Spatial changes in algal assemblages promoted by water quality in the Sabie River catchment

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DECLARATION

I hereby declare that this dissertation, entitled, *Spatial changes in algal assemblages promoted by water quality in the Sabie River catchment*, is my own work conducted under the supervision of my respective supervisors. Any assistance, sources, quotes that I have received has been duly indicated and acknowledged in this dissertation by means of complete references. This information is submitted in fulfilment of the requirements for the degree Masters of Science in Environmental Sciences at the North-West University (NWU Potchefstroom Campus).

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ABSTRACT

The Sabie River catchment forms part of the bigger Inkomati Catchment Management Area under the management of the Inkomati Usuthu Catchment Management Agency, in the Mpumalanga Province and covers about 6 320 square kilometres. The headwaters of the Sabie River and its tributaries such as the Sand River and Marite River arise from the upper Drakensberg escarpment, flowing eastwards into the Lowveld through drastically changing topography, through the Kruger National Park (KNP) into Mozambique where it becomes part of the Inkomati River system. The water of the Sabie River system is vital to the economy of the communities in the area and plays a role in agriculture and ecotourism. It is imperative to monitor and manage the Sabie-Sand sub-catchment's water quality as it is also important to the ecosystem health of the KNP. The Inkomati River system is an international shared watercourse with Mozambique and therefore South Africa has an obligation to meet the international water quality requirements in the Mpumalanga area, with a further obligation to ensure high-quality water sharing between the three co-basin areas.

This study proposed to measure the relationship between water quality and spatial and temporal changes in the algal composition of the Sabie River and its main tributaries namely the Marite and Sand Rivers as well as in the Inyaka Dam. Observing algal assemblages has been important in environmental assessments both to indicate changes in environmental conditions that might impair or threaten ecosystem health as well as to determine if algae themselves are causing problems. Therefore, during this study, the changes in the algal assemblages were determined with specific regard to genera diversity, as well as changes in assemblages during different environmental conditions experienced during the study period. The water quality and algal assemblages of the Inyaka Dam, which is situated in the Marite River, was also included in this study as it is the main water source of the Inyaka Water Supply Scheme and therefore does not only impact on the Sabie River system but directly influences the communities depending on it as a potable water resource.

This study was a collaborative project between the North-West University (NWU), Rand Water, Inkomati-Usuthu Catchment Management Agency (IUCMA) and South African National Parks (SANParks). Sampling commenced in January 2016 and continued until July 2017. Four sampling occasions were undertaken per year, so as to occur seasonally (four times in 2016 and three times in 2017). Sampling took place during the 3rd week of each of the following months; January, April, July and October of 2016, and January, April and July of 2017. Surface grab samples were collected at various sites in the Sabie River catchment. The following variables were measured *in situ* at each sampling site with an YSI multi-meter (YSI 556 handheld field instrument): pH, temperature (°C), dissolved oxygen (%), dissolved oxygen (mg/L) and specific conductivity (mS/m).

Chemical analyses were carried out by Rand Water's Analytical Services. Concurrently with the water quality parameter determinations. Planktonic algal cell enumeration was done at the North-West University according to standard laboratory procedures and a sedimentation technique. The study area received 888 mm rainfall during 2016 compared to 1073 mm during 2017. It was therefore decided to compare the data obtained during the dry year of 2016 to that obtained during the high rainfall year of 2017.

Overall 86 algal genera were identified in 2016 and 88 in 2017 from 6 different phyla which include 14 (15 genera during 2017) genera from the phylum Cyanophyta, 33 (35 genera during 2017) from the Bacillariophyta, 32 (30 genera during 2017) genera from the Chlorophyta, 1 genus from the Chrysophyta, 3 genera from the Dinophyta and 3 (4 genera during 2017) from the Euglenophyta. The Bacillariophyta was the dominant phylum at most sites for both sampling years. Genera such as *Achnanthes, Achnanthidium, Cocconeis, Cymbella, Gomphonema, Gyrosigma, Navicula* and *Nitzschia* occurred frequently at most sites. *Chlamydomonas*, *Desmodesmus*, *Monoraphidium* and *Scenedesmus* were the most frequent genera from the Chlorophyta. Genera such as *Trachelomonas* and *Euglena* were the dominant Euglenophyta while the Chrysophyta genus *Dinobryon,* was mostly dominant in the Inyaka Dam. The algal cell concentrations were higher during 2016 (24801 cells/ml) compared to in 2017 (1613 cells/ml).

During the 2016 sampling occasions, the impacts of the drought were clearly visible. Site 7 in the Sand River experienced very low flow and the invasive plant species *Azolla filiculoides* was observed at this site. Increased wildlife was also witnessed especially at site 9 in the hippopotamus pools, along with the invasive plant species *Pistia stratiotes*. During the drier period there was limited dilution of pollution. This was evident at site 12 where increased nutrient concentrations (maximum ammonia of 11 mg/l and max total nitrogen of 38 mg/l) were measured. The algal composition and increased chlorophyll-*a*, at this site reflected the higher nutrient concentrations. Site 12 was the site most impacted upon by the non-functioning wastewater treatment plant (WWTP) and rural settlements especially during the dry year. The extremely high *E. coli* concentrations are also an indication of that the impact that the surrounding communities and WWTP have on this site. Site 12 showed the greatest overall improvement during the higher rainfall year. The %DO increased from lethal to sub-lethal according to the target water quality range (TWQR) and the ammonia, total nitrogen, total phosphorus and ortho-phosphate concentrations all decreased during 2017.

The higher rainfall experienced during 2017 relieved the drought conditions experienced as follows: the water levels improved at all the sites and the invasive species (*Pistia stratiotes* and *Azolla filiculoides*) were flushed downstream. The total nitrogen and ammonia concentrations decreased and there were clear improvements in the %DO at most sites. The turbidity measured at all the sites were higher during the higher rainfall period due to the increased runoff. The aluminium and iron concentrations increased significantly in the sites located in the Sand River and in the Marite River. This may be reason for concern since these metals can become toxic to users. The high *E. coli* concentrations observed at all the sites (except for sites 1 and 11) are reason for concern as it poses a serious health risk, especially to the surrounding rural communities that might come in contact with sources of faecal pollution.

