorley, 2015) was used to determine the similarities or variances between the dominant diatom species at each sampling site.

Chapter 5 - RESULTS

The results presented in the chapter below represent the water quality and diatom results determined for each site.

5.1 Water quality results

The physicochemical water variables for each site will be discussed in detail below. Each of the water quality variables is discussed separately to illustrate the differences in the results determined for each site. A complete list of the water quality results for each site are presented in Appendix A.

5.1.1 *In-situ* water quality variables

The temperature, pH and percentage dissolved oxygen saturation (%DO) measured for the different sites are presented in Figure 5-1 below. The temperature ranged between 20.3 C and 28.8 °C with the lowest temperatures measured at Site 4 and the highest at Site 3. It should however be noted that the temperature for all sites were taken at different times during the day which could explain the variability in the temperature results. The pH levels measured for the different sites were all between 6.74 and 8.22 except for Site 3 which had a very low pH measurement of 3.37. The %DO was the highest at Site 2 (86.7%) while Site 4 had the lowest concentration at 33%.

There were differences in the measured electrical conductivity (EC) and total dissolved solids (TDS) between the different sites (Figure 5-1). Electrical conductivity and TDS was highest at Site 3 with a concentration of 1993 µS/cm and 1400 mg/L respectively, whilst the lowest concentrations were at Site 8 at 94 µS/cm and 62.2 mg/L respectively. The measured turbidity at the different sites were lowest at sites 5, 7 and 8 with a total of 5 FAU while the highest concentration was measured at Site 1 with a total of 19 FAU.

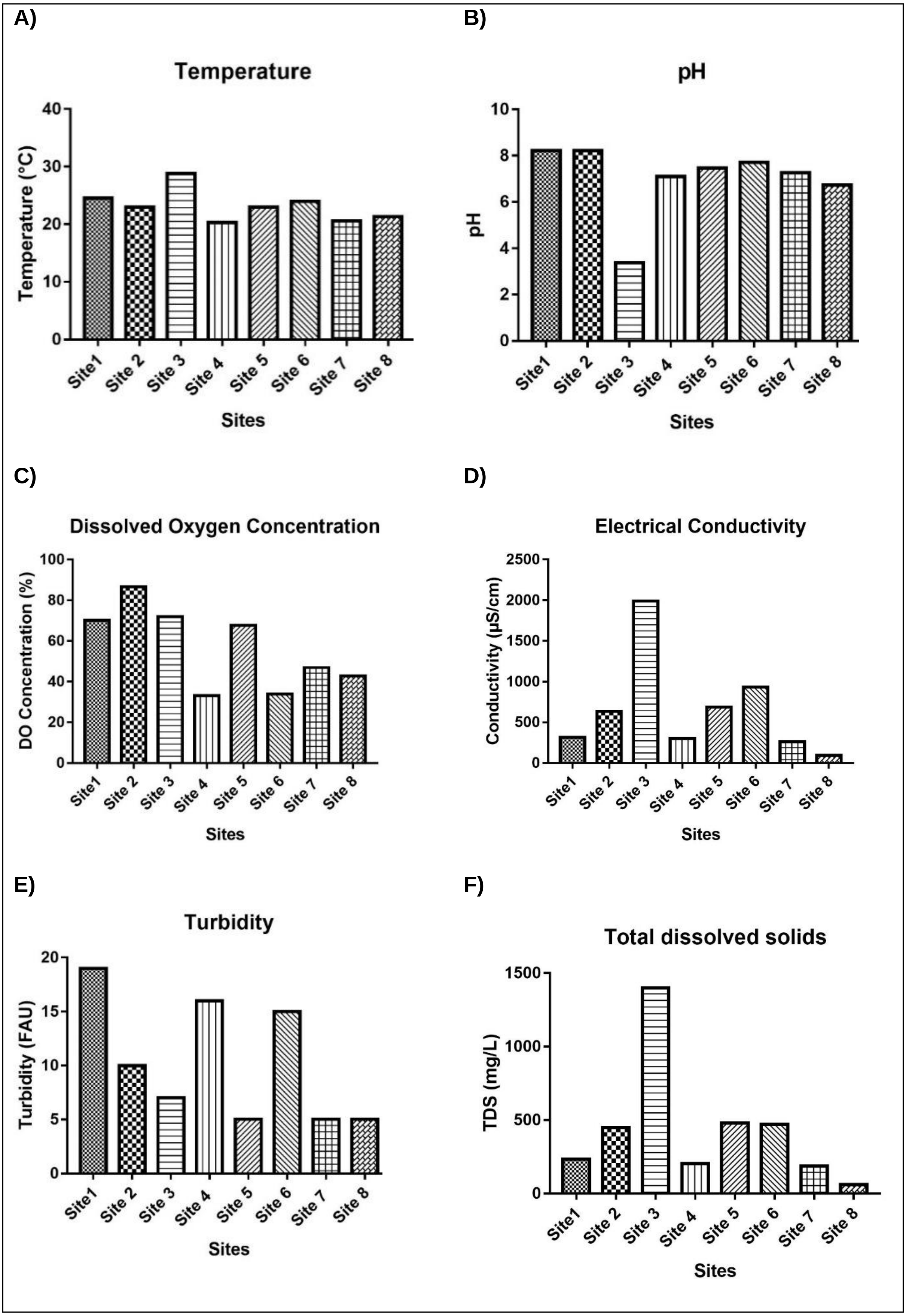

Figure 5-1 Column graphs illustrating the (A) Temperature, (B) Ph, (C) Percentage Dissolved Oxygen (%DO), (D) Electrical Conductivity, (E) Turbidity and (C) TDS concentrations measured for the different sites.

5.1.2 Nutrients, Sulphate and Chloride

The nutrients analysed for each site included nitrites (NO_2), nitrates (NO_3), ammonium (NH_4) phosphates (PO_4) and sulphate (SO_4) and was measured in mg/L as shown in Figure 5-2. The nitrite concentration was the highest at Site 4 (0.18 mg/L), compared to all the other sites with the lowest concentration identified at Site 3 (0.03 mg/L). Site 5 had the highest nitrate concentration (7.2 mg/L) with the concentration at Site 3 (6.1 mg/L) slightly less than Site 5 while Site 4 had the lowest nitrate concentration (1.8 mg/L).

The ammonium concentrations were highest at Site 6 (5.7 mg/L) while the lowest concentrations were at Site 1 (0.2 mg/L) and Site 8 (0.16 mg/L). The phosphate concentrations were highest at site 3 (8.68 mg/L), Site 6 (8.34 mg/L) and Site 7 (8.66 mg/L) with the lowest concentration at Site 8 (0.87 mg/L). Site 4 had the highest concentration of sulphate at 212 mg/L while site 3 had the lowest concentration of 46 mg/L. Site 1 and Site 2 had very similar concentrations at 110 and 109 mg/L respectively. The sulphate concentration drops down to its lowest level at Site 3 which is located just downstream of Poortjie Dam at Spitskopspruit. Site 6 had the highest concentration of Chloride (26.4 mg/L) while sites 2 to 5 had similar chloride concentrations ranging between 21- 23.4 mg/L as seen in Figure 5-2 (F). Site 8 had the lowest concentration at 12.3 mg/L.

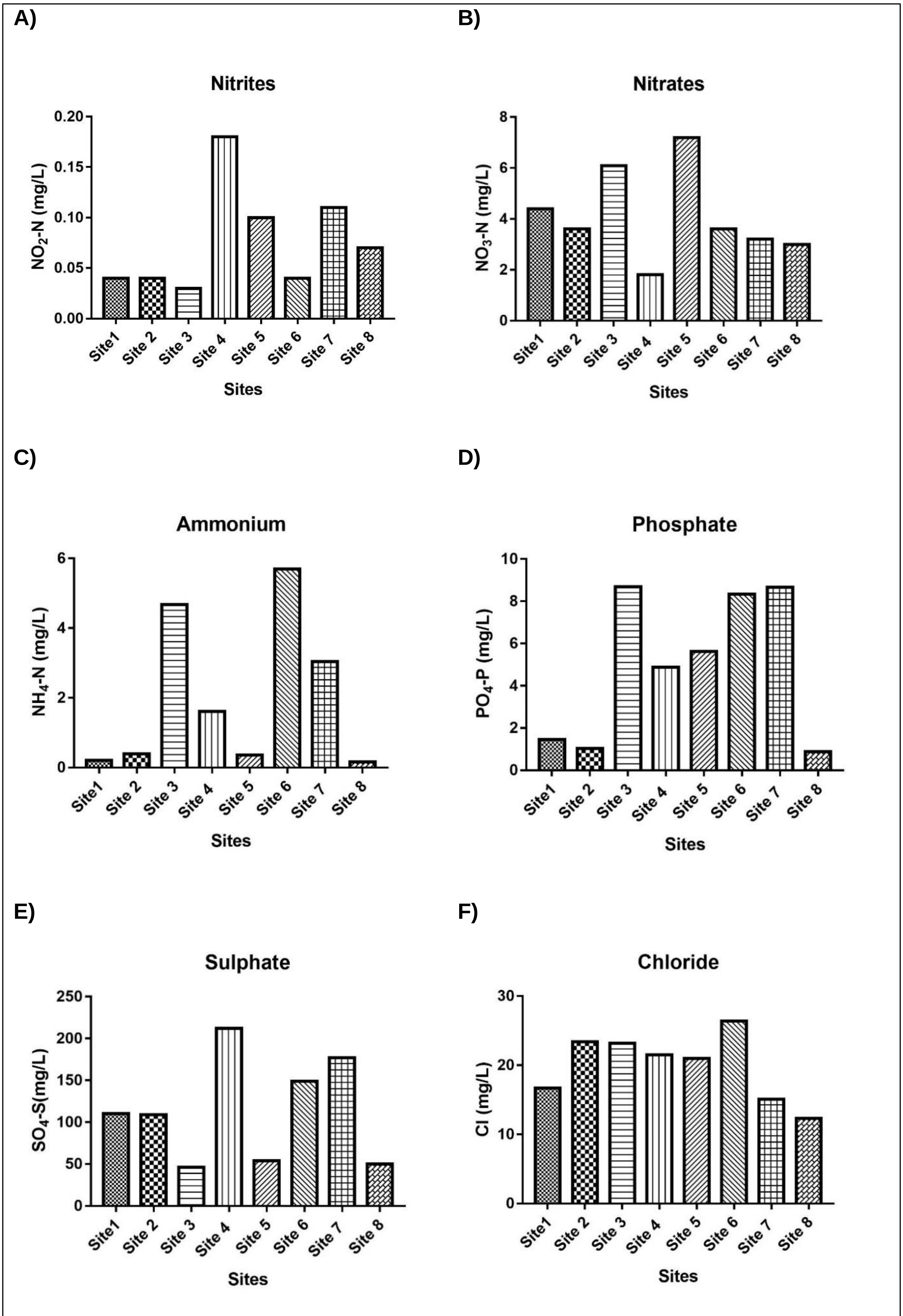

Figure 5-2. Column graphs illustrating the different nutrient concentrations A) Nitrites, B) Nitrates, C) Ammonium and D) Phosphate as well as the E) Sulphate and F) Chloride concentrations measured for each site.

5.2 **Diatom results**

Results on the identified diatom species at each site as well as their abundances and diversity are presented in this section. Results also include a correlation analysis between the measured water quality variables and the various diatom indices. A complete species list and abundances as well as the calculated diatom indices are available in Appendix B (Table B) and Appendix C (Table C) respectively. The diatom species identified for each site is presented in Table 5-1 and the dominant species identified at each site is marked in bold. At each site, two sets of diatom samples were collected for analysis of the live and fixed diatoms species present. The results of the live diatom samples are represented by the letter L before the sampling site number, for example, L1 is the live sample of Site 1 while the fixed diatom species are represented by the letter F before the sampling site number, for example, F1 is the fixed sample of Site 1. There is no information for the fixed sample of Site 8 as there were no fixed diatom species identified for the site.

The relative abundance percentage was determined for each site for the live and the fixed diatom samples. For the live diatom species, the dominant species identified included *Cymbella tumida* (30.69%) for Site 1, *Aulacoseira muzzanensis* (22.66%) at Site 2, *Melosira varians* at Site 3 (54.90%), *Gomphonema pseudoaugur* (78.39%) at Site 4, *Navicula erifuga* (37.98%) for Site 5, *Gomphonema parvulum* (28.57%) at Site 6 *Aulacoseira granulata* (45.83%) at Site 7 and *Nitzschia* sp. (34.68%) at Site 8.

The dominant species identified for the fixed diatom samples included the *Navicula* sp. (42.20%) for Site 1, *Nitzschia palea* (44.22%) at sites 2 and 3 (93.78%), *Gomphonema parvulum* (31.27%) at Site 4, *Navicula* sp. (30.18%) at Site 5, *Nitzschia* sp. (32.56%) at Site 6 and *Gomphonema parvulum* (20%) at Site 7.