Most of the physical and chemical water quality parameters determined complied with the recommended TWQR. Nutrients such as the total nitrogen, total phosphorus (phosphorus & ortho-phosphate) did however not comply with the set resource quality objectives (RQO) for the Sabie River, Marite River and Sand River. Heavy metals concentrations, namely aluminium and zinc, also exceeded the TWQR. The Inyaka Dam is the most important site concerning the aesthetic value of the drinking water. This site can face some taste and odour problems in future due to high iron concentrations present as well as emergent chlorophyll-*a* and possible related geosmin and 2-MIB concentrations.

The total nitrogen and total phosphorus concentrations can potentially support high algal and plant productivity and this study area might experience bloom formation in future since problematic algae such as *Anabaena*, *Oscillatoria* and *Cylindrospermopsis* were also found in the study area.

KEY WORDS: Algae, algal assemblages, cyanobacteria, physical-chemical variables, Sabie-Sand River catchment, Kruger National Park, water quality.

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LIST OF ABBREVIATIONS

APHA	American Public Health Association
2-MIB	2-Methylisoborneol
COD	Chemical Oxygen Demand
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
DIN	Dissolved Inorganic Nitrogen
DIP	Dissolved Inorganic Phosphorus
DOC	Dissolved Organic Carbon
DO	Dissolved Oxygen
EC	Electrical Conductivity
E. coli	*Escherichia coli*
EPA	Environmental Protection Agency
EPPO	European and Mediterranean Plant Protection Organization
GM	Geosmin
IUCMA	Inkomati-Usuthu Catchment Management Agency
KNP	Kruger National Park
MELP	Ministry of Environment Lands and Parks
NTU	Nephelometric turbidity units
NWU	North-West University
RQO	Resource quality objective
SANAS	South African National Accreditation System
SANS	South African National Standards
SANParks	South African National Parks
SPC	Specific Conductance
SD	Standard Deviation
SE	Standard Error
TWQR	Target Water Quality Range
TDS	Total Dissolved Salts
TN	Total Nitrogen
TP	Total Phosphorus
TOC	Total Organic Carbon
WWTP	Wastewater Treatment Plant
WTW	Water Treatment Plant
WHO	World Health Organisation

CHAPTER 1 INTRODUCTION

1.1 Background

A healthy river ecosystem is of the utmost importance to the surrounding communities that depend on it for drinking water, agriculture and developing industries. Monitoring of water quality and the anthropogenic disturbances of a water resource is essential to not only determine the effect of these disturbances on water quality and the ecology of the river environment but also on the quality and quantity of clean water available for domestic use. This is particularly important in times of climate change when extreme weather conditions can lead to droughts such as experienced during 2016 and high rainfall conditions in 2017(Anon., 2017; Pretorius, 2016).

According to the DWA, (2013), the Sabie River catchment forms part of the bigger Inkomati Catchment Management area in the Mpumalanga Province and covers about 6 320 square kilometres. The headwaters of the Sabie River and its tributaries such as the Sand River and Marite River arise from the upper Drakensberg escarpment, flowing eastwards into the Lowveld through drastically changing topography, then through the Kruger National Park into Mozambique where it becomes part of the Inkomati River system (DWA, 2013). The Sand River is a major tributary of the Sabie River and converges with the Sabie River within the Kruger National Park (KNP).

Since the water of the Sabie River system is vital to the economy of the communities in the area and plays a role not only in agriculture, but in ecotourism as well, it is imperative to monitor the number of anthropogenic activities in the system, which can impact on the system's health. Management and monitoring of the Sabie-Sand sub-catchment water quality are also important to the ecosystem health of the KNP. The Inkomati River system is an international shared watercourse with Mozambique. South Africa has an obligation to meet international water quality requirements in the Mpumalanga area, and a further obligation to ensure high-quality water sharing between the three co-basin areas, namely the Inkomati River basin, Swaziland and Mozambique (DWAF), 2006). According to DWA (2010) and Roux and Selepe (2011), the Sabie River catchment is in good health and is only moderately changed in some sections. Currently, the eco-status of the Sand River is rated as moderately impaired, mostly due to the rural transformation of the upper reaches and the conservation in the lower reaches (Roux & Selepe, 2011).

As with all the rivers in South Africa, the rivers in Mpumalanga are under threat of a growing population as well as agricultural and industrial use. Management of the freshwater in South Africa is very important and the Blue Drop and Green Drop programmes show that not all issues pertaining to water are managed well. The Blue Drop certificate program that rates potable water, however, gave Mpumalanga Province a score of 61% in 2012, the lowest of all the provinces in South Africa (DWA, 2012; DWA, 2014a).

This improved to a score of 69% in 2014. The Bushbuckridge area improved from a score of 30.80% in 2012 to 64% in 2014 (DWA, 2012; DWA, 2014a). The Blue Drop program report acknowledged the improvement but it was stated that some of the final water still failed to meet the SANS 241 standards and that the province should focus on improving drinking water quality (DWA, 2014a). The Green Drop score of Mpumalanga Province decreased from 56% in 2011 to 44% in 2013. The Bushbuckridge area showed a substantial decrease in scores from 28.5% in 2011 to 13.36% in 2013 (DWA, 2011b; DWA, 2014b). The DWA (2011b) reported that wastewater management in the Bushbuckridge area is substandard and did not perform well, nor did it meet the expectations at the last green drop inspection. The low scores indicate that the wastewater service is not being managed properly nor is it complying with legislation and that wastewater is not being treated as required. The DWA (2013) stated that the Bushbuckridge area has the highest population density in the country with approximately 67% of the population residing in rural areas. The ecological health of the system is at risk due to the amount of pit latrines used in an area of predominant sandy soil types as well as the non-functioning of wastewater treatment works. This coupled with the unsustainable and unmanaged use of the natural environment, as well as the degradation of the area's natural resources and sensitive ecosystems. Predicted increases in population and services demands can result in the degradation of the water quality if the area is not properly monitored and managed (DWA, 2011a).

The objectives of river health surveys, such as those completed by Roux and Selepe (2011) and Weeks *et al.* (1997), are to provide useful ecological information through aquatic assessment of macroinvertebrates and fish species, as well as through the use of physical and chemical analysis of the water. This study proposes the use of changes in algal assemblages as another indicator of ecosystem health as these organisms have a high rate of reproduction that allows them to respond rapidly to changing environmental conditions, leaving them vulnerable to natural as well as anthropogenic changes (Sharov, 2008). Algae form the basis of most aquatic food chains and they play an important role in nutrient uptake and biochemical cycling of nutrients (Tyrrell, 2001). Algae can however also rapidly increase in population densities known as blooms, which can cause problems and produce taste and odour compounds namely Geosmin and 2-Methylisoborneol (2-MIB). Certain cyanobacteria genera, for instance *Microcystis*, can release cyanotoxins such as microcystin into the water during a bloom (Henderson *et al*., 2008). These toxins can impact negatively on human and animal health. High levels of algal growth have been observed in the Marite River and Sand River due to pollution as well as runoff (DWA, 2013). With an increase in the human population and in light of the drought situation in South Africa, harmful algal blooms pose a substantial threat to the health of rural communities. Not only will it impact negatively on both domestic and wild animals, but it has the potential to cause numerous problems within water treatment plants as well (Hitzfeld *et al*., 2000).

This study will determine changes in the algal assemblages specifically regarding harmful species, and species causing taste and odour problems in drinking water, and link changes in spatial algal assemblages to the water quality. The water quality and algal assemblages of the Inyaka Dam, which is situated in the Marite River, has also been included in this study as it is the main water source of the Inyaka Water Supply Scheme and therefore does not only impact on the Sabie River system but directly influences the communities surrounding it.

1.2 Hypothesis

Increasing rural development in the Sabie River catchment will impact negatively on the water quality of the Sabie River resulting in changes in the algal assemblages.

1.3 The aim of the study

Determine the water quality and changes in the algal composition of the Sabie-Sand River catchment.

1.4 Specific objectives

- Measure the physical and chemical attributes of the water quality of the Sabie, Sand and Marite Rivers.
- Determine the physical and chemical characteristics of the water quality of the Inyaka Dam.
- Determine the spatial and temporal changes in biological assemblages of algae in the Sabie, Sand and Marite Rivers, and the Inyaka Dam.

CHAPTER 2 LITERATURE STUDY

Phytoplankton plays an important role in reflecting changes in the water quality due to its sensitivity to changes in the environment (Sharov, 2008). Characterisation of algal assemblages is important in environmental assessments both to indicate changes in environmental conditions that impair or threaten ecosystem health as well as to determine if algae themselves are causing problems (Wehr *et al*., 2015).

2.1 Algal assemblages as indicators of water quality

Algae is a diverse group in terms of colour (green, blue-green, yellow, brown and red), form (single, colonial, filamentous) and habitat (aerial, fresh-water, soil and marine) and consists of at least 8 phyla, 7 of which are eukaryotes in the Domain Eukarya and cyanobacteria that is part of the prokaryotes which in the Domain Bacteria (Sherwood *et al.*, 2011). Algal diversity and changes in the diversity are ideal indicators of human disturbances in fresh water resources (Kshirsagar, 2013). Algae have short life cycles and can reflect short-term impacts rapidly and effectively (Kshirsagar, 2013; Omar, 2010; Stevenson, 2014).

Bellinger and Sigee (2010) identified various algae as good indicators of water quality and changes in the aquatic ecosystem. Genera such as *Dinobryon* can be used as indicators of oligotrophic waters. Filamentous green algae and *Phormidium* are indicators of degradation (Schneider, 2015). A study done by Reavie *et al.* (2010) found that *Aphanothece* mostly occurred in ecosystems with high nutrient levels and increased sodium and calcium concentrations. Genera such as *Euglena*, *Microcystis*, *Oscillatoria* and *Scenedesmus* can be used as indicators of organically polluted waters (Ganai & Parveen, 2014). Pinedo *et al.* (2007) stated that genera such as *Oscillatoria*, *Lyngbya* and *Phormidium* could be indicative of degraded environments. Diatoms are also widely used as monitoring tools, as they could reflect the quality of the water as well as changes in the ecosystems, and are also good indicators of organic pollution (Giorgio *et al.*, 2016; Harding *et al.*, 2005). Diatoms such as *Navicula* and *Nitzschia* are regularly found in waters with high organic nutrient levels (Ganai & Parveen, 2014), while *Cymbella* and *Gomphonema* are commonly found in more pristine waters (Taylor *et al.*, 2007b). A study done by Giorgio *et al.* (2016) found that genera such as *Gomphonema* and *Planothidium* are less sensitive to water pollution and will occur even when pollutants are present. Omar (2010) stated that anthropogenic stress can result in changes or alterations in the algal assemblages or population composition, causing an increase in the more tolerant species and a decrease in sensitive species. Algal species composition and algal biomass are therefore important indicators of changes in the ecosystem, such as increased nutrient inputs caused by agriculture or other land uses It can also be used as indicators of threats to drinking water quality in terms of aesthetic values or stressors especially concerning the dissolved oxygen levels or pH of the system (Stevenson, 2014).

2.1.1 Algal metabolic compounds and the effects on water quality

Algae are known to produce numerous compounds that can contribute to taste and odour problems in drinking water, or to produce toxins which can be harmful to other species and humans (Watson *et al.*, 2008; Zhao *et al.*, 2013). These algal compounds can have effects on the ecosystem as well as the economic sector and may affect the safety and aesthetic value of the water sources (Watson *et al.*, 2008).