Table 5-1. A list of the diatom species sampled and identified at each sampling site is indicated with an (x) under each site. The dominant species identified at each site is marked with a capital X in bold. L = Live samples; F = Fixed samples

Diatom species	Abbrev.	Site L1	Site L2	Site L3	Site L4	Site L5	Site L6	Site L7	Site L8	Site F1	Site F2	Site F3	Site F4	Site F5	Site F6	Site F7	Site F8
***Amphora* sp.**	**AMPS**												x				
***Aulacoseira muzzanensis* (Meister) Krammer**	**AMUZ**		**X**							x	x						
***Aulacoseira granulata* (Ehrenberg) Simonsen**	**AUGR**	x	x			x		**X**	x					x	X		
***Aulacoseira* sp.**	**AMUZ**		x														
***Caloneis* sp.**	**CALS**												x				
***Caloneis aequatorialis* Hustedt**	**CAQT**													x			
***Craticula halophila* () D.G. Mann**	**CHAL**										x						
***Cyclotella meneghiniana* Kützing**	**CMEN**					x	x										
***Cocconeis pediculus* Ehrenberg**	**CPED**		x														
***Cocconeis placentula* Ehrenberg**	**CPLA**									x							
***Craticula cuspidata* (Kützing) D.G. Mann**	**CRCU**	x															
***Cymbella tumida* (Brébisson)Van Heurck**	**CTUM**	**X**									x						
***Diatoma vulgaris* Bory**	**DVUL**		x	x													
***Eunotia bilunaris* (Ehrenberg) Mills**	**EBIL**						x										

Diatom species	Abbrev.	Site L1	Site L2	Site L3	Site L4	Site L5	Site L6	Site L7	Site L8	Site F1	Site F2	Site F3	Site F4	Site F5	Site F6	Site F7	Site F8
Eunotia formica **Ehrenberg**	**EFOR**						x										
Eunotia minor **(Kützing) Grunow**	**EMIN**	x															
Epithemia **sp.**	**EPIS**				x									x			
Eunotia **sp.**	**EUNS**						x	x	x								
Fragilaria nanana **Lange-Bertalot**	**FNAN**											x					
Fragilaria **sp.**	**FRAS**			x	x	x			x		x			x	x		
Frustulia tugelae **Cholnoky**	**FRSP**													x			
Fragilaria ulna **var.** ***acus*** **(Kützing) Lange-Bertalot abnormal form**	**FUAT**	x															
Fragilaria ulna **(Nitzsch) Lange-Bertalot**	**FULN**						x			x	x			x			
Gomphonema affine **Kützing**	**GAFF**	x								x							
Gomphonema gracile **Ehrenberg**	**GGRA**										x						
Gomphonema insigne **Gregory**	**GINS**												x				
Gomphonema lagenula **Kützing**	**GLGN**												x			x	
Gomphonema **sp.**	**GOMS**	x			x		x			x	x	x		x	x		
Gomphonema parvulum **(Kützing) Kützing**	**GPAR**	x	x		x		**X**	x			x		**X**		x	**X**	
Gomphonema pseudoaugur **Lange-Bertalot**	**GPSA**				**X**			x									

Diatom species	Abbrev.	Site L1	Site L2	Site L3	Site L4	Site L5	Site L6	Site L7	Site L8	Site F1	Site F2	Site F3	Site F4	Site F5	Site F6	Site F7	Site F8
Hantzschia amphioxys **(Ehrenberg) Grunow**	**HAFC**													x		x	
Melosira varians **Agardh**	**MVAR**	x		**X**		x			x								
Nitzschia amphibia **Grunow**	**NAMP**										x						
Navicula **sp.**	**NASP**	x	x		x				x	**X**		x	x	**X**		x	
Nitzschia capitellata **Hustedt**	**NCPL**					x											
Navicula erifuga **Lange-Bertalot**	**NERI**					**X**											
Nitzschia filiformis **(W.M.Smith) Van Heurck**	**NFIL**	x															
Nitzschia fonticola **fo.** ***minutissima*** **Compere**	**NFOM**										x						
Nitzschia **sp.**	**NITZ**	x	x	x		x		x	**X**	x	x		x	x	**X**	x	
Nitzschia liebetruthii **Rabenhorst**	**NLBT**										x						
Nitzschia palea **(Kützing) W.Smith**	**NPAL**	x	x		x	x	x	x			**X**	**X**		x	x		
Navicula radiosa **Kützing**	**NRAD**												x	x		x	
Navicula recens **(Lange-Bertalot) Lange-Bertalot**	**NRCS**														x		
Navicula riediana **Lange-Bertalot & Rumrich**	**NRIE**		x														
Nitzschia sigma **(Kützing)**	**NSIG**								x				x			x	

Diatom species	Abbrev.	Site L1	Site L2	Site L3	Site L4	Site L5	Site L6	Site L7	Site L8	Site F1	Site F2	Site F3	Site F4	Site F5	Site F6	Site F7	Site F8
W.M.Smith																	
***Navicula tripunctata* (O.F. Müller) Bory**	**NTPT**		x														
***Nitzschia umbonata* (Ehrenberg) Lange-Bertalot**	**NUMB**								x			x	x	x		x	
***Navicula veneta* Kützing**	**NVEN**	x	x			x											
***Pinnularia borealis* Ehrenberg**	**PBOR**															x	
***Pinnularia* sp.**	**PINS**	x															
***Pinnularia subcapitata* Gregory var*. elongata* Krammer**	**PSEL**										x						
***Rhoicosphenia abbreviata* (C.Agardh) Lange-Bertalot**	**RABB**									x				x			
***Rhopalodia gibba* (Ehr.) O.F. Müller**	**RGIB**													x			
***Surirella crumena* Brébisson**	**SCRU**										x						
***Sellaphora pupula* (Kützing) Mereschkowksy**	**SPUP**										x						
***Tryblionella* sp.**	**TRYS**								x								

5.2.1 **Diatom indices**

The Omnidia software was used to calculate the diatom indices for the live and fixed diatom samples for the different sites. The diatom indices were used to determine the water quality in terms of the trophic state and ecological status for each site through use of the diatom community present at each site. The score interpretation of these diatom indices are described in more detail in section 4.2.3.

The calculated SPI scores for the live diatom samples (Figure 5-3 (A)) were below 9 for sites 2, 5, 7 and 8 and are thus indicative of a bad ecosystem quality and these sites are classified as eutrophic ecosystems. Sites 1, 4 and 6 of the live diatom samples had SPI scores ranging between 9.9 - 11.1 which are indicative of poor ecosystem quality and classified as meso-eutrophic trophic state. Site 3 of the live diatom samples were the only site that had a SPI score indicative of a moderate ecosystem quality and mesotrophic tropic state. The scores calculated for the fixed diatom samples as shown in Figure 5-3 (B) reveals that, for the SPI, several of the sites, such as sites 2, 3, 4, 6 and 7, had scores below 9 indicating bad quality and eutrophic level. According to the SPI score Site 1 of the fixed diatom samples, is classified in a moderate quality and a mesotrophic trophic state while Site 5 is classified in a poor quality and a meso-eutrophic trophic state.

Sites 5 and 8 had a GDI score below 9 for the live diatom samples (Figure 5-3(C)), indicating that the ecosystem quality of these sites is of bad quality whilst sites 1, 3, 4 and 6 had a score above 12 indicating that these sites consisted of a moderate ecosystem quality with a mesotrophic ecosystem level. The GDI scores for the fixed samples (Figure 5-3(D)) indicated that sites 2, 3, 6 and 7 had a bad ecosystem quality while Site 1 consisted of moderate ecosystem quality.

The calculated TDI scores (Figure 5-4(A-B)) for each site of the live and fixed diatom samples indicated that all the sites had a score below 20 which is indicative of an oligotrophic trophic state. Figure 5-4 (C) shows the %PTV score for the live diatom samples for each site. The results indicate that sites 1, 3, 4 and 7 do not contain any organic pollution, while sites 2, 5, 6 and 8 indicated some evidence of organic pollution.

The %PTV is shown in Figure 5-4 (D) for the fixed diatom samples reveal that sites 1 and 5 have scores below 20 and are therefore indicative of not containing any organic pollution while sites 2 and 3 had scores far higher than 61 which indicates that these sites are heavily contaminated with organic pollution.

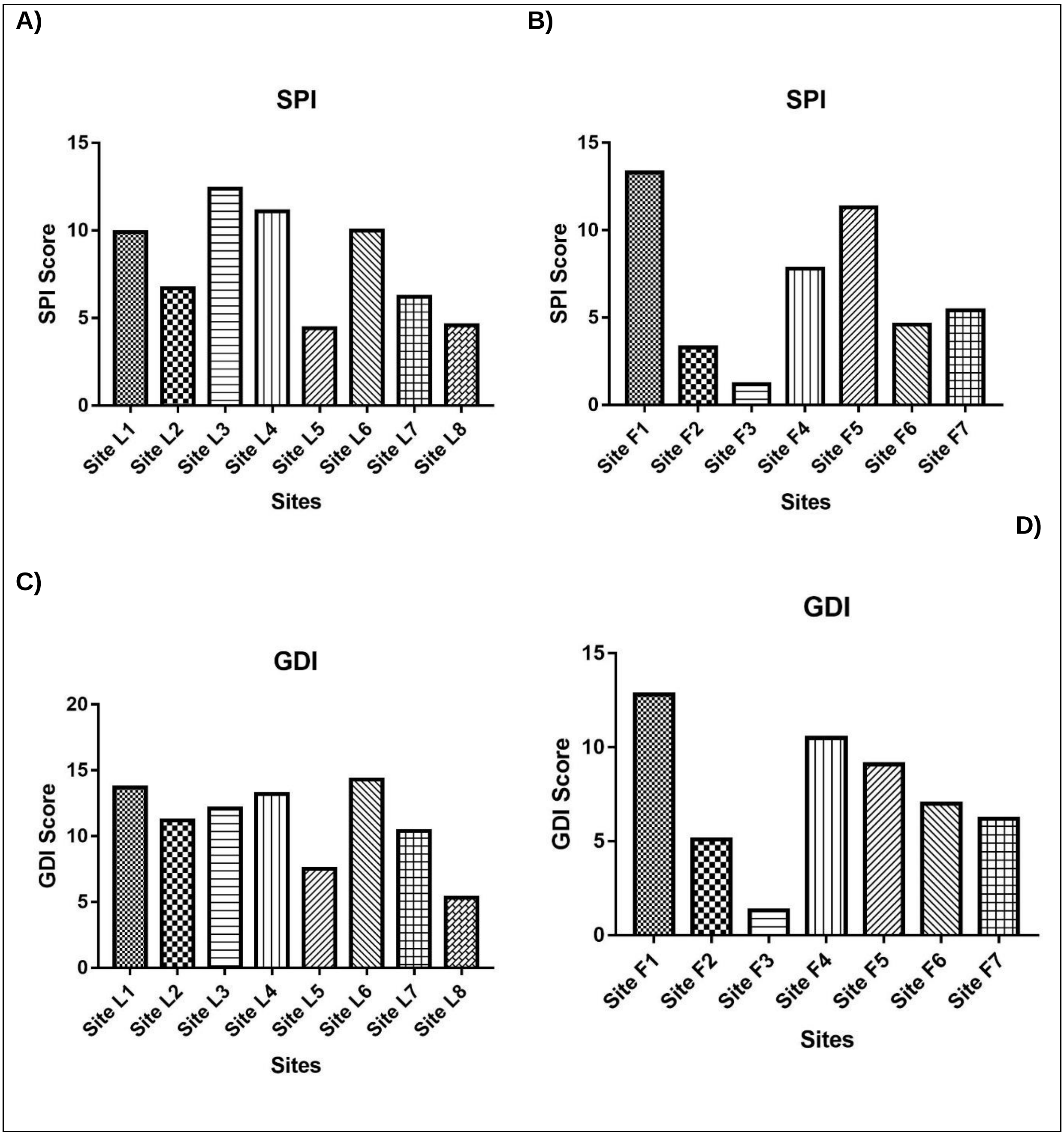

Figure 5-3 Column graph illustrating the diatom index scores for the Specific Pollution sensitivity Index (SPI) for the (A) live and (B) fixed diatom samples while the Generic Diatom Index (GDI) scores are illustrated for the(C) live and the (D) fixed diatom species. The letter L before the sampling site number represents the live diatom samples while the letter F represents the fixed diatom species.

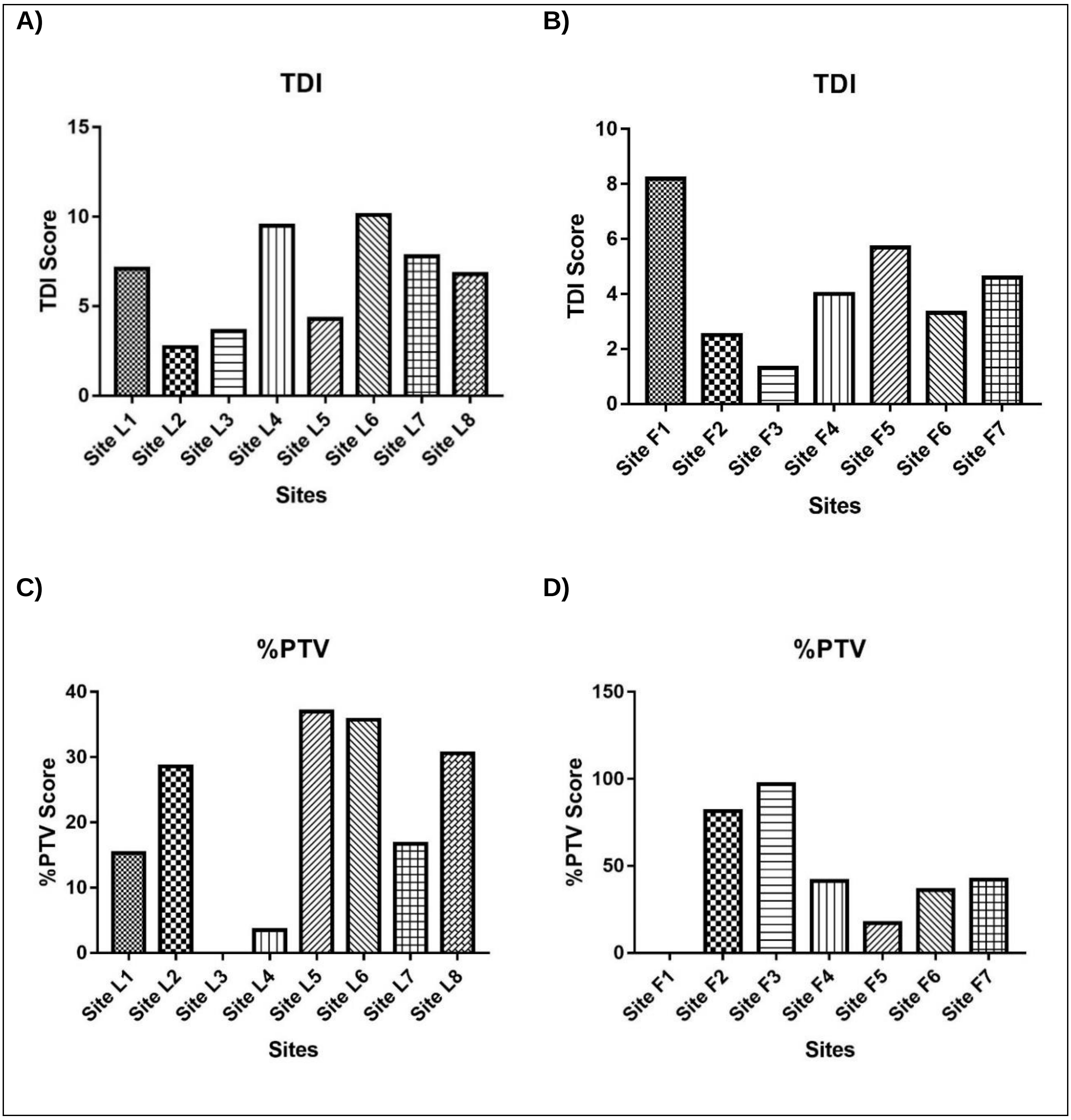

Figure 5-4 Column graph illustrating the Trophic Diatom Index (TDI) scores for the (A) live and the (B) fixed samples while the percentage Pollution Tolerant Valve (%PTV) is illustrated for the (C) live and the (D) fixed diatom species for the different sites. The letter L before the sampling site number represents the live diatom samples while the letter F before the sampling site number represents the fixed diatom samples.