Cyanophyta is considered to be an ancient prokaryote group that has thylakoids containing photosynthetic pigments in their cells and therefore have the ability to photosynthesise (Janse van Vuuren *et al.*, 2006; Van Ginkel, 2012). This group of organisms is problematic in water systems and can cause an array of problems ranging from tastes and odours to skin rashes and even death of livestock (Falconer & Humpage, 2005). Cyanophyta such as *Microcystis, Anabaena, Planktothrix* and *Oscillatoria* are the main genera responsible for the production of hepatotoxins and neurotoxins, in addition to taste and odour problems due to the production of 2-Methylisoborenol (2-MIB) and geosmin (GM) (Falconer & Humpage, 2005; Maruthanayagam *et al.*, 2013; Srinivasan & Sorial, 2011; Ye *et al.*, 2009). The neurotoxin known as anatoxin-a is mainly produced by genera such as *Anabaena*, whilst saxitoxins can be produced by genera such as *Anabaena* and *Lyngbya*. Hepatotoxins are mainly created by *Microcystis*, *Planktothrix*, *cylindrospermopsis* and *Anabaena*, and are known to contaminate drinking water (Falconer & Humpage, 2005). The bloom-forming genus *Microcystis* produces toxins such as Microcystin-LR which are resistant to boiling and can therefore be a great threat to underdeveloped countries and rural communities (Falconer & Humpage, 2005).

Cyanobacteria are not solely responsible for the production of 2-MIB and GM. Actinomycetes are also known for the production of these compounds (Lanciotti *et al.*, 2003; Zaitlin & Watson, 2006). Zaitlin and Watson (2006) established that increased geosmin concentrations could be due to surface runoff which transfers terrestrially produced geosmin to the surrounding water sources. A study done by Lanciotti *et al.* (2003) found a connection between the presence of Actinomycetes, cyanobacteria, some algal species and the production of 2-MIB and geosmin. The study identified the Actinomycetes (*Micromonospora, Nocardia,* and *Streptomyces*), diatoms such as *Melosira* and *Navicula*, green algae (*Chlorella* and *Pediastrum*) together with the cyanobacteria (*Anabaena*, *Oscillatoria* and *Nostoc*) as the organism responsible for the production of these taste and odour problems. The study of Lanciotti *et al.* (2003) concluded that the production of geosmin can be an indication of cooperation between all the above-mentioned groups and the production of 2-MIB is linked to the activities of cyanobacteria or Actinomycetes. Srinivasan and Sorial (2011) stated that the greatest concern with taste and odour problems such as 2-MIB and GM is very low odour threshold concentrations and its persistence during the water treatment process. These compounds give an earthly or soil-like odour to the drinking water, and the low palatability will therefore decrease the aesthetic value of the water (Srinivasan & Sorial, 2011; Zaitlin & Watson, 2006).

Other algal groups are also known to cause taste and odour problems, for instance, a study done by Sun *et al.* (2014) identified genera and compounds responsible for fishy odours in drinking and surface waters. According to Sun *et al.* (2014), odour producing genera found in the Sabie-Sand catchment include *Eudorina, Pandorina, Dinobryon*, *Cyclotella* and *Chlamydomonas*. The odour originates from amines, polyunsaturated aldehydes and aldehydes these compounds are volatile and can be easily detected in the water causing a decrease in quality of the drinking water (Sun *et al.*, 2014; Zhao *et al.*, 2013).

2.2 Land-use effects on algal assemblages

The Mpumalanga escarpment and the KNP are some of South Africa's most important tourism scenes and environmental concerns in the Sabie-Sand catchment can have a negative impact on the tourism industry. The catchment is impacted by large-scale forestry and growth in the rural population contributes to a great deal of stress on this ecosystem. Alien plant invasion is also an increasing problem in the catchment (Van Wyk *et al.*, 2001).

Anthropogenic activities and land-use have a direct impact on water quality and on the phytoplankton community structure. Anthropogenic activities such, as deforestation, can increase the nutrient and sediments in the system and can impact the amount of light penetration and the temperature of the system. The runoff during the rainy season will have a greater effect where the areas have been cleared (Vázquez *et al.*, 2011). Ganai and Parveen (2014) stated that water quality variables such as nitrate, phosphate, temperature and pH play an important role in altering the algal community structure, and that these factors are mainly caused by anthropogenic activities.

A study by Katsiapi *et al.* (2012) also found that phytoplankton biomass increased in areas where the leading land-uses are artificial or agricultural related. The study concluded that land-uses, especially agricultural and urban, are the main drivers of phytoplankton community composition or diversity and that runoff are the main sources of increased nutrient input in natural systems (Katsiapi *et al.*, 2012). A shift in the population dynamics may indicate changes in the ecosystem as well as the trophic state of a system (Katsiapi *et al.*, 2012). A population shift to less Chrysophyta and more Cyanophyta, for example, can be an indication of increasing eutrophic conditions in the system. Degraded environments will also decrease in diversity with only a few species increasing in abundance (Katsiapi *et al.*, 2012).

Yang *et al.* (2016) identified water level fluctuations as an important part of changes that occur in the phytoplankton community, implicating that, the phytoplankton composition is therefore driven by the water level fluctuations. The water fluctuations are influenced by meteorological characteristics and human activities. Water level fluctuation has increased due to increased populations and demand for freshwater combined with climate change (Yang *et al.*, 2016). The study by Yang *et al.* (2016) found that the cyanobacteria biomass increased during low water levels and decreased during higher water levels. It was also reported that periods of low flow and droughts result in increased nutrient concentrations and increased salinity. These conditions will ultimately result in cyanobacteria blooms (Yang *et al.*, 2016).

2.3 Climate change, droughts, floods and the impact on species

Climate change is one of the greatest threats to society. It impacts not only on freshwater availability but also river characteristics, such as decreased agricultural production, and increases in the occurrence of extreme hydro biological events such as droughts and floods (Daneshvar *et al.*, 2017). According to Maponya *et al.* (2013), the higher temperatures and changes in weather patterns such as rainfall can be a great concern for rain-fed agriculture and farmers with limited financial capacity and a dependence on the natural resources. Maponya *et al.* (2013) did a study in the Mpumalanga Province to determine the climate changes awareness of the farmers in the area and found that 61% are sustenance or small-scale farmers in the area and 82% of these farmers are not aware of climate change. The study concluded that education is imperative in informing households in Mpumalanga to make better crop decisions to decrease crop and income loss.

Freshwater ecosystems and aquatic organisms are also influenced by climate change and the occurrence of drought and floods. These changes can lead to a decrease or loss of biodiversity (Daneshvar *et al.*, 2017). Biggs and Smith (2002) described rivers and streams as the environments most affected by anthropogenic activities, and Lake (2000) described disturbances as one of the most important role players in community structure. Lake (2000) found that there are more studies focusing on the effects of high rainfall and floods which created a significant gap in knowledge regarding the effects of drought. The community structure will respond differently to disturbances depending on the intensity and duration. Floods are usually short-term and have a sudden impact, while droughts can be long-term and thus have a greater impact as time progresses (Lake, 2000).