The results for the SPI and TDI scores between the live and fixed diatom samples showed a very similar trend while there were some differences in the GDI and %PTV scores. This could be due to different species identified in the composition for the live and fixed samples.

5.2.2 **Diatom diversity indices**

The diversity indices were based on the diatom species abundances for each site for the live and fixed samples and are presented in Figure 5-5 (A-D) and Figure 5-6 (A-D) respectively.

The results from the live samples for the diversity indices did not differ, compared to the results for the diversity indices of the fixed diatom samples described below. Site 1 had the highest number of species and therefore species richness whilst Site 3 had the lowest number of species and species richness. The results of the Shannon diversity index and the Pielou's evenness index between the sites had a similar pattern with Site 6 having the highest evenness score and Site 1 the highest diversity score.

From Figure 5-6 (A and B) it can be seen that sites 2 and 5 had the highest number of species and therefore species richness whilst Site 3 had the lowest number of species and species richness for the fixed samples. The Shannon diversity index between the sites was very similar ranging from 1.04 to 2.4 with Site 3 having the lowest score. The Pielou's evenness index was also similar between the different sites ranging between 0.64 - 0.97 with Site 5 the highest and Site 3 the lowest.

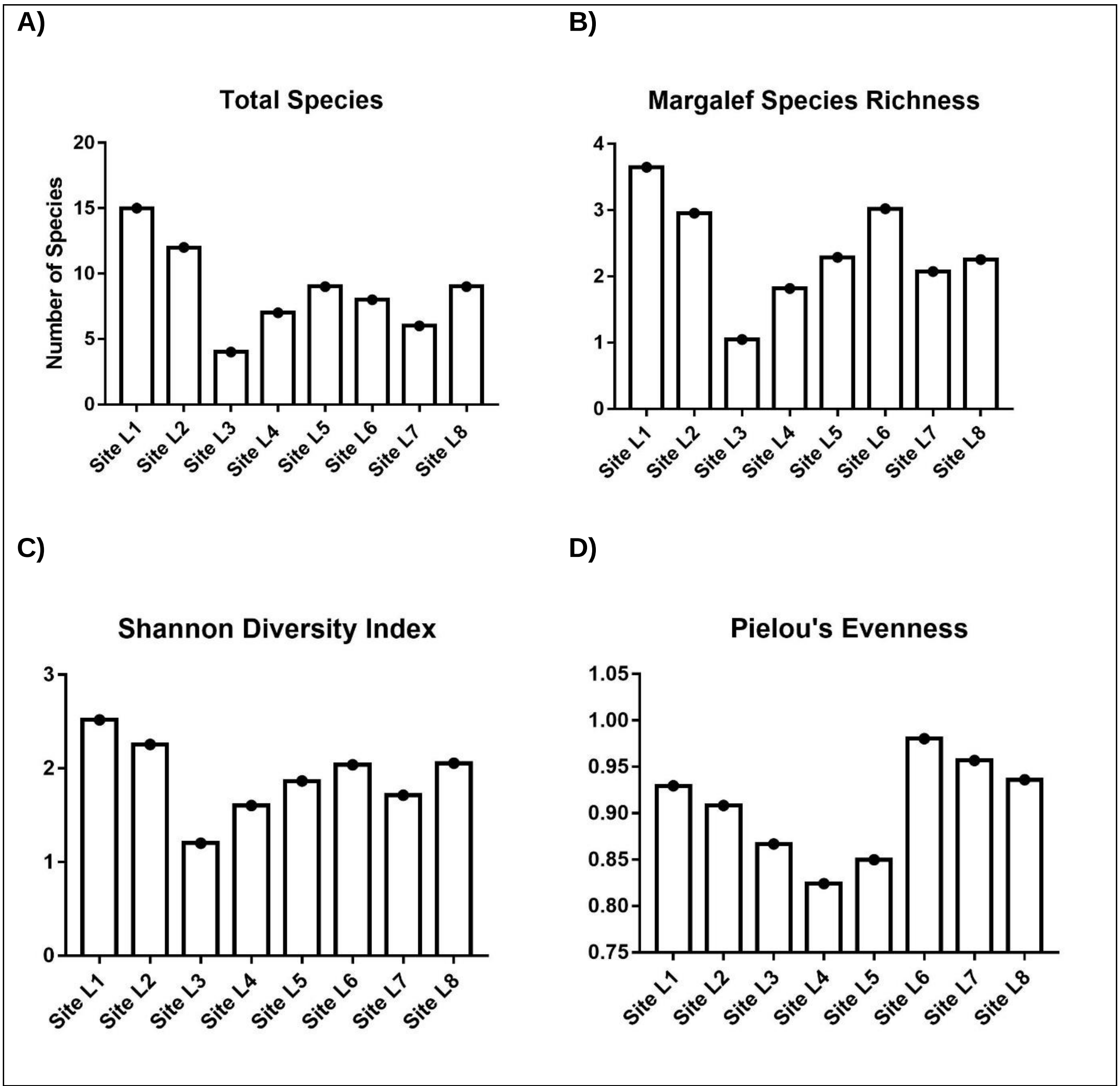

Figure 5-5 Graphs for the live samples indicating different diversity scores for each site. (A) represents the total number of species per season, (B) Margalef species richness, (C) Shannon diversity index and (D) Pielou's evenness for the live samples. The letter L before the sampling site number represents the live diatom samples.

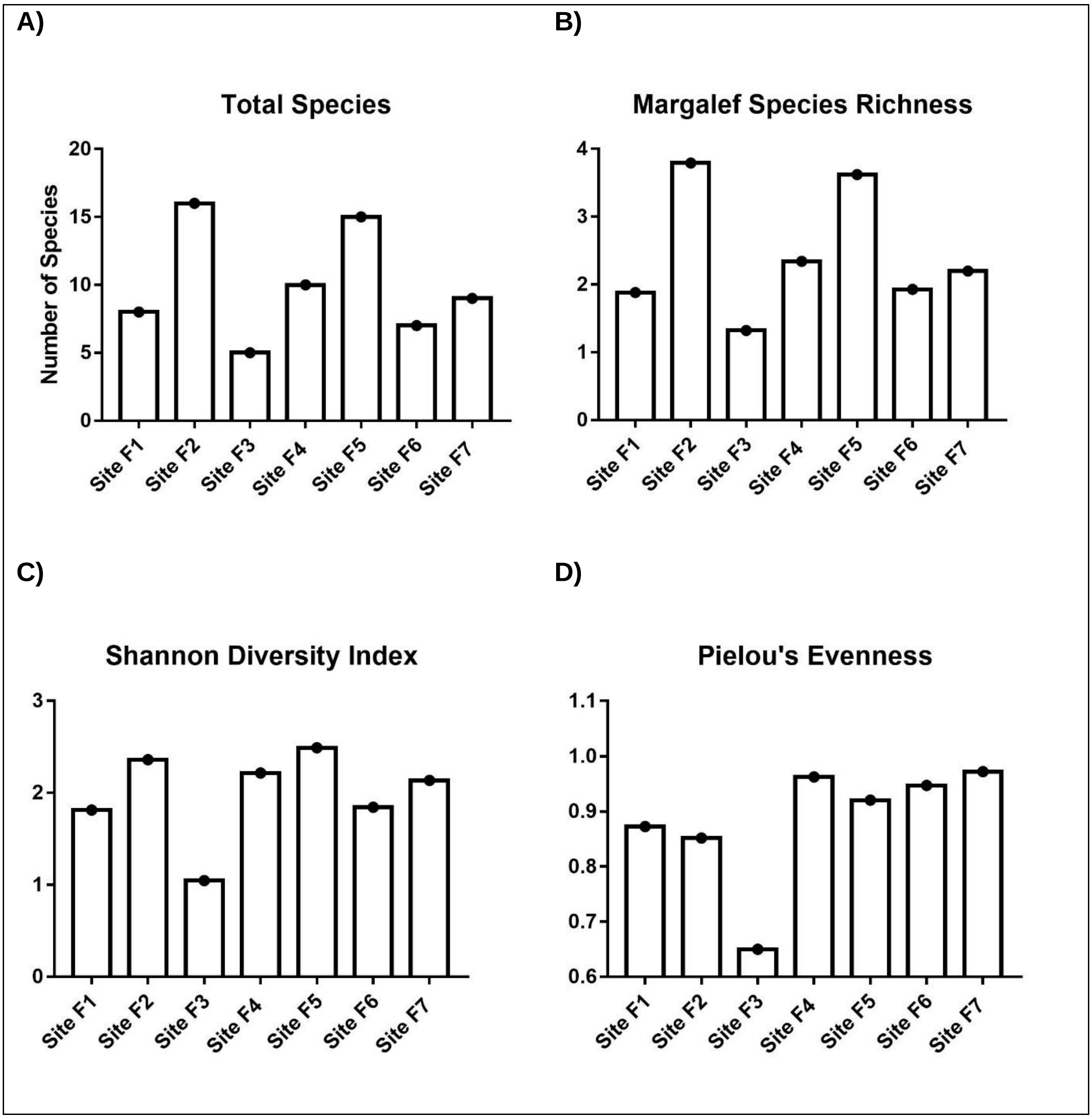

Figure 5-6 Graphs showing the results of the diversity indices for the fixed diatom samples. (A) represents the total number of species per season, (B) Margalef species richness, (C) Shannon diversity index and (D) Pielou's evenness for the fixed samples. The letter F before the sampling site number represents the fixed diatom samples.

5.2.3 Spatial variation

The non-metric multidimensional scaling (nMDS) plot, based on the Bray Curtis similarity matrix, is illustrated below for the live and fixed diatom samples in Figure 5-7. The hierarchical cluster for the live and fixed diatom samples are presented below for the different sites in Figure 5-8 and Figure 5-9. The results from the nMDS plot for both the live and fixed samples indicates little similarity between sites as they are sparsely plotted away from one other (Figure 5-7). Only sites 4 and 7 of the fixed samples grouped closer together indicating some similarity between the two sites for the fixed diatom samples. The rest of the sites are situated far from each other indicating very little resemblance between the different sites. The hierarchical cluster in Figure 5-8 illustrated the highest similarity of 39.31% between sites 1 and 2 of the live diatom samples while the highest similarity in Figure 5-9 was 63.12% between sites 4 and 7 of the fixed diatom samples.

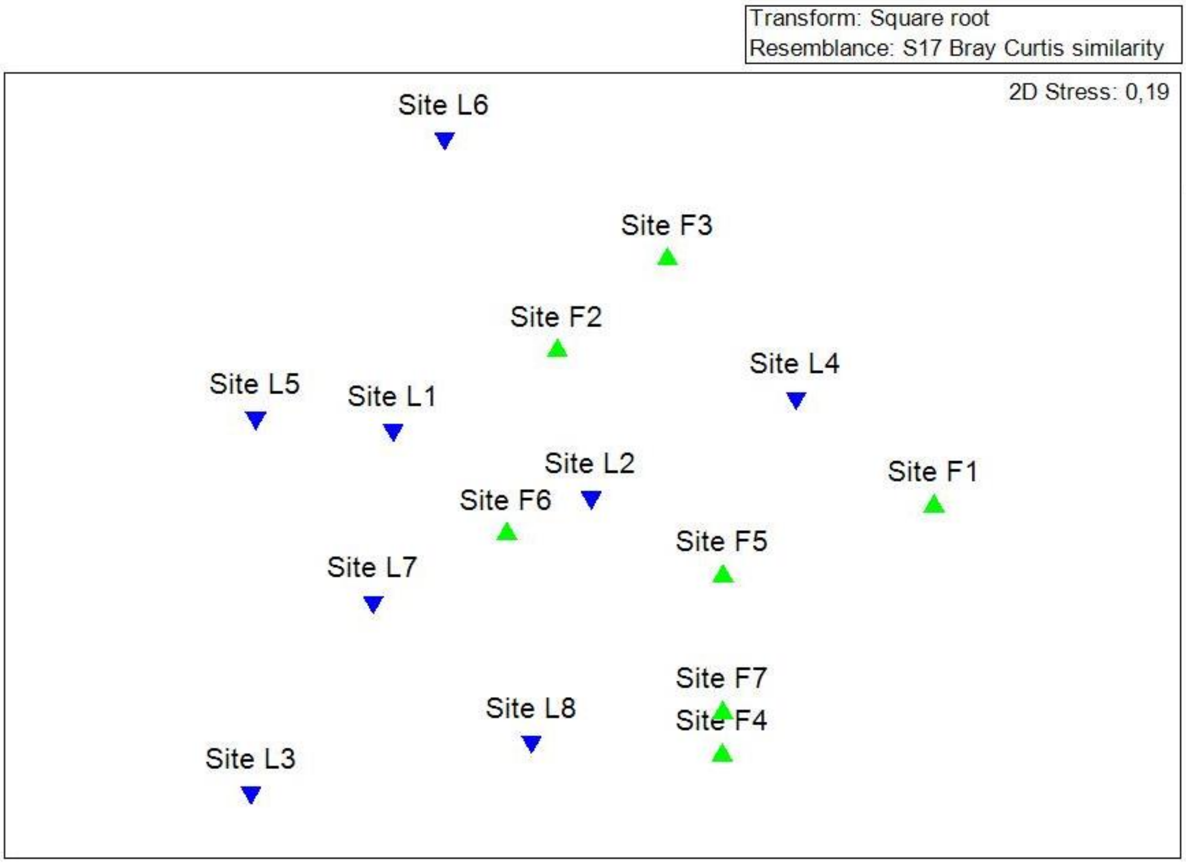

Figure 5-7. Non-metric multidimensional scaling (nMDS) plot showing the Bray-Curtis similarity between the live and fixed diatom samples. The letter L before the sampling site number represents the live diatom samples while the letter F before the sampling site number represents the fixed diatom samples.

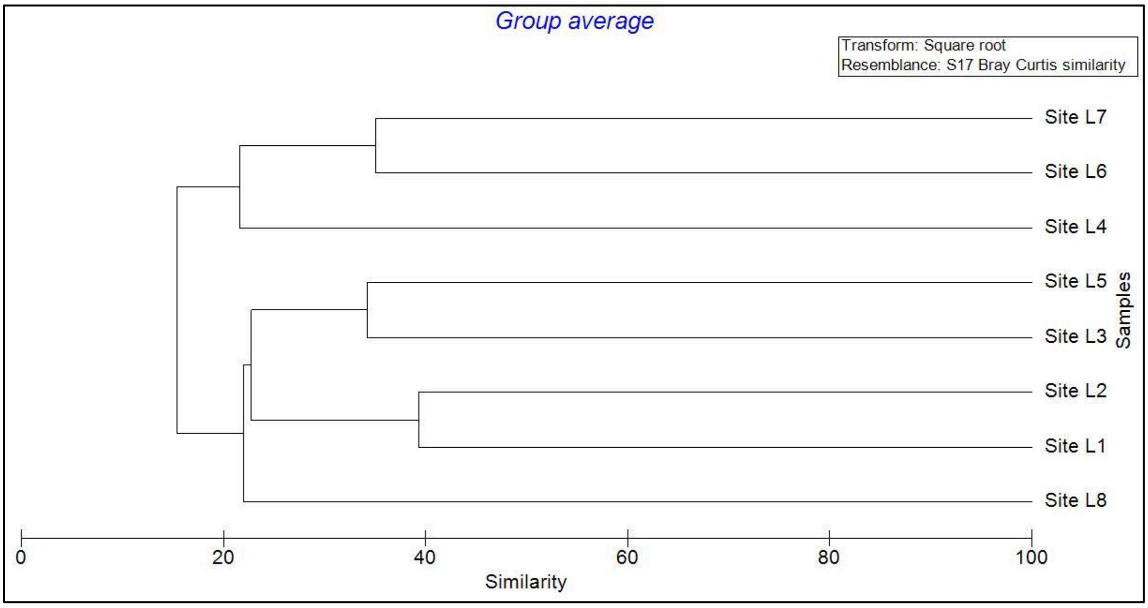

Figure 5-8. Hierarchical cluster showing the similarity between live diatom samples. The letter L before the sampling site number represents the live diatom samples.

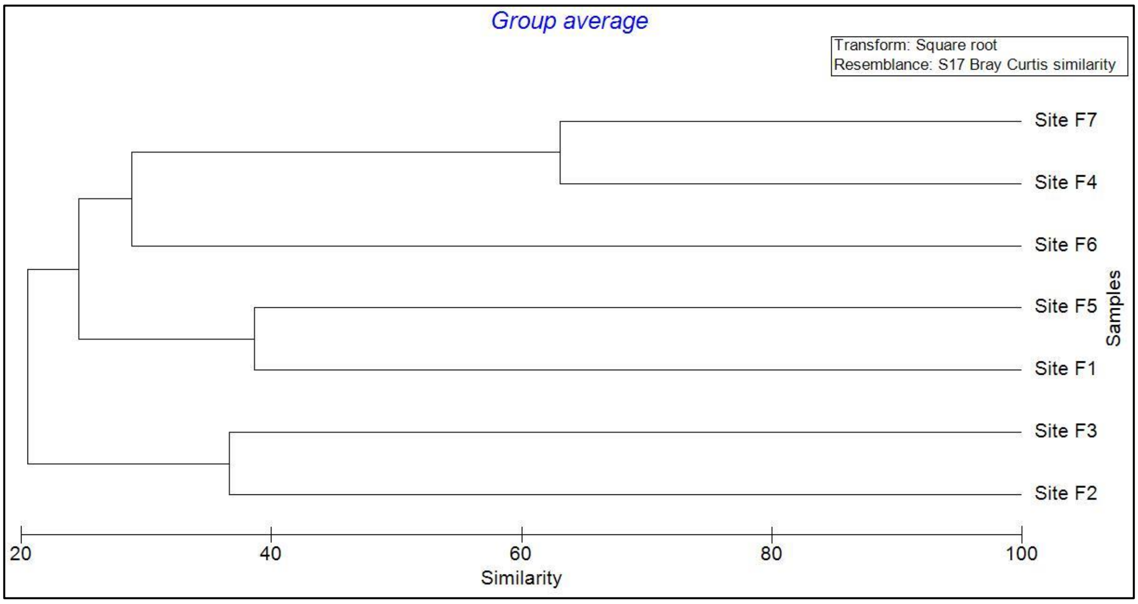

Figure 5-9. Hierarchical cluster showing the similarity between fixed diatom samples. The letter F before the sampling site number represents the fixed diatom samples.

In Figure 5-10 the principle components analysis (PCA) biplot illustrates the relationship between the water quality variables and sampling sites. Sites 4, 6 and 7 which are at the top half of the PCA biplot are grouped in group 1 and were influenced most by sulphate, pH, ammonium, phosphate, turbidity and nitrites. Sites 3 and 5 are in the bottom left quadrant of the PCA biplot and formed a second group. This group was influenced by chloride, electrical conductivity, temperature, and percentage dissolved oxygen. The rest of the sampling sites were grouped in group 3 as they were not influenced by any water quality variable as they had the lowest water quality variable concentrations. The variation explained in axis 1 was 52.35% and 25.06% in axis 2, with the cumulative variation for axis 1 and 2 calculated at 77.41%. The nitrites and pH indicated a positive correlation while the nitrates and nitrites indicated a negative correlation with one another.

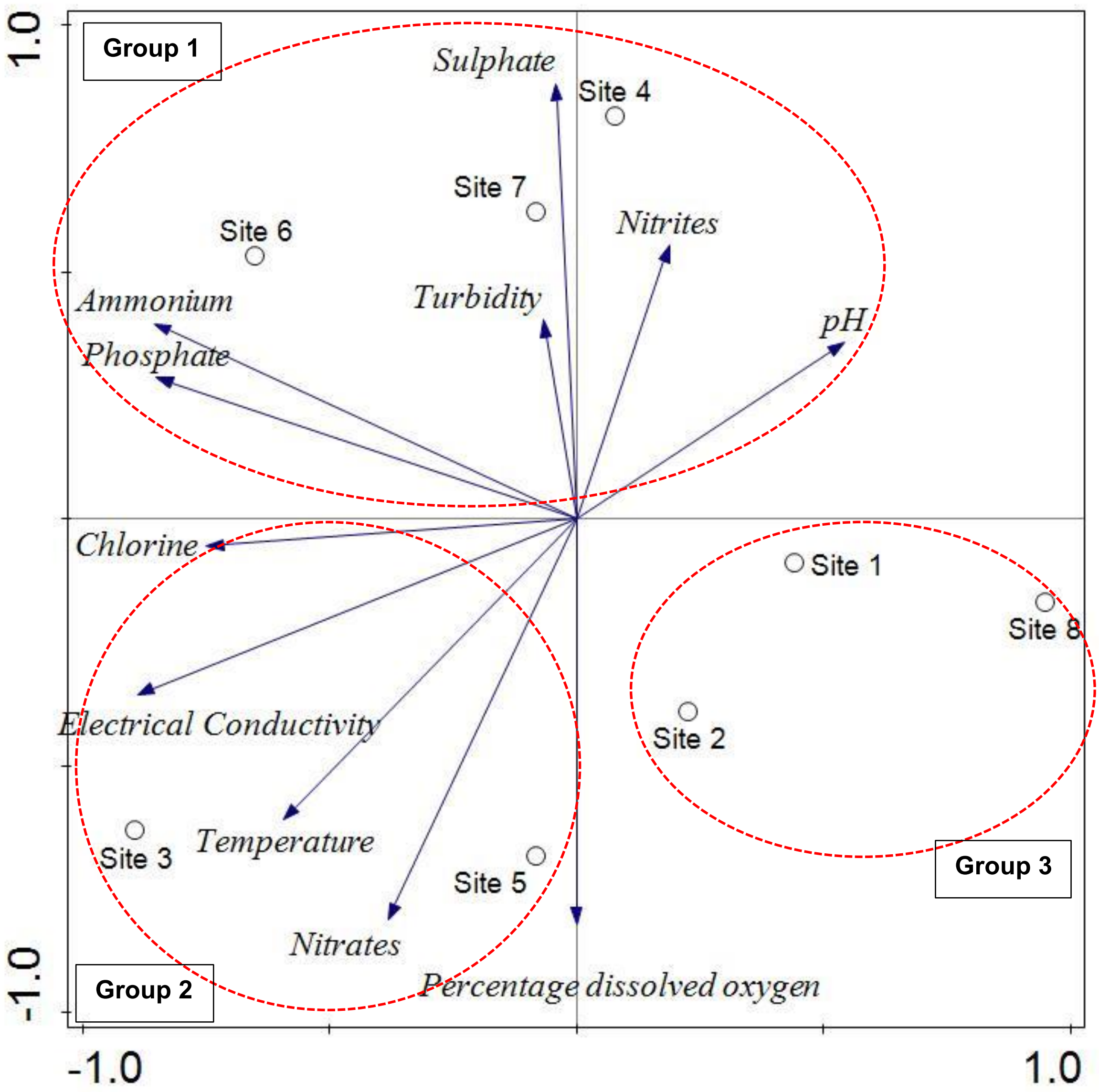

Figure 5-10 The principle components analysis (PCA) biplot illustrating the correlation between the water quality and the sampling sites.

Figure 5-11 illustrates the RDA triplot for the live diatom samples and the correlation between the water quality and the diatom indices. The SPI, GDI and TDI indices are grouped in group 1 and were driven by higher concentrations of ammonium, phosphate, sulphate, nitrites, and pH. Group 2 represents the %PTV index and is related to higher concentrations of nitrates and percentage dissolved oxygen. The variation explained in the first axis accounted for 29.67% while the second axis accounted for 22.76%. The total explanatory variables accounted for 59.10%.

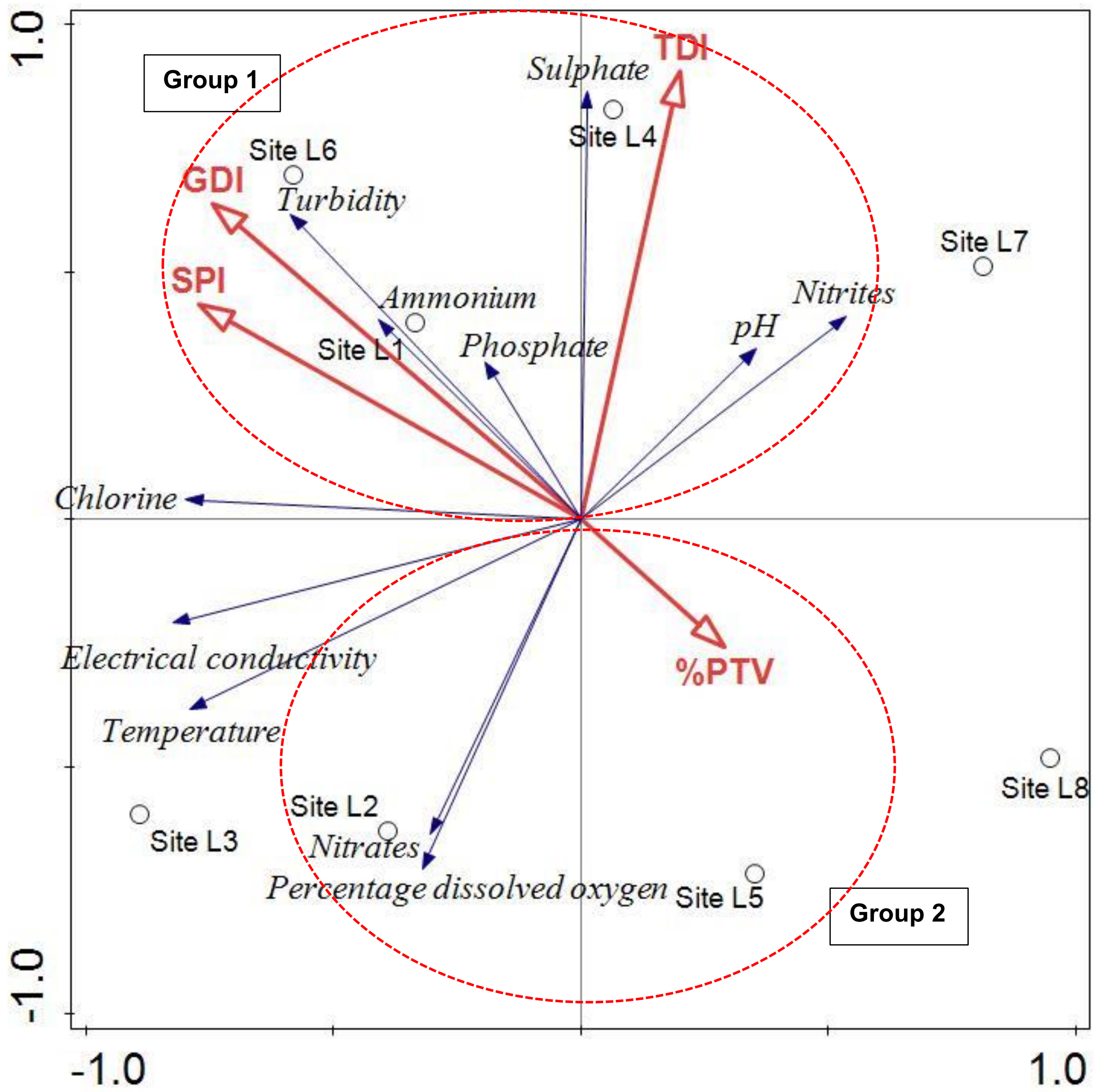

Figure 5-11. The Redundancy analysis (RDA) triplot illustrating the correlation between water quality and the live diatom indices results from the different sites.

In Figure 5-12 the RDA triplot illustrates the correlation between the water quality and the results of the fixed diatom sample's indices for the different sites. The diatom indices are divided into two groups. Group 1 represents the diatom indices that were influenced by higher levels of nitrates and electrical conductivity. This group included the diatom indices such as GDI, TDI and SPI. Group 2 represented the %PTV diatom index, which was related to higher concentrations of ammonium, phosphate, chloride nitrites, pH, turbidity, and sulphate. The variation explained in the first axis accounted for 41.19% while the second axis accounted for 26%. The indices indicated that they were influenced by the water quality variables. The total explanatory variables accounted for 73.94%.