2.3.1 Droughts

Defining droughts can be quite challenging. There are many sectors, such as agricultural, economic and social structures, affected by droughts and each of these sectors describe and measure drought differently. Stream health drought is defined as a time period with insufficient stream flow where the ecosystem and aquatic biota are under stress or damaged (Esfahanian *et al.*, 2017). Bond *et al.* (2008) conducted a study on the effects of drought on aquatic ecosystems focusing from an Australian perspective. Droughts can have adverse effects on standing and flowing water and the flora and fauna and habitat loss are imminent. The water quality will decrease during times of drought which can impact on the system (Bond *et al.*, 2008).

According to Bond *et al.* (2008), not enough research is being done on the effects of droughts on the ecological, hydrological, social and economic sector. The study by Bond *et al.* (2008) concluded that the effects of drought on the algal community structure are better understood than the effects of drought on ecosystem processes which are not completely clear. The study found that river systems lost the ability to resist drought, due to anthropogenic activities combined with extraction that can alter the natural vegetation and introduce alien species into the ecosystems.

2.3.2 Floods

Rountree *et al.* (2000) described floods as a primary source of disturbance in river ecosystems that can remove natural vegetation and sand as well as increase sediment input. There was a high rainfall episode in the Sabie River during February 2000, where Skukuza received 245 mm precipitation in a short period of time and this was considered the largest flood in the area in 60 years (Heritage *et al.*, 2001). Heritage *et al.* (2015) conducted a study on the 2000 and 2012 floods and studied the sequencing of sediment stripping using optically stimulated luminescence dating. The study found that the Sabie River does not contain deposits older than 1000 years and concluded that these two extreme events caused sediment stripping and accumulation of sediments. These stripping events can lead to altered bedrock and increased sediment deposits in the Sabie River itself. Although floods can remove natural biota of a system, recovery is usually fast. Abiotic and biotic interactions will also decrease during high flow periods. Droughts will have more serious effects on a system which will escalate over time, as the habitat loss and decreased water availability become more severe (Lake, 2000).

Biggs and Smith (2002) did a study on the effects of flood disturbances and nutrients on the benthic algal community and concluded that streams with frequent flooding had a lower species richness compared to infrequent flooding areas. Previous studies found that floods can disrupt the nutrient input and can impact on the species richness and evenness, or it can have no effect at all (Biggs & Smith, 2002). The study showed that the species richness recovered within a week after the flood and did not show a significant decrease in richness compared to infrequent flood areas. The decreased effects of floods in the study can be due to short flood periods and a resistance to changes in the community. Genera such as *Achnanthidium* and *Stigeoclonium* can resist these stripping events (Biggs & Smith, 2002). Biggs and Smith (2002) also concluded that downstream migration of species during high rainfall events could possibly account for the unexpected species richness.

2.4 Knowledge gaps in the field, notions to keep in mind for future studies.

Van Wyk *et al.* (2001) attempted to identify gaps in information and research done on the topic of water quality management. The study used the Sabie-Sand catchment as an example and stated that the management of this catchment can benefit from interdisciplinary research to support management and the restoration of degraded environments. The previous paradigm of water supply was replaced with a new paradigm of water conservation and protection of water sources for future generations. Van Wyk *et al.* (2001) identified a need for new approaches regarding water management. The study reviewed current information available and aimed to determine whether the historical research can support the new water management requirements. The research conducted in the catchment largely focuses on conservation, forest hydrology and alien plant management which created a knowledge gap between ecological and aquatic systems because of a shortage of integrated research. There are uncertainties about the Sabie-Sand catchment's ability to cope with the surrounding development and the origin of the sedimentation in the catchment is also an important unanswered question.

Van Wyk *et al.* (2001) concluded that there is a need for increased research in the area, with integrated projects focusing on fields such as monitoring to support and identify the current and future requirements of water source management. Stevenson (2014) also identified a need for inter-disciplinary collaborations and integration to increase our knowledge and understanding, especially the impact of anthropogenic activities and the effects that worldwide alteration of ecosystems has on algal biodiversity. According to Stevenson (2014), the assessment of algal communities and knowledge of ecology have greatly increased but there is still a need for scientists, algal biologists in particular, to collaborate with other fields to improve management strategies.

Physical and chemical parameters provide data on the presence of pollutants and degradation of an ecosystem but do not reflect the environmental stress on the living organisms present in the system. Biological monitors, such as algae, can be used together with the chemical and physical parameters to determine the ecological changes or stress (Omar, 2010). This study provides a rare opportunity to observe the changes in the algal community during a dry season followed by a higher rainfall event.

CHAPTER 3 STUDY AREA

3.1 Background

The study area is located in the Sabie-Sand catchment that forms part of the bigger Inkomati Catchment Management area in the Mpumalanga Province (DWA), 2013). The study was conducted at twelve different sampling localities situated from the headwaters of the Sabie River to as close as possible to the Mozambican border. The Sabie River forms the main river with the Sand and Marite as major tributaries in the system. The Sand River has a length of 125 km and the Marite River a length of 58 km before the confluence with the Sabie River (DWAF), 1996a). The Inyaka Dam which is situated in the Marite River has also been included in this study. The Sabie River flows into the KNP and then into Mozambique where it becomes part of the Inkomati River system (DWA, 2013). The names and coordinates of each site are listed in Table 3-1 and Figure 3-1. The catchment of this river system has a surface area of 7096 km^2 of which 6347 km^2 falls within the South African border.

Table 3-1: Names and coordinates of sampling sites.