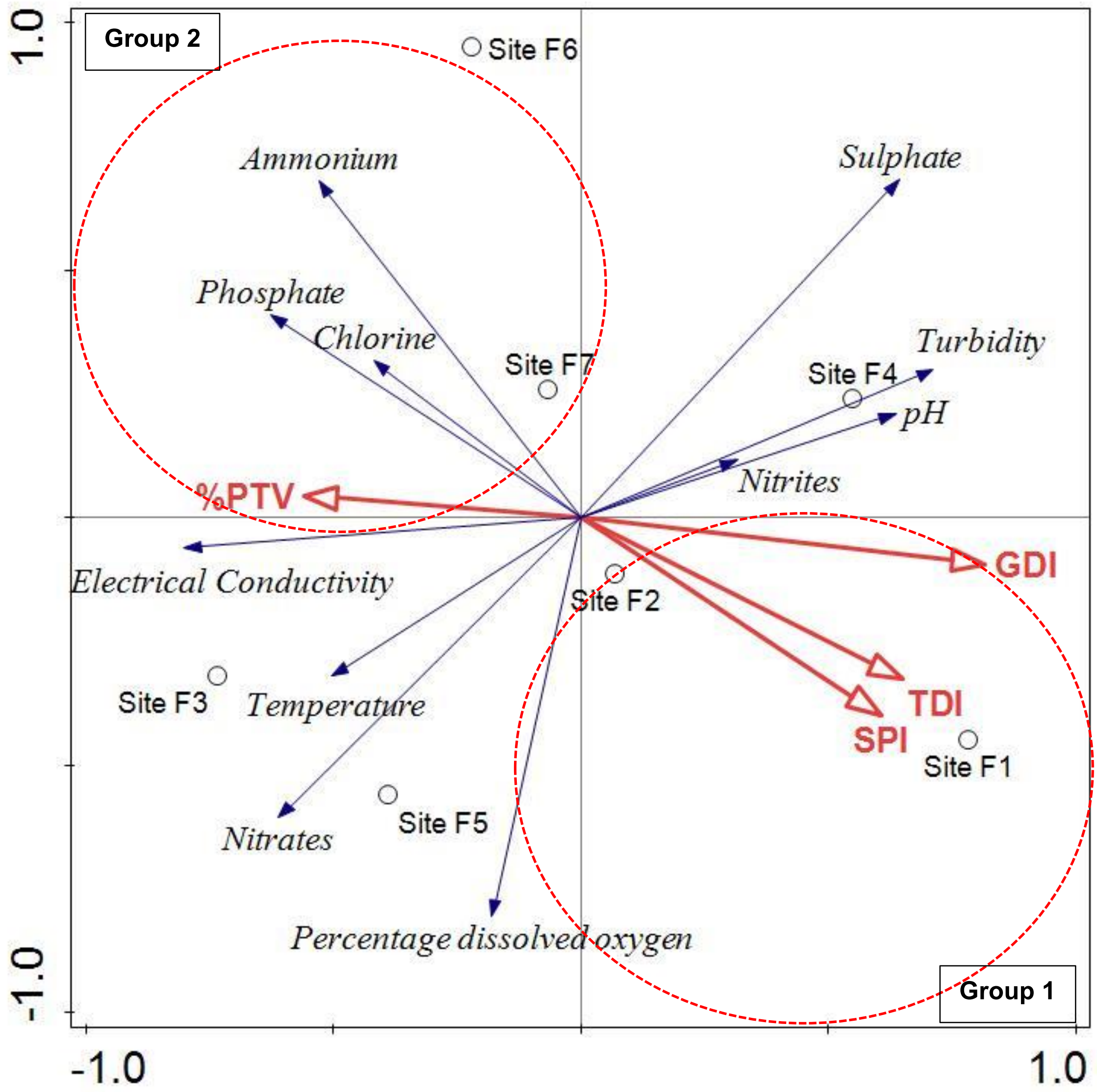

Figure 5-12. The Redundancy analysis (RDA) triplot illustrating the correlation between water quality and the fixed diatom indices results from the different sites.

Figure 5-13 illustrates the correlation between the water quality variables and the live diatom species identified at the different sites. The majority of the diatom species grouped together at sites 1 and 2 and are located within group 2. In group 1 the diatom species such as *Gomphonema* sp. (GOMS), *Gomphonema pseudoaugur* (GPSA), *Epithemia* sp. (EPIS), *Eunotia bilunaris* (EBIL), *Eunotia formica* (EFOR), *Fragilaria* sp. (FRAS), *Eunotia* sp.(EUNS) and *Fragilaria ulna* (FULN) are associated with higher concentrations of nitrites, sulphate, ammonium and phosphate and pH.. The variation explained in axis 1 was 52.35% and

25.06% in axis 2, with the cumulative variation for axis 1 and 2 calculated at 77.41%. The species from group 2 were driven by higher concentrations of chloride, nitrates, temperature and percentage dissolved oxygen.

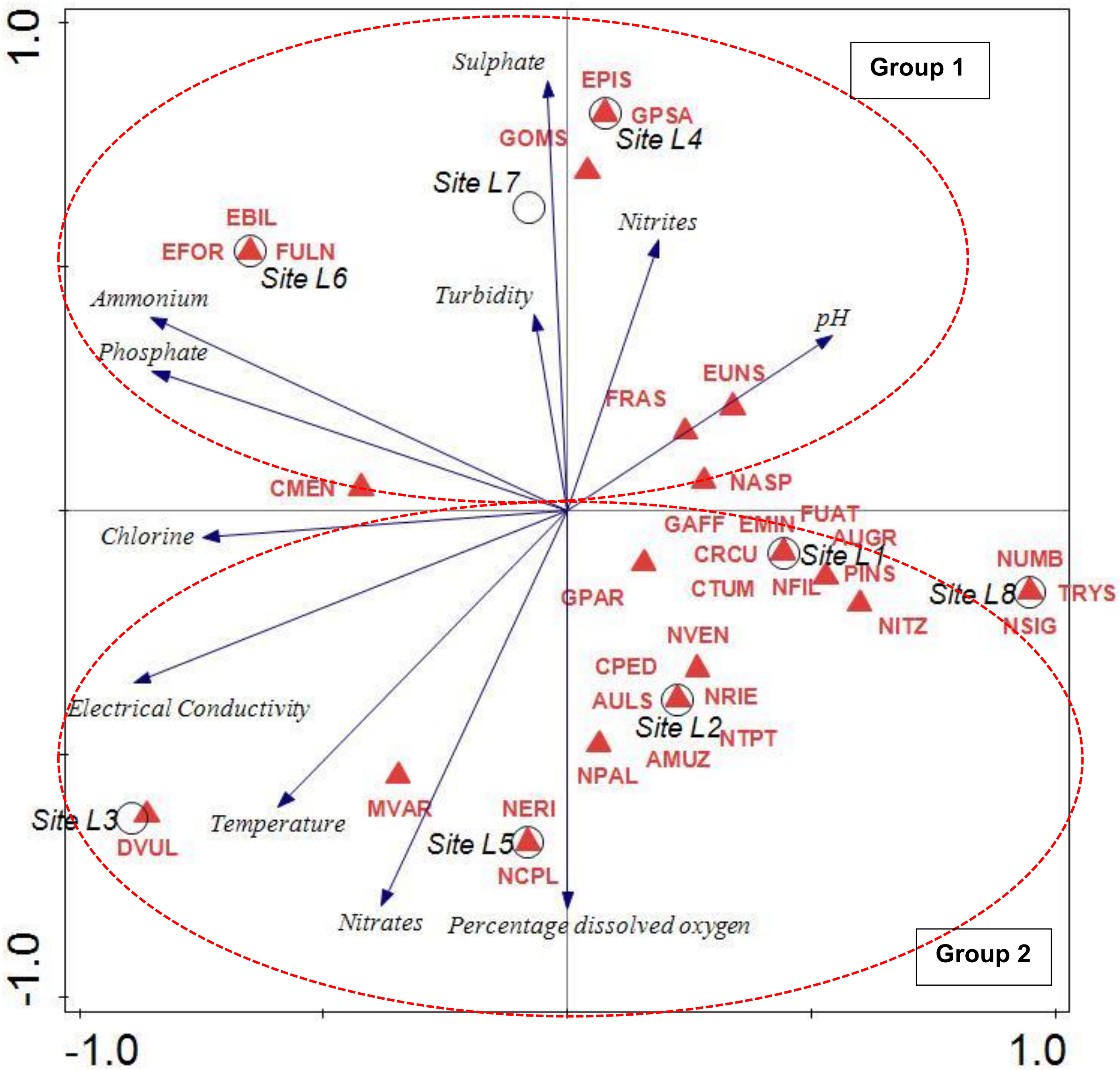

Figure 5-13 Redundancy analysis (RDA) triplot illustrating the correlation between the live diatom indices results and water quality for the different sites.

In Figure 5-14 the RDA triplot illustrates the correlation between the water quality and the fixed diatom species results at the different sites. The majority of the diatom species are grouped around sites 2, 4 and 7. Diatom species such as *Nitzschia umbonata* (NUMB), *Nitzschia* sp. (NITZ), *Hantzschia amphioxys* (HAFC), *Gomphonema parvulum* (GPAR), *Pinnularia borealis* (PBOR), *Gomphonema insigne* (GINS), *Nitzschia sigma* (NSIG), *Gomphonema lagenula* (GLGN), *Caloneis* sp. (CALS), *Amphora* sp. (AMPS), *Navicula recens* (NRCS) and *Aulacoseira granulata* (AUGR) from group 1 were related to higher concentrations of nitrites, sulphate, ammonium and phosphate. The water quality variables such as chloride, electrical conductivity, temperature and nitrates indicated a positive correlation with the species from group 2, which included species such as *Gomphonema* sp. (GOMS), *Fragilaria* sp. (FRAS), *Navicula radiosa* (NRAD), *Nitzschia palea* (NPAL), *Fragilaria nanana* (FNAN), *Frustulia tugelae* (FRSP), *Epithemia* sp. (EPIS) and *Caloneis aequtorialis* (CAQT). The variation explained in axis 1 was 52.35% and 25.06% in axis 2, with the cumulative variation for axis 1 and 2 calculated at 77.41%.

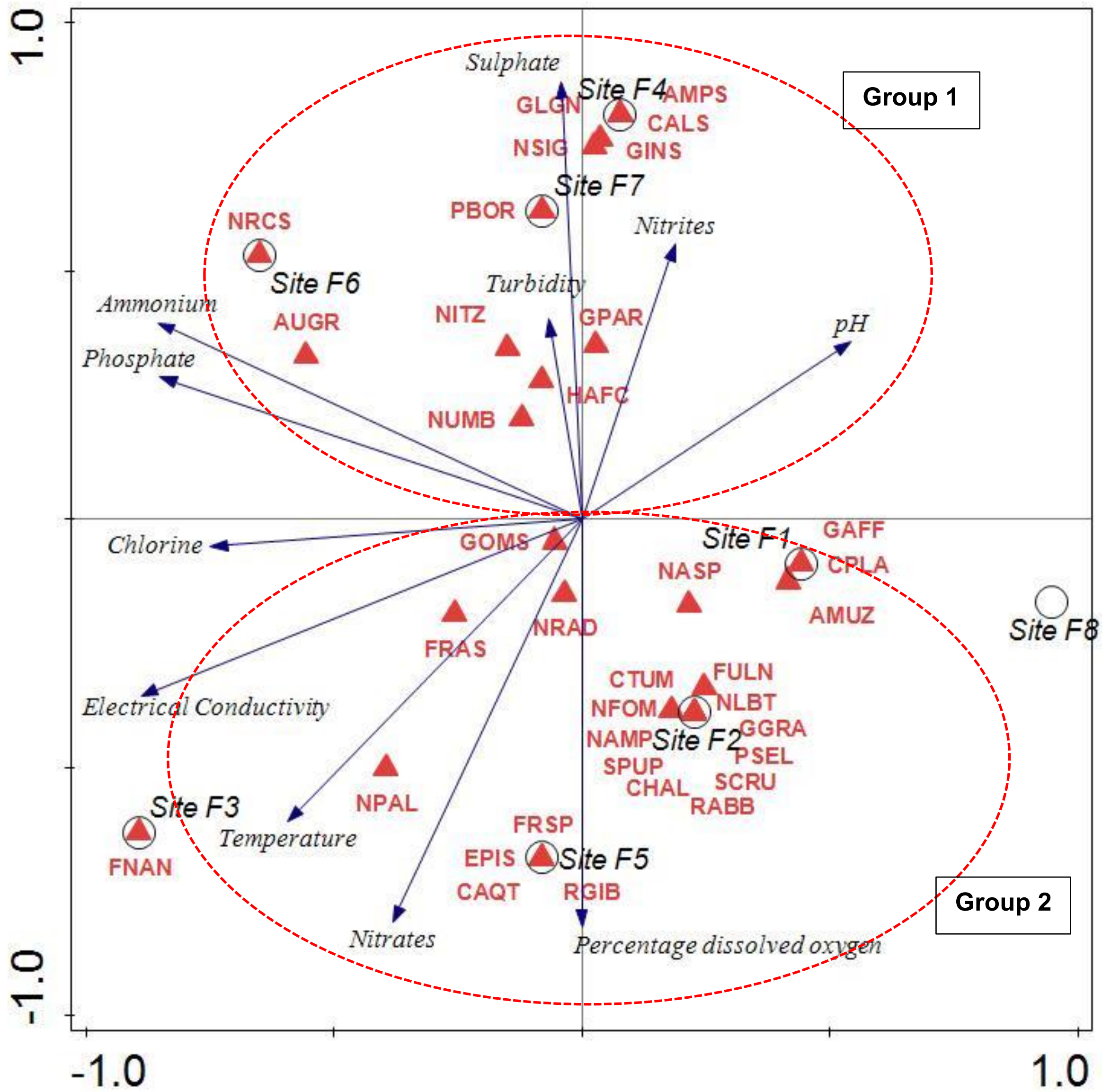

Figure 5-14 Redundancy analysis (RDA) triplot illustrating the correlation between the fixed diatom indices results and water quality for the different sites.

Chapter 6 - DISCUSSION

The water quality and diatom results for the different sampling sites were based on a once-off sampling at the sampling sites during the 15th and 16th of February 2019. The results, therefore, represent the water quality and ecosystem trophic state of the sampling sites at the time of the investigation and does not include the results from the average measurements undertaken over time.

6.1 Water Quality

According to Khatri and Tyagi (2015), the leachate from poor SW disposal contaminates the ground- and surface water resources as it increases metals, nutrients, organic contaminants, inorganic nitrogen and pathogens of the affected waters as well as contribute to elevated levels of ammonium in the water which can be harmful to aquatic organisms and can also cause negative effects for the people consuming the water (Kamal *et al.*, 2015). According to Deshmukh and Aher (2016), the leachate from dumping sites could also cause the total salts in the water to increase and thereby cause a spike in the EC and TDS concentrations of the water. The samples taken at each sampling site were therefore analysed for most of the parameters mentioned above such as nitrites, nitrates, ammonium, phosphate, sulphate and chloride as well as in situ water quality variables were measured such as electrical conductivity, pH, salinity, total dissolved solids, temperature and dissolved oxygen.

The electrical conductivity of a site can be explained as the water's ability to conduct an electrical current (DWAF, 1996). This ability is due to the presence of ions in the water that has an electrical charge, such as sodium, calcium, carbonate, chloride, bicarbonate, nitrate, sulphate, magnesium and potassium (DWAF, 1996). As the water flows downstream the salts accumulate as they are continuously being deposited into the water through anthropogenic or natural sources while other natural processes or precipitation removes very little of the salt concentration (DWAF, 1996). The TDS concentration in the water is proportional to the measured EC concentration in the water (DWAF, 1996). Electrical conductivity is regularly used as an estimate of the concentration TDS in the water because it is easier to measure than the TDS concentration (DWAF, 1996). Some of the sources that cause an increase in the TDS concentrations are effluent discharges form industries and domestic activities, as well as the surface runoff from cultivated, industrial and urban areas that enter the water resources (DWAF, 1996). The total salt concentrations can also increase as a result of evaporation (DWAF, 1996). The types of inorganic salts present in the water resources govern the effects of the TDS and EC (DWAF, 1996). The major ion concentrations present can cause the water's buffering capacity to be affected and therefore also affect the metabolism of the organisms (DWAF, 1996). The secondary effects are those affecting the chemistry of the water which causes the fate and impact of other contaminants or chemical constituents on the aquatic environment to be affected (DWAF, 1996).

Sites 1 - 3 form part of the same river system flowing in the same direction, as the water from Site 1 flows through the sampling sites 2 and 3. There was an increase in the EC and TDS concentrations from sites 1 to 2 as the water flowed downstream, and then at Site 3, the concentrations were at their highest. The effects of the downstream transportation can be observed by the increase in the EC and TDS concentrations from Site 1 to sites 2 and 3. As the water flows downstream it transports nutrients and waste products down the stream which accumulates and influences the quality of the water of the sites located downstream. This was observed by the increased EC and TDS concentrations measured at sites 2 and 3.

Sampling sites 4 – 7 form part of a different river system where the water at sampling Site 4 flows through sampling sites 6 - 7. Sampling Site 5 forms part of a small tributary that flows into the river system at Site 6. There is however another tributary that connects to the river system after sampling site 4 and just before sites 5 - 7. This tributary flows through the rural area where the illegal dumping sites area located and then connects to the river system. The tributary can impact the water quality variables of the river system depending on whether the tributary is subject to impacts upstream. It can therefore either dilute the impact or increase the impact of the river system through the transportation of nutrients and waste products of the impacts that affect the tributary upstream before it connects to the river system. Sampling Site 8, which was used as a reference site, forms part of a different river system and is not linked to the two systems mentioned above.

The EC values are lower at Site 4 and higher at sites 5 and 6 with a final decrease for Site 7 and a lower concentration at site 8. The high EC concentration at Site 3 could be as a result of the shallow water level at the sampling site, which results in the salt concentration to be higher due to evapotranspiration. There was also a prominent unbearable stench during the sampling at Site 3, which was assumed to be as a result of the sewerage inflow from the surrounding communities. According to Bhateria and Jain (2016), the EC of a system can also increase as a result of a failing sewage system due to the nitrates, phosphates and chloride concentrations that increase due to the sewerage inflow. The site was also subject to illegal dumping of litter and building rubble and the leachate from dumping site could cause the total salts in the water to increase and thereby cause the spike in the EC and TDS concentrations (Deshmukh and Aher, 2016). Site 8 had the lowest concentration EC and TDS. The site is located 21.1 km South-West of Ikageng and located far from any residential areas with no observed anthropogenic impacts which could be the result for having the lowest concentrations.

According to DWAF (1996), the turbidity is defined as an expression of the optical property that causes the light to be absorbed and scattered instead of being transmitted through the water, in straight lines. The discharge of organic waste into the water resource may cause an increase in the turbidity levels (Dallas and Day, 2004). When the turbidity levels increase it causes the primary production and light penetration to decrease resulting in a decrease in food availability for higher trophic level organisms (Dallas and Day, 2004).

In Figure 5-4 (b) it is observed that the turbidity levels decreased after Site 1 and that the levels were higher at sites 4 and 6. Sites 5, 7 and 8 had the lowest turbidity values of 5 FAU. This could be a result of low flow rate and minimal inflow at these sites. There is an increase in turbidity for sites 4 and 6 and can be a result of increased flow rate, as the water at Site 4 is channelled to flow underneath a bridge and at Site 6, the overflowing manhole causes wastewater to flow into the channel which could increase the level of turbidity due to the increased amount of particles from the wastewater channel flowing in. The turbidity values were the highest at Site 1 and can be a result of higher flow and the clay/mud composition of the sediment. The dust and runoff from the gravel roads and sandy areas at these sites can also cause the turbidity at the sites to increase.

Temperature plays a critical role as it affects the chemical reaction rates which in effect changes the organism’s metabolic rates (DWAF, 1996). Therefore, one of the main components controlling the distribution of the organisms within an aquatic environment is the temperature (DWAF, 1996). When there is an increase in the temperature there is also an increase in the vapour pressure and the thermal conductivity whereas the surface tension, viscosity, specific heat, compressibility, the latent heat of vaporization and the ionization constant decreases (DWAF, 1996).

In South Africa, the water temperatures range between 5 – 30 °C for inland waters (DWAF, 1996). In waters with higher temperatures, the dissolved oxygen solubility is reduced which results in reduced concentration and availability of dissolved oxygen to the aquatic organisms (DWAF, 1996). Several hydrological factors can cause the temperatures to change, these include the source of the water, the inflow or outflow rate of the water, the groundwater contribution, the volume of water, and many more factors (Ward, 1985).

The water quality at the sites was undertaken in February during the summer month which explains the higher water temperature measured for the different sites. The measured temperature at the sites ranged from 20.3 °C for Site 4 to a maximum temperature of 28.8 °C for Site 3. The high temperatures measured at Site 3 could be as a result of the time (early afternoon) that the sampling took place, as the temperatures were warm. The sampling at Site 4 took place during the early morning hours, while the temperature was cooler, which could be the reason for the lower temperatures measured at the sampling site. The shallow water at Site 3 could also influence the temperature as shallower waterbodies tend to warm-up quicker than deeper water bodies and therefore reach higher temperatures. At Site 4, which was located underneath the bridge of Kopanong Street, the water channel was identified to be quite deep and also flowing faster in comparison to Site 3.

With these differences in mind the measured water temperature fell within the accepted range for the inland waters of South Africa, however, a once of sampling of water temperature is not useful in measuring if there are temperature changes within the system that could raise concern. According to DWAF (1996), the temperatures of a site needs to be measured for at least 24 hours to assess the temperature variations that occur within the system.

In a water sample, the hydrogen ion activity is used to determine the pH value of the water (DWAF, 1996). As the hydrogen ion [H^+] concentration in the water increases, the pH concentration is reduced causing the solution to be more acidic and vice versa (DWAF, 1996). The pH values of surface waters usually range between 4 and 11 while in South Africa, most of the country's freshwater resources have a more neutral and well-buffered pH concentration ranging between 6 and 8. The pH levels measured at the sites were all within a relatively neutral range, ranging between 6.74 and 8.22 except for Site 3 which had the lowest pH concentration at 3.37. This pH level is extremely low, indicating that the water at Site 3 is acidic. It was observed during the site visit that the site was subject to illegal dumping which could also cause the pH concentration to decrease and the system to become acidic. Just upstream of Site 3 is the Kynoch Gypsum Tailings Dump of the Kynoch Fertilizer Factory. During a study conducted by Smit (2017), the seepage from the sides of the tailings was measured and results indicated that these tailings cause a drastic reduction in the pH levels which could therefore also be contributing factor causing the pH levels at Site 3 to be so low.

The assurance of adequate dissolved oxygen (DO) supply is very important for the functioning and survival of the organisms within the aquatic environment because all aerobic organisms require it for respiration (DWAF, 1996). The DO concentration can therefore be used as a useful tool to determine the health status of an aquatic ecosystem (DWAF, 1996). The oxygen dissolution rate of oxygen can increase if the water's turbulence increases causing the oxygen from the atmosphere to enter the system through the entrainment of air

(DWAF, 1996). According to the WQG of DWAF (1996), the TWQR for the dissolved oxygen concentration should be between 80% - 120%.

The percentage dissolved oxygen concentrations measured at the sites ranged between 33% at Site 4 with the maximum concentration of 86.7% measured at Site 2. The low DO concentrations measured at most of the sites could be as a result of the illegal dumping from the surrounding community, run-off from the surrounding areas flowing into this channel or from the decay of excessive algae or submerged plants within the system. According to Irfan (2016), a low concentration of DO mainly results from the excessive growth of algae and is usually caused by phosphorus and/or nitrogen that enter the water system from surface run-off (Irfan, 2016). When the algae decompose and die-off, the DO in the water is used in the process which causes a decrease in the DO available for the aquatic life (Irfan, 2016). Another reason for the low DO concentrations could be due to the decomposition and die-off of submerged plants (Irfan, 2016).

The measured physico-chemical water quality variables in an aquatic ecosystem indicate the quality of the water in that system. As the water flows downstream it transports nutrients and waste products down the stream which accumulates and influences the quality of the water of the sites located downstream. The concentrations of the water quality variables indicate the nutrient chemical concentrations which are then compared to the standards set out in the Water Quality Guidelines (WQG) to determine whether these ecosystems are enriched, depleted or within the range set out by the guidelines. The WQG used is the South African WQG specified for freshwater aquatic ecosystems (DWAF, 1996).

According to DWAF (1996), nitrite is an inorganic intermediate, while nitrate is the end product of the oxidation of organic ammonia and nitrogen. The more stable chemical between the two is nitrate and is also the most abundant in aquatic environments. Usually, the nitrate and nitrite concentrations are considered together as nitrogen and measured together because of their rapid inter-conversion and co-occurrence (DWAF, 1996). Ammonium is a reduced inorganic form of nitrogen and its concentration controlled by the pH and temperature of the water (DWAF, 1996). The term inorganic nitrogen, therefore, according to DWAF (1996), includes all of the inorganic nitrogen components present in the water, such as the nitrites, nitrates and ammonium (DWAF, 1996). The main concern with inorganic nitrogen is its stimulatory effect on the growth of algae and aquatic plants (DWAF, 1996). Thus, for the discussion nitrite, nitrate and ammonium will be discussed together as inorganic nitrogen.

In unimpacted (<0.5 mg/L nitrogen) waterbodies, the inorganic nitrogen concentrations are seldom identified to be high due to the rapid uptake of inorganic nitrogen by aquatic plants, which then converts it into other organic nitrogen forms and proteins within the plant cells (DWAF, 1996). According to DWAF (1996), the inorganic nitrogen concentrations measured in South Africa in aerobic, unimpacted surface water bodies is usually identified to be below 0.5 mg/L while it could increase in highly enriched waters to above 5 - 10 mg/L.

It is important, when determining the impact of the inorganic nitrogen (nitrate, nitrites and ammonium) concentration in the system, that the inorganic nitrogen is coupled to the inorganic phosphorus ratio and evaluated (DWAF, 1996). In unimpacted systems, the ratio for the N:P is usually greater than 25-40:1 (DWAF, 1996). In impacted systems, the ratios are less than 10:1 for the N:P which could result in nitrogen fixation as these ratios are very low which will contribute to the system gaining additional inorganic nitrogen (DWAF, 1996). For the current study, the N:P ratios for all the sites ranged from 3.2– 10.8:1 which indicates that the majority of the systems are impacted and could result in nitrogen fixation as there is an increase in nitrogen within the systems.

Some of the main sources of inorganic nitrogen entering aquatic ecosystems includes effluent discharges from animal and human excrement, surface runoff from the surrounding areas within the catchment and organic industrial waste fertilisers from agricultural practices (Ghaly, and Ramakrishnan, 2015). In rural areas malfunctioning and overloading of septic tanks results in surface run-off into nearby aquatic ecosystems which increases the nitrogen, phosphorus and pathogen (faecal matter) concentrations in these systems (Khatri and Tyagi, 2015).

The measured inorganic nitrogen levels at the sampling sites ranged from 3.23 mg/L to 10.81 mg/L (Figure 5-2(A-C)). These sites inorganic nitrogen levels were within the 2.5 – 10 mg/L concentration range which is indicative of a eutrophic ecosystem when compared to the WQG (DWAF, 1996). According to DWAF (1996), eutrophic conditions are aquatic ecosystems with a low species diversity, high productivity, problematic occurrence of blue-green algae blooms and aquatic plant growth, and some toxic species might be included in the algal blooms which could be harmful to livestock, humans and wildlife. It has been identified that leachate from poor solid waste (SW) disposal contaminate the ground- and surface water resources as it increases metals, nutrients, organic contaminants, and pathogens of the affected waters (Khatri and Tyagi, 2015).

According to the WQG, all of the sites fall within the concentration range explained as eutrophic conditions. Site 3 had the highest inorganic nitrogen concentration measured at 10.81 mg/L. During the sampling at Site 3, the site had a prominent unbearable stench, which was assumed to be as a result of the sewerage inflow from the surrounding communities which could also contribute to the site having the highest inorganic nitrogen concentrations. As the water flows downstream the nutrients and waste products are also transported down the stream which accumulates and influences the quality of the water of the sites located downstream, which could also be the reason for the high concentrations measured at Site 3. Another source of inorganic nitrogen could be the surface run-off at the sites which could contain fertiliser from the small-scale agricultural practices within the surrounding area. Ammonium is used as a key contaminant variable when conducting risk assessments for landfill sites as it is usually found when there is leachate from the landfill (Kamal *et al.,* 2015). Therefore, the leachate from the illegal dumping sites could also contribute to the elevated levels of ammonium in the water at the sampling sites. High levels of ammonium in the water can be harmful to aquatic organisms and can also cause negative effects for the people consuming the water (Kamal *et al.,* 2015).

According to DWAF (1996), the phosphorus concentrations in South Africa are <0.5 μg/L in unimpacted surface water bodies and are seldom identified to be of a higher concentration due to the active uptake of phosphorus by aquatic vegetation. The concentrations commonly measured in South African waters range between 10 and 50 μg/L, however, in pristine aquatic ecosystems, the soluble inorganic phosphorus has been measured as low as 1 μg/L, while in certain enclosed saline waters the phosphorus concentration was measured to be much higher at 200 μg/L (DWAF, 1996).

Phosphorus mostly occurs as phosphates. All sampling sites had phosphate values > 250 μg/l (Figure 5-2 (d)) which is indicative of hypertrophic conditions according to the WQG (DWAF, 1996). Hypertrophic conditions within an aquatic ecosystem can be described as a system where the species diversity levels are very low and the productivity of the system is high with the problematic occurrence of blue-green algae blooms and aquatic plant growth, and some toxic species might be included in the algal blooms which could be harmful to livestock, humans and wildlife (DWAF, 1996). The phosphate concentrations measured at the sites were much higher than the usual concentrations measured for aquatic ecosystems, thus indicating that there are impacts on these sites.

Some point-source discharges could cause the increase in phosphorus levels such as effluents from industrial or domestic activities or there are some non-point sources (diffuse sources) in which subsurface and surface drainage generates the phosphorus load (DWAF, 1996). Other non-point sources include urban runoff, atmospheric precipitation, drainage form agricultural land on which fertilisers have been used (DWAF, 1996). The discharge of sewage into a water resource also contributes to high concentrations of phosphorus in the water (Dallas and Day, 2004). This could be a contributing factor at Site 3 where raw sewerage is being discharged into the stream as well as at Site 6 where there is an overflowing manhole spilling effluent into the channel upstream from sampling Site 6.