	Name	Coordinates (in DD)
Site 1	Sabie River Headwaters	-25.147472, 30.668722
Site 2	Sabie River Wastewater Treatment Works	-25.073861, 30.850806
Site 3	Sabie River Before town of Hazyview	-25.030083, 31.025306
Site 4	Sabie River Hoxane site	-25.019333, 31.217333
Site 5	Sabie River Kruger Gate Bridge	-24.979722, 31.48275
Site 6	Sabie River Skukuza	-24.990889, 31.60175
Site 7	Sand River Skukuza	-24.967778, 31.625611
Site 8	Sabie River Lower	-24.975278, 31.768056
Site 9	Sabie River Mozambique	-25.160417, 31.99875
Site 10	Marite River	-24.9608121, 31.1085032
Site 11	Inyaka Dam Wall	-24.885389, 31.084694
Site 12	Sand River Thulamahashe	-24.721861, 31.237167

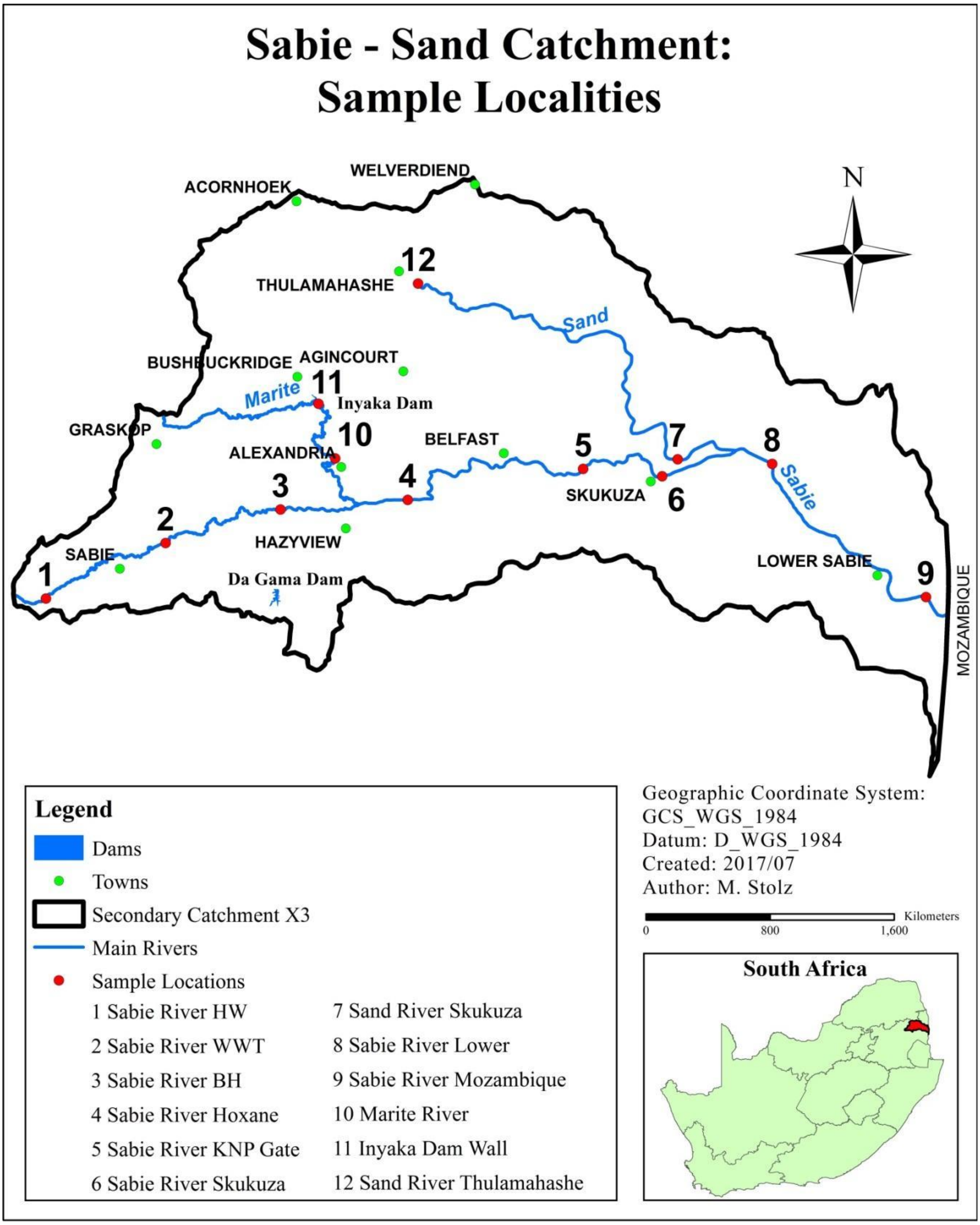


Figure 3-1: A map showing the chosen study sites for the duration of the study.

Site 1: Sabie River Headwaters; Site 2: Sabie River Wastewater Treatment Works; Site 3: Sabie River Before the town of Hazyview; Site 4: Sabie River Hoxane site; Site 5: Kruger Gate Bridge; Site 6: Sabie River Skukuza; Site 7: Sand River Skukuza; Site 8: Sabie River Lower; Site 9: Sabie River Mozambique; Site 10: Marite River; Site 11: Inyaka Dam and Site 12: Sand River Thulamahashe.

3.2 Description of the Sabie-Sand catchment

Mpumalanga Province can be divided into a western half, called the Highveld, and an eastern half situated at a lower altitude, namely the subtropical Lowveld. Both areas receive summer rainfall but the Highveld is drier with more extreme temperatures, while the Lowveld has warm temperatures with higher annual rainfall (Williamson & Balkwill, 2015). The Sabie-Sand catchment receives most of its rain during the months of November to March. The highest rainfall area of the Sabie River is closest to the Drakensberg with 2000 mm/a but the rainfall declines towards the Mozambique border, where an annual rainfall of 450 mm/a is received (Van Niekerk & Heritage, 1993). The Sand River has an annual rainfall of 400-1200 mm, partly due to the topography that ranges from 400-1500m above sea level (Van Niekerk & Heritage, 1993). The sampling sites are situated in the Lowveld region with an average rainfall of 518 to 1194 mm per annum (Mucina & Rutherford, 2006).