Sulphur is known as a very important element in living systems as it is an important component of protein (Dallas and Day, 2004). In water, sulphur mainly occurs as the sulphate (SO_4) ion which in natural waters, usually occurs in a concentration lower than that of the chloride or bicarbonate ions (Dallas and Day, 2004). In themselves, sulphates are not known to be toxic, however, when in excess it forms sulphuric acid which has been identified to have detrimental impacts on the aquatic ecosystem as it results in a decrease in pH levels as it is a strong acid (Dallas and Day, 2004). The sulphate levels can be very high at mines which can cause problems when the runoff of the mines seeps into the water resources causing the sulphate levels to increase in affected water resources (Dallas and Day, 2004). The sulphate levels can increase in areas where the river system is poorly buffered which could result in the pH level drastically dropping (Dallas and Day, 2004).

In the study, it was observed that the sulphate concentrations at Site 4 (212 mg/L) were much higher than the concentrations measured at site 3 (46 mg/L). After Site 4 the sulphate concentration levels decreased, which could be as a result of the inflow from the tributary between sites 4 and 6 and the tributary at site 5 as there was an increase again at Site 6 (149 mg/L) and Site 7 (177 mg/L) with a low concentration of 50 mg/L at Site 8. The increased sulphate and nitrate concentrations could be as a result of runoff from sewage effluents and agricultural run-off containing fertilisers (Khatri and Tyagi, 2015). There was an overflowing manhole observed at Site 6 which causes wastewater to flow into the channel.

The chloride concentration measured for the different sites is shown in Figure 5-2 (f) above. Chloride as either available chlorine (chloramines) or free forms (OCl^- and $HOCl^-$) enter the aquatic ecosystem due to activities such as the chlorination of drinking water, pulp and paper industry, the cooling of waters, disinfectants used in swimming pools, sewage treatment, and the textile industry (DWAF, 1996). According to DWAF (1996), the measured chloride values at sites should fall below the Chronic Effect Value (CEV) and ninety percent (90 %) of the measurements should fall within the Target Water Quality Range (TWQR) to ensure that the aquatic ecosystems are protected.

The chloride measurements for all the sites exceeded the TWQR of 0.2 µg/L by far and also exceeded the CEV of 0.35 µg/L and the Acute Effect Value (AEV) of 5 µg/L. The chloride concentrations in the water can be derived from sources of pollution such as septic tanks, fertilizers and domestic and industrial effluents (Böhlke and Horan, 2000; Edmunds *et al.,* 2003; Négrel and Pauwels, 2003; Petelet-Giraud *et al.,* 2003; Widory *et al.,* 2004; Valdes *et al.*, 2007).

The acute and chronic toxicity effect can occur in the event of an accidental spill where the measurements of the chloride concentration exceed the AEV and usually, these toxic effects are irreversible (DWAF, 1996). Diatoms are very sensitive to chloride compared to green algae while newly hatched fish larvae are more sensitive than fish eggs to chloride (DWAF, 1996). When invertebrates are exposed to chloride, they become immobile and indicate signs of reduced survival and reproduction rates (DWAF, 1996). The fact that the chloride levels were high at the sampled sites raises a lot of concern as these concentrations can cause toxic effects in the aquatic ecosystem and therefore harm the aquatic biodiversity of the area.

6.2 Diatom species assemblage

Diatoms are considered to be very good indicators of water quality as they have a rapid response to changes within their environment and different species have very specific responses to changes within their environment such as organic enrichment, eutrophication, salinization and especially changes within the pH (Battarbee *et al.,* 1997; Rott *et al.,* 1998; Martín and de los Reyes Fernández, 2012). For instance, when some disturbance causes the environment to change, the sensitive diatom species would be the first to die-off while the more tolerant diatom species would be able to survive and become more dominant within the system. Therefore, the dominant species can be used to interpret the short-term changes in their environment.

During the study, a total of 56 diatom species were identified over the eight sampling sites. The dominant species identified for each site (marked in bold in Table 5-1) were those found to be most abundant during the live and fixed diatom identification. The dominant species identified at the sampling sites indicated that all the sites (except sites 1 and 8) are eutrophic as these are species that prefer nutrient-enriched waters and are indicators of polluted waters. The majority of these species according to Taylor *et al.* (2007a), are those commonly identified in waters known to be eutrophic and heavily to extremely polluted. This corresponds with the measured physicochemical water variables which also indicated these sites as nutrients enriched and affected by some sort of pollution. The elevated levels of nutrients could be as a result of the leachate of the illegal dumping sites found around the sampling sites as indicated by previous studies conducted by Khatri and Tyagi (2015). *Melosira varians* which is usually an abundant species in eutrophic and slightly brackish waters (Taylor *et al.,* 2007c), was a dominant species at Site 3 where the water also consisted of low pH concentrations. The dominant species identified at Site 1 (*Cymbella tumida* and *Navicula* sp.) is indicative of oligo- to mesotrophic waters while the dominant diatom at Site 8 (*Nitzschia* sp.) could not be identified to species level to determine the ecology preference of the species as the ecology of each species differ.

During the results from the diatom identification, it was observed that the live and fixed species composition for the different sites were different which, according to Wilson and Holmes (1981), is usually the case. This is as a result of the procedures followed to preserve the fixed samples as it destroys all the cellular components of the diatom cells which makes it impossible to differentiate between the cells that were alive and those that were dead during the time of sampling (Wilson and Holmes, 1981). Therefore, the results of the fixed samples contain cells that were not alive during the sampling which could have been deposited in the system anything from a week to a year ago, and could sometimes, for this reason, be regarded as misleading (Wilson and Holmes, 1981). The live diatom samples differ as they only represent the cells that were alive during the time of sampling (Wilson and Holmes, 1981). This explains why the diatom species composition identified for the different sites consisted of different species for the live and fixed diatom samples of the same sites.

6.3 Diatom indices

Selected diatom indices were also used to determine the water quality of the sampled sites. The indices selected for the study included the SPI, GDI, TDI and %PTV. These indices are calculated based on the diatom community identified at each site and on the sensitivity of the diatoms to their environment based on already available information. Index scores for the fixed and live samples are discussed together as these scores were similar for all sites.

The SPI and GDI indices were used to determine the trophic state of the sampling sites based on the calculated scores which indicated all sites to be either in a meso-eutrophic or eutrophic trophic state (poor to bad water quality range). However, for sites 1 (fixed) and 3 (live) the samples' SPI score and sites 4 and 6's GDI scores for the (live) samples indicated these sites as mesotrophic (moderate ecological state).

These indications of poor to bad water quality also explain why most of the dominant species identified at the sites are species usually identified in eutrophic and slightly brackish waters and some in heavily to extremely polluted waters. These results, therefore, indicate that the ecosystem is enriched with nutrients which correlates with the water quality and dominant diatom species results.

It was expected that the water quality at Site 8 would be in a better ecological state when compared to the other sites as this site is located 21.1 km South-West from the sampling sites in Ikageng, just upstream from the N12, and there were no visible impacts leading up to the site. The site runs through no urban areas, with no visible illegal dumping or other pollutants except for a highway close by. This site was chosen as a reference site as it had a similar-sized stream as the other sites and no visible impacts. However, according to the water quality, dominant diatom species and diatom indices this was not the case. It could be that there were some disturbances taking place upstream of Site 8, which affected the water quality downstream at the site.

The calculated TDI index scores for the sites were low (1.3-10.1) indicating that the sites were of an oligotrophic level and high ecosystem quality. However, it is stated according to Kelly and Whitton (1995), that the diatom community can be influenced by other environmental changes (light, temperature and water velocity) other than nutrient influences, which could occur over a medium to long term period causing the TDI score to be influenced. The TDI index score, therefore, needs to be carefully interpreted and used together with the %PTV index as this index determines the cause for the TDI score, whether it be organic pollution or nutrient enrichment (Kelly and Whitton, 1995). Therefore, the results of the TDI score stating that the sites were oligotrophic and of high ecosystem quality, is in contrast with that stated by the SPI and GDI index scores.

The %PTV results for the fixed samples classified that sites 1 and 5 did not contain any organic pollution whilst the live samples reflected that some evidence of organic pollution was identified at Site 5. Sites 2 and 3 from the fixed samples were classified as heavily contaminated with organic pollution. The %PTV index for the live diatom samples, however, indicated limited organic pollution at Site 2 while indicating no organic pollution at Site 3. Site 8 indicated limited organic pollution from the live diatom samples.

According to Wilson and Holmes (1981), the diatom species composition for the live and fixed samples will be different. This is as a result of the procedures followed to preserve the fixed samples as it destroys all the cellular components of the diatom cells which makes it impossible to differentiate between the cells that were alive and those that were dead during the time of sampling (Wilson and Holmes, 1981). Therefore, the results of the fixed samples contain cells that were not alive during the sampling which could have been deposited in the system anything from a week to a year ago, and could sometimes, for this reason, be regarded as misleading (Wilson and Holmes, 1981). The live diatom samples differ as they only represent the cells that were alive during the time of sampling (Wilson and Holmes, 1981). This was confirmed during the diatom identification as during the live sample identification the diatoms were alive and the samples/diatoms contained a chloroplast.

The %PTV scores for the fixed diatom samples of sites 4 and 7 indicated that the sites are subject to organic pollution which is likely to contribute to eutrophication, while the %PTV scores for the live diatom samples indicated that these two sites were free of organic pollution. The %PTV index score for Site 6 indicated organic pollution in the system. This could be as a result of the overflowing manhole that was observed at Site 6, which caused wastewater to flow into the stream channel or it could be as a result of the inflow from the two tributaries, that connects to the river system after sampling site 4 and at site 5. Wastewater discharge is also a source of organic pollutants according to Wen *et al.* (2017). The dominant species identified for the live and fixed diatom identification could be the reason for the %PTV scores for the live and fixed diatom samples to be different for each site. All of the sites had vegetation growing on the edge of the streams and along the edge of Poortjie Dam at Site 2. The decay of plant material and livestock manure in the area can also cause the organic material in the water to increase (Irfan, 2016).

According to Obinna and Ebere (2019), pollutants that are described as organic in nature are known as organic pollutants and these pollutants contain carbon that has covalently bonded with other compounds. Organic pollutants can be carcinogenic or toxic in nature. Some of the sources of organic pollutants include disinfecting by-products, detergents, herbicides, insecticides, food processing waste, fuel combustion by-products (Obinna and Ebere, 2019), and wastewater discharge (Wen *et al.,* 2017). The discharge of wastewater from human activities into rivers causes organic pollution and can have negative effects on the ecosystem health of the river and human health (Wen *et al.,* 2017). Pathogens are contained in untreated sewage and can cause a range of diseases of which diarrhoea is one of them and is the leading cause globally of waterborne illness and death (Wen *et al*., 2017).

The calculated %PTV scores for the fixed diatom samples indicated that sites 2 and 3 were heavily contaminated with organic pollution which could be as a result of wastewater discharge from the surrounding areas causing organic pollution. These sites are located within the rural areas of Ikageng and Promosa. During the site visits, it was observed that these areas lack proper waste and sanitation services as there were heaps of illegal dumping sites scattered all around and there were several areas where wastewater was directly being released into the water resources (sites 3 and 6). At Site 3 there was a stench assumed to be from wastewater that is contaminating the stream.

The positive correlation between SPI, GDI and TDI indices and ammonium, phosphate, chloride, electrical conductivity, temperature and nitrates in Figure 5-12 were expected as the nutrient concentrations for the sites were high and indicative of eutrophic conditions. These indices were grouped with the nutrients which indicates that nitrate was a driving force in eutrophication, as identified earlier in section 6.1 from the N:P ratios determined for the sites. The SPI and GDI index scores were low and within the range indicative of poor to bad water quality and meso-eutrophic or eutrophic conditions. Therefore, with an increase in the nutrient concentrations there is a decrease in these index scores, and therefore in the water quality which is what was expected as this can be seen in the water quality and index score results. The TDI index scores indicated all sites to be within an oligotrophic trophic state and high ecosystem quality. The %PTV indicated a positive correlation to the ammonium, phosphate, chloride, electrical conductivity, temperature and nitrate results which could mean that organic pollution could be the primary driver influencing the water quality at some of the sites.

The live diatom sample's SPI and GDI scores indicated a positive correlation to the turbidity, ammonium and phosphate while the TDI indicates a positive correlation to the sulphate and a negative correlation to the nitrates and percentage dissolved oxygen. This was expected as the ammonium and phosphate concentrations for the sites were identified to be high and the SPI and GDI concentrations were low and therefor all indicative of eutrophic conditions. The %PTV indicated a negative correlation to the ammonium and phosphate which could mean that organic pollution had very little to no influence in affecting the nutrient concentrations at sites 5 and 8.

The poor water quality found at the sampling sites can be as a result of the illegal dumping sites located near these sites (1-7). It was expected that the water quality at Site 8 would be in a better ecological state due to the site being chosen as a reference site as it had a similar-sized stream compared to the other sites and no visible impacts. However, according to the result of the water quality, dominant diatom species and diatom indices it could be that there were some disturbances taking place upstream of Site 8, which affected the water quality downstream at the site.

The leachate from the illegal dumping sites at sites 1-7 could, according to Kamal *et al.* (2015), contribute to the elevated levels of ammonium measured in the water and be the reason for the increase in the EC and TDS concentrations measured at the different sampling sites (Deshmukh and Aher, 2016). According to Khatri and Tyagi (2015), the elevated concentrations of inorganic nitrogen measured for the different sites could also be as a result of the leachate from surrounding dumping sites. The increased inorganic nitrogen from the leachate from the illegal dumping sites could result in an excessive growth of algae in the water resources. When the algae decompose and die-off, the DO in the water is used in the process which causes a decrease in the DO concentrations available for the aquatic life (Irfan, 2016). These indications of the poor to bad water quality also explains why most of the dominant species identified at the sites are species usually identified in eutrophic and slightly brackish waters and some in heavily to extremely polluted waters and therefore also explains the low SPI and GDI index scores and the %PTV scores calculated for the different sites.

These results, therefore, indicate that the ecosystem is enriched with nutrients which correlates with the water quality and dominant diatom species results. According to Khatri and Tyagi (2015), the leachate from poor SW disposal contaminate the ground- and surface water resources as it increases metals, nutrients, organic contaminants, inorganic nitrogen and pathogens of the affected waters as well as contribute to elevated levels of ammonium in the water which can be harmful to aquatic organisms and can also cause negative effects for the people consuming the water (Kamal *et al.,* 2015). The elevated levels of nutrients could be as a result of the leachate of the illegal dumping sites found around the sampling sites as indicated by previous studies conducted by Khatri and Tyagi (2015). It should however be stressed that various other pollution sources (such as waste water discharge and agricultural runoff) were also found at the sampling sites which could have also contributed to the certain elevated water quality variables measured. It can therefore be concluded that illegal dumping together with various other sources (such as waste water and agricultural runoff) does have an impact on the quality of the selected water resources within the Ikangeng and Promosa area.