3.2.1 Sabie River

Site 1 is located within the Sabie River headwaters and is situated upstream of the town of Sabie (Figure 3-1). The headwaters of the Sabie River and tributaries such as Sand, Mac-Mac and Klein Sabie arise from the upper Drakensberg escarpment. This Sabie River section consists of cold mountain streams with fast flowing waters due to the moderately steep gradients (Roux & Selepe, 2011). The Sabie River catchment is a geomorphological diverse river, as the catchment contains sedimentary, intrusive and extrusive igneous as well as metamorphic bedrocks (Figure 3-3) (Van Niekerk & Heritage, 1993). The Sabie headwaters are situated in Transvaal sediments as illustrated in Figure 3-3. This site is mainly surrounded by commercial forests but is still considered to be in pristine condition.

Site 2 is situated downstream of the town of Sabie (Figure 3-1). This site mostly consists of Chuniespoort dolomites and the Nelspruit Suite (Heritage & Moon, 2000; Norman & Whitfield, 2006), and are mostly used for commercial forestry. Deforestation was witnessed during sampling. Commercial forestry can have severe impacts on the environment such as extensive water extraction, erosion, siltation and introduction of alien species into the system. This can lead to a decrease in biodiversity that can impact river health and function (Roux & Selepe, 2011). This site is situated downstream from a wastewater treatment plant, impacts such as increases in nutrient concentrations can be expected at this site (Dallas & Day, 2004).

Site 3 (Figure 3-1), is situated upstream from the town of Hazyview and the confluence with the Mac-Mac River. The river is wider and the stream flow is slower, due to the declining gradient. The geology found at this site is mainly the Nelspruit Suite (Heritage & Moon, 2000; Norman & Whitfield, 2006). The land-use includes forestry and some citrus and banana plantations (DWA, 2013).

Site 4 is situated downstream from the town Hazyview (Figure 3-1), and approximately 1.2 km downstream from the Hoxane Water Treatment works. The geology found at this site is the Nelspruit Suite Gneiss and this section is also characterised by slow-flowing waters and a wider stream (Heritage & Moon, 2000; Norman & Whitfield, 2006; Roux & Selepe, 2011).

Site 5 is located before the Paul Kruger Gate of the KNP, where the samples were collected from the bridge (Figure 3-1). Sites 6, 8 and 9 are located in the KNP. These sites have slow-flowing waters and mostly Nelspruit Suite Gneiss as the underlying geology (Heritage & Moon, 2000; Norman & Whitfield, 2006; Roux & Selepe, 2011). In the KNP, anthropogenic activities are limited but the occasional loss of habitat and increased erosion can be observed in this section (Roux & Selepe, 2011).

3.2.2 Marite River

The Marite River is situated upstream from the town of Hazyview (Figure 3-1). Figure 3-3 illustrates that the Marite River consists mainly of the Cunning Moor Tonalite and Nelspruit Suite Gneiss (Heritage & Moon, 2000; Norman & Whitfield, 2006). This site (10) is situated in a rural area where agriculture, erosion and overgrazing may affect the river health (DWA, 2013).

3.2.3 Inyaka Dam

The Inyaka Dam (Site 11) is situated in the Marite River upstream from site 10 and the main purpose of the dam is to supply water to the urban and rural towns and settlements in the area, but it is also used for recreation and tourism (Figure 3-1). The Inyaka Dam has similar geology to the Marite River (Figure 3-3) and consists of the Cunning Moor Tonalite (Norman & Whitfield, 2006). The land-use activities in this area include agriculture, aquaculture, conservation, fishing, forestry, water sport and recreation as well as tourism (DWAF, 2000).

3.2.4 Sand River

There are 2 sites representing the Sand River, Site 7 situated in the KNP itself and site 12, which is situated in Thulamahashe area surrounded by rural communities (Figure 3-1). The Sand River area contains forests and a nature reserve, coupled with people living in rural circumstances. Gardening, subsistence farming and cattle grazing are the dominant anthropogenic activities in the area (DWA, 2002). Environmental impacts of these anthropogenic activities include extensive soil erosion and sedimentation, habitat loss and changes in natural vegetation. According to DWA (2010) the water quality in the Sand River is not as good as the Sabie River mainly due to over-abstraction of water and the lack of functional waste water systems for the community in the area.

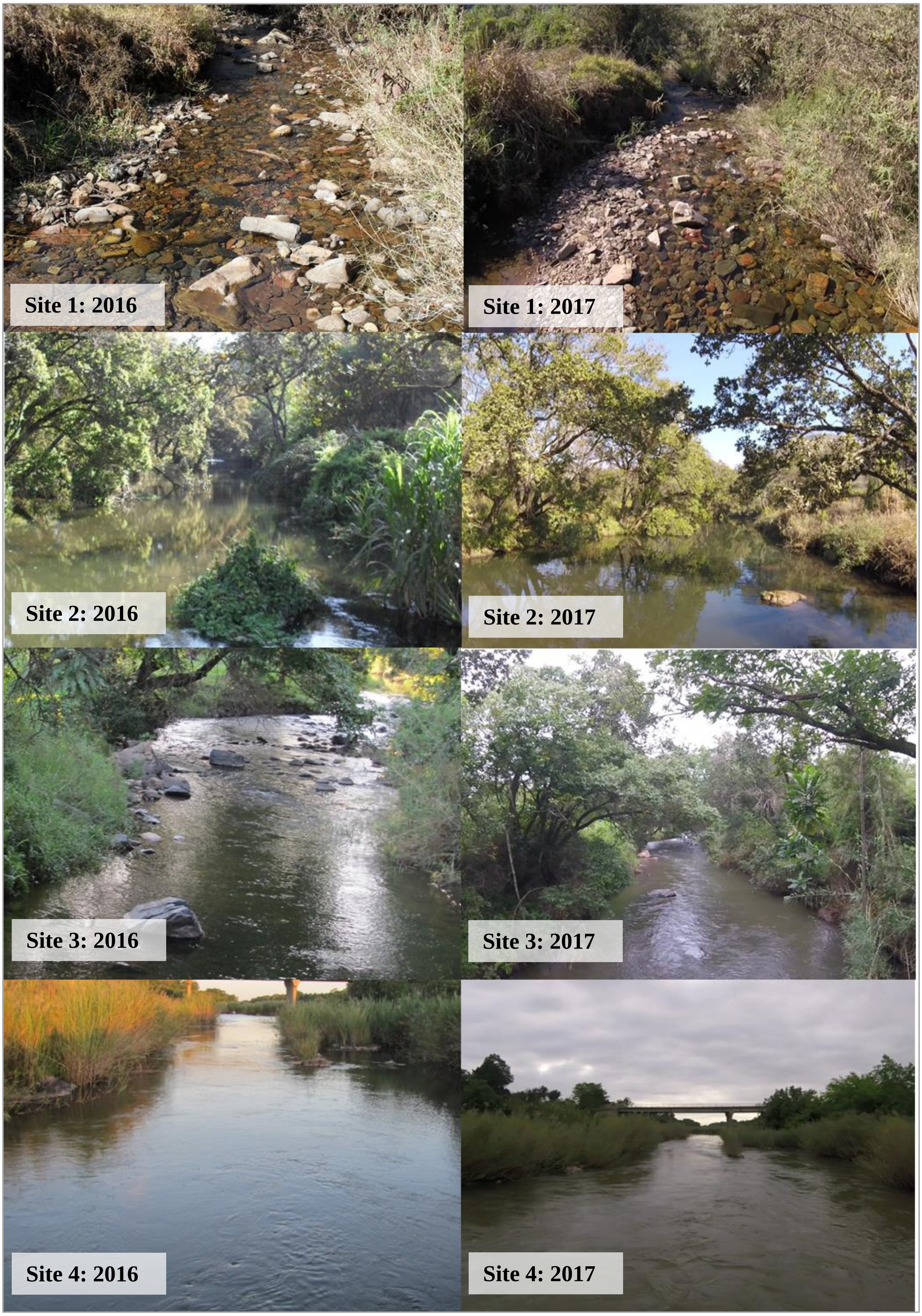
Figure 3-2: Photographs of each site during 2016 and 2017