Chapter 7 - CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Waste management services are under considerable pressure, worldwide, which is only increasing as the human population increases. An increase in human population causes an increase in the food consumption of the country and therefore results in more waste being generated. This pressure on the waste management services result in a lack of municipal service delivery in certain areas and contributes to events of illegal dumping which results in negative effects on the health of humans and the environment (Abel, 2014). Illegal dumping can threaten aquatic and wildlife habitats (Hanfman, 2012). The study aimed to assess the impact that illegal dumping has on the surface water quality of selected watercourses within the Ikageng and Promosa areas of Potchefstroom, through the use of diatoms as a bioindicator of the health and ecological state of the surrounding aquatic ecosystem.

During the study, water and diatom samples were collected from eight different sites. Seven sites were subject to illegal dumping where waste has been disposed of next to and/or within the water resources. Site 8 was used as a reference site to determine the anthropogenic impacts at the other sites and the effect of the illegal dumping on the water quality of those sites. There was no evidence of potential pollution sources observed at Site 8 during the field investigation, however, during the analysis, it was identified that the water quality of the site was also impacted and in a poor ecological state. The water quality results analysed for the other sites indicated that these sites were also impacted. The concentration of some of the water quality variables raised concern as they exceed the specified concentration range within the WQG specified for aquatic ecosystems (DWAF, 1996).

The inorganic nitrogen (nitrate, ammonium and phosphate) concentrations were very high and indicated the sites to be of a eutrophic/hypertrophic ecological state. These eutrophic conditions at the sites are problematic as it can cause excessive growth of aquatic plants and blue-green algae blooms of which some species could be toxic and harmful to the livestock, humans and wildlife within the area (DWAF, 1996).

The chloride concentrations for all sites far exceeded the chronic and the acute effect value. The pH level measured at Site 3 was extremely low and indicates that the system is very acidic, with pH values within the recommended range measured for all the other sites. During the sampling at Site 3, the site had a prominent unbearable stench, which was assumed to be as a result of the sewage inflow from the surrounding communities as well as visible illegal dumping.

The elevated nutrient concentrations can be as a result of the illegal dumping, however, there are also other pollution sources upstream from the sites which could cause these concentrations to increase. The presence of the illegal dumping at these sites will definitely contribute to these elevated nutrient concentrations as previous studies have indicated illegal dumping to be a contributing factor in certain elevated water quality variables such as nutrients.

The dominant diatom species identified at the sites were indicative of bad water quality and specifically eutrophic, brackish and extremely polluted waters. The diatom indices (SPI and GDI) indicated that the sites had poor to bad water quality and were classified as eutrophic. These results correspond with the measured water quality and dominant diatom species identified at each site. The %PTV scores for sites 2 and 3 (fixed) indicated that these sites are heavily contaminated with organic pollution which could be as a result of wastewater discharge from the surrounding areas causing organic pollution. The fixed and live diatom samples had a similar trend for some of the index scores for most of the sites while Site 3 had little resemblance in the index trend for the live and fixed samples.

The results from the water quality and diatom sampling indicate that the water resources at all the sites are impacted and have poor water quality and that the aquatic ecosystems present at the sites were in eutrophic or hypertrophic condition. The hypothesis of the study is therefore supported as it can be concluded that the illegal dumping of waste near water sources does negatively influence the water quality of these water resources by altering the water quality parameters which has led to eutrophic polluted conditions. However, it was also found that the negative alteration of water quality was not just because of the illegal dumping at these sites but a combination of factors, such as waste water and agricultural runoff, contributing to this decrease in water quality.

The local municipality must be informed of the extent of all these illegal dumping sites within the Ikageng and Promosa areas. South Africa has national policies and strategies in place to deal with dumping and sanitation needs, but the challenge is the effective implementation of these policies and strategies at a local municipal scale. It is therefore important that more effort and planning is undertaken to ensure that sound municipal waste management is effectively implemented and to get stakeholder involvement at all levels ranging from government and local authority down to the participation of the community. All measures must be taken to develop a common front in which the effects of illegal dumping can be reduced on a global scale while allowing for the environmental conditions to improve and allow for sustainable development.

7.2 Recommendations

- It is recommended that the sampling of the water quality and diatoms is more regularly undertaken, and also seasonally to determine how water quality variables change over time and seasons.
- To gather more information regarding the effect of illegal dumping on the water quality, more water quality variables should be considered to be measured such as COD (sewage variable), VOC, THM, CR_{6+} (disposal of hazardous waste variables), COD (general waste variable), Mn (mine pollution variable) (DWAF, 1998) as well as the microplastic pollution within the affected water resources.
- Analyse the different forms of waste present (organic, inorganic, metal, chemical) and their effects on the water quality and diatom community, to determine which waste form is most common and/or causes the greatest negative effect on the ecosystem.
- Other biotic indicators can also be used to determine how the aquatic health and ecosystem is impacted by the illegal dumping sites.
- It is also recommended that another site is chosen upstream from the rural areas and illegal dumping sites to determine how the water quality changes as it flows downstream through these rural areas and towns.
- The local municipality must be informed of the extent of all these illegal dumping sites within the Ikageng and Promosa area which is deteriorating the environment and can also have effects on the health of both humans and the biodiversity.
- In poorer rural areas, it is not always possible for the residents to pay the tariffs for municipal waste removal. It is therefore recommended that the municipality provides designated areas within the rural community area, where residents can dispose of their waste which the municipality must then remove, once a week, to ensure the protection of the environment and the community.
- It is also important that awareness is raised, and that the community is educated on sustainable waste management practices. The community should be made aware of the impacts that these activities of illegal dumping have on the environment and the water quality resources on which they depend.
- The fine for being caught dumping waste illegally should also be emphasized so that the residents understand the consequences of their actions.
- Law enforcement personnel should be appointed to monitor the illegal dumping events within the community area and also determine who the big offenders are in terms of illegal dumping in each area.

- Signs prohibiting illegal dumping should also be placed at areas where illegal dumping occurs. These areas should be well lit and landscaped to help in preventing people from dumping illegally. The signs will also make residents aware that it is illegal to dump their waste and that they can be prosecuted or fined if caught.

Chapter 8 - REFERENCES

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APPENDIX A

Table A. Measured water quality results for all sites during one survey in February 2019.

	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
DO (%)	70.2	86.7	72	33	67.7	33.9	46.9	42.7
Temperature (°C)	24.5	23	28.8	20.3	23	24	20.6	21.3
Ph	8.22	8.22	3.37	7.1	7.47	7.72	7.26	6.74
Turbidity (FAU)	19	10	7	16	5	15	5	5
Electrical Conductivity (µS)	315	636	1993	300	684	931	260	94
SO_4 (mg/L)	110	109	46	212	54	149	177	50
NH_4 (mg/L)	0.2	0.39	4.68	1.6	0.35	5.7	3.04	0.16
NO^-_3 (mg/L)	4.4	3.6	6.1	1.8	7.2	3.6	3.2	3
NO^-_2 (mg/L)	0.04	0.04	0.03	0.18	0.1	0.04	0.11	0.07
PO_4 (mg/L)	1.46	1.02	8.68	4.88	5.64	8.34	8.66	0.87
CL (mg/L)	16.7	23.4	23.2	21.5	21	26.4	15.1	12.3
TDS (mg/L)	234	448	1400	204	479	470	186	62.2

APPENDIX B

Table B. The results of the diatom species and counts identified for the different sites for the fixed (site F1-F8) samples and the live (site L1-L8) diatom samples.

	Site L1	Site L2	Site L3	Site L4	Site L5	Site L6	Site L7	Site L8	Site F1	Site F2	Site F3	Site F4	Site F5	Site F6	Site F7	Site F8
***Amphora* sp.**	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0
***Aulacoseira muzzanensis* (Meister) Krammer**	0	46	0	0	0	0	0	0	59	8	0	0	0	0	0	0
***Aulacoseira granulata* (Ehrenberg) Simonsen**	15	20	0	0	5	0	11	41	0	0	0	0	3	15	0	0
***Aulacoseira* sp.**	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Caloneis* sp.**	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0
***Caloneis aequatorialis* Hustedt**	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
***Craticula halophila* (Grunow) D.G.Mann**	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
***Cyclotella meneghiniana* Kützing**	0	0	0	0	2	3	0	0	0	0	0	0	0	0	0	0
***Cocconeis pediculus* Ehrenberg**	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Cocconeis placentula* Ehrenberg**	0	0	0	0	0	0	0	0	93	0	0	0	0	0	0	0
***Craticula cuspidata* (Kützing) D.G. Mann**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Cymbella tumida* (Brébisson)Van**	62	0	0	0	0	0	0	0	0	23	0	0	0	0	0	0

	Site L1	Site L2	Site L3	Site L4	Site L5	Site L6	Site L7	Site L8	Site F1	Site F2	Site F3	Site F4	Site F5	Site F6	Site F7	Site F8
Heurck																
***Diatoma vulgaris* Bory**	0	1	35	0	0	0	0	0	0	0	0	0	0	0	0	0
***Eunotia bilunaris* (Ehrenberg) Mills**	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
***Eunotia formica* Ehrenberg**	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
***Eunotia minor* (Kützing) Grunow**	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Epithemia* sp.**	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0
***Eunotia* sp.**	0	0	0	0	0	1	2	3	0	0	0	0	0	0	0	0
***Fragilaria nanana* Lange-Bertalot**	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
***Fragilaria* sp.**	0	0	1	4	1	0	0	3	0	1	0	0	4	3	0	0
***Frustulia* sp.**	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
***Fragilaria ulna* var. *acus* (Kützing) Lange-Bertalot abnormal form**	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Fragilaria ulna* (Nitzsch.) Lange-Bertalot**	0	0	0	0	0	1	0	0	2	3	0	0	1	0	0	0
***Gomphonema affine* Kützing**	41	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
***Gomphonema gracile* Ehrenberg**	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
***Gomphonema insigne* Gregory**	0	0	0	0	0	0	0	0	0	0	0	28	0	0	0	0
***Gomphonema lagenula* Kützing**	0	0	0	0	0	0	0	0	0	0	0	54	0	0	18	0

	Site L1	Site L2	Site L3	Site L4	Site L5	Site L6	Site L7	Site L8	Site F1	Site F2	Site F3	Site F4	Site F5	Site F6	Site F7	Site F8
***Gomphonema* sp.**	1	0	0	8	0	1	0	0	11	1	1	0	5	8	0	0
***Gomphonema parvulum* (Kützing) Kützing**	7	34	0	5	0	4	3	0	0	69	0	81	0	20	36	0
***Gomphonema pseudoaugur* Lange-Bertalot**	0	0	0	156	0	0	2	0	0	0	0	0	0	0	0	0
***Hantzschia amphioxys* fo. *capitata* O. Müller**	0	0	0	0	0	0	0	0	0	0	0	0	11	0	31	0
***Melosira varians* Agardh**	19	0	56	0	39	0	0	4	0	0	0	0	0	0	0	0
***Nitzschia amphibia* Grunow**	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
***Navicula* sp.**	1	32	0	22	0	0	0	9	138	0	4	10	67	0	18	0
***Nitzschia capitellata* Hustedt**	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
***Navicula erifuga* Lange-Bertalot**	0	0	0	0	79	0	0	0	0	0	0	0	0	0	0	0
***Nitzschia filiformis* (W.M.Smith) Van Heurck**	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Nitzschia fonticola* Grunow fo. *minutissima* Compère**	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
***Nitzschia* sp.**	3	2	10	0	2	0	5	60	2	14	0	22	11	28	25	0
***Nitzschia liebetruthii* Rabenhorst**	0	0	0	0	0	0	0	0	0	63	0	0	0	0	0	0
***Nitzschia palea* (Kützing) W.Smith**	21	24	0	2	75	1	1	0	0	153	196	0	17	11	0	0

	Site L1	Site L2	Site L3	Site L4	Site L5	Site L6	Site L7	Site L8	Site F1	Site F2	Site F3	Site F4	Site F5	Site F6	Site F7	Site F8
***Navicula radiosa* Kützing**	0	0	0	0	0	0	0	0	0	0	0	25	54	0	6	0
***Navicula recens* (Lange-Bertalot) Lange-Bertalot**	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
***Navicula riediana* Lange-Bertalot & Rumrich**	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Nitzschia sigma* (Kützing) W.M.Smith**	0	0	0	0	0	0	0	13	0	0	0	10	0	0	5	0
***Navicula tripunctata* (O.F.Müller) Bory**	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Nitzschia umbonata* (Ehrenberg) Lange-Bertalot**	0	0	0	0	0	0	0	8	0	0	7	16	21	0	35	0
***Navicula veneta* Kützing**	14	35	0	0	3	0	0	0	0	0	0	0	0	0	0	0
***Pinnularia borealis* Ehrenberg**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
***Pinnularia* sp.**	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
***Pinnularia subcapitata* Gregory var. *elongata* Krammer**	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
***Rhoicosphenia abbreviata* (C.Agardh) Lange-Bertalot**	0	0	0	0	0	0	0	0	19	0	0	0	19	0	0	0
***Rhopalodia gibba* (Ehrenberg) O.F. Müller**	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0

	Site L1	Site L2	Site L3	Site L4	Site L5	Site L6	Site L7	Site L8	Site F1	Site F2	Site F3	Site F4	Site F5	Site F6	Site F7	Site F8
***Surirella crumena* Brébisson**	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
***Sellaphora pupula* (Kützing) Mereschkowksy**	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0
***Tryblionella* sp.**	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0

APPENDIX C

Table C. The diatom index scores determined for the fixed and live diatom samples. There is no information for the fixed sample of Site 8 as there were no diatoms identified for Site 8.

	Site L1	Site L2	Site L3	Site L4	Site L5	Site L6	Site L7	Site L8	Site F1	Site F2	Site F3	Site F4	Site F5	Site F6	Site F7
SPI	9.9	6.7	12.4	11.1	4.4	10.0	6.2	4.6	13.3	3.3	1.2	7.8	11.3	4.6	5.4
GDI	13.7	11.2	12.1	13.2	7.5	14.3	10.4	5.3	12.8	5.1	1.3	10.5	9.1	7.0	6.2
TDI	7.1	2.7	3.6	9.5	4.3	10.1	7.8	6.8	8.2	2.5	1.3	4.0	5.7	3.3	4.6
%PTV	15.3	28.6	0.0	3.5	37.0	35.7	16.7	30.6	0.0	81.4	97.1	41.3	17.1	36.0	42.2