Site 1: Sabie River Head Waters;

Site 2: Sabie River Waste Water Treatment;

Site 3: Sabie River Before Hazyview;

Site 4: Sabie River Hoxane Dumping site.

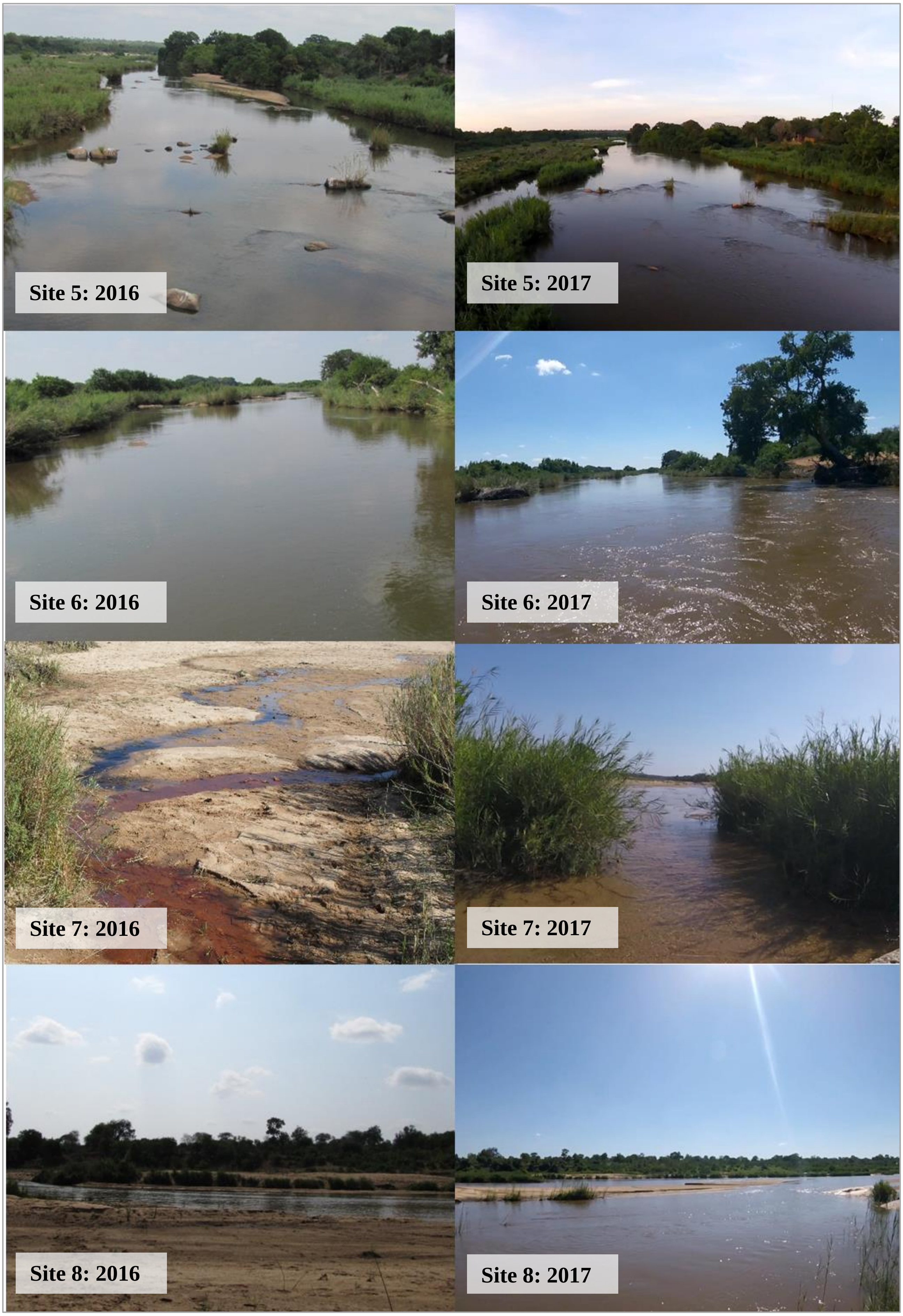

Site 1: 2016
Site 1: 2017
Site 2: 2016
Site 2: 2017
Site 3: 2016
Site 3: 2017
Site 4: 2016
Site 4: 2017

Site 5: Sabie River Kruger Gate;

Site 6: Sabie River Skukuza;

Site 7: Sand River Skukuza;

Site 8: Sabie River lower.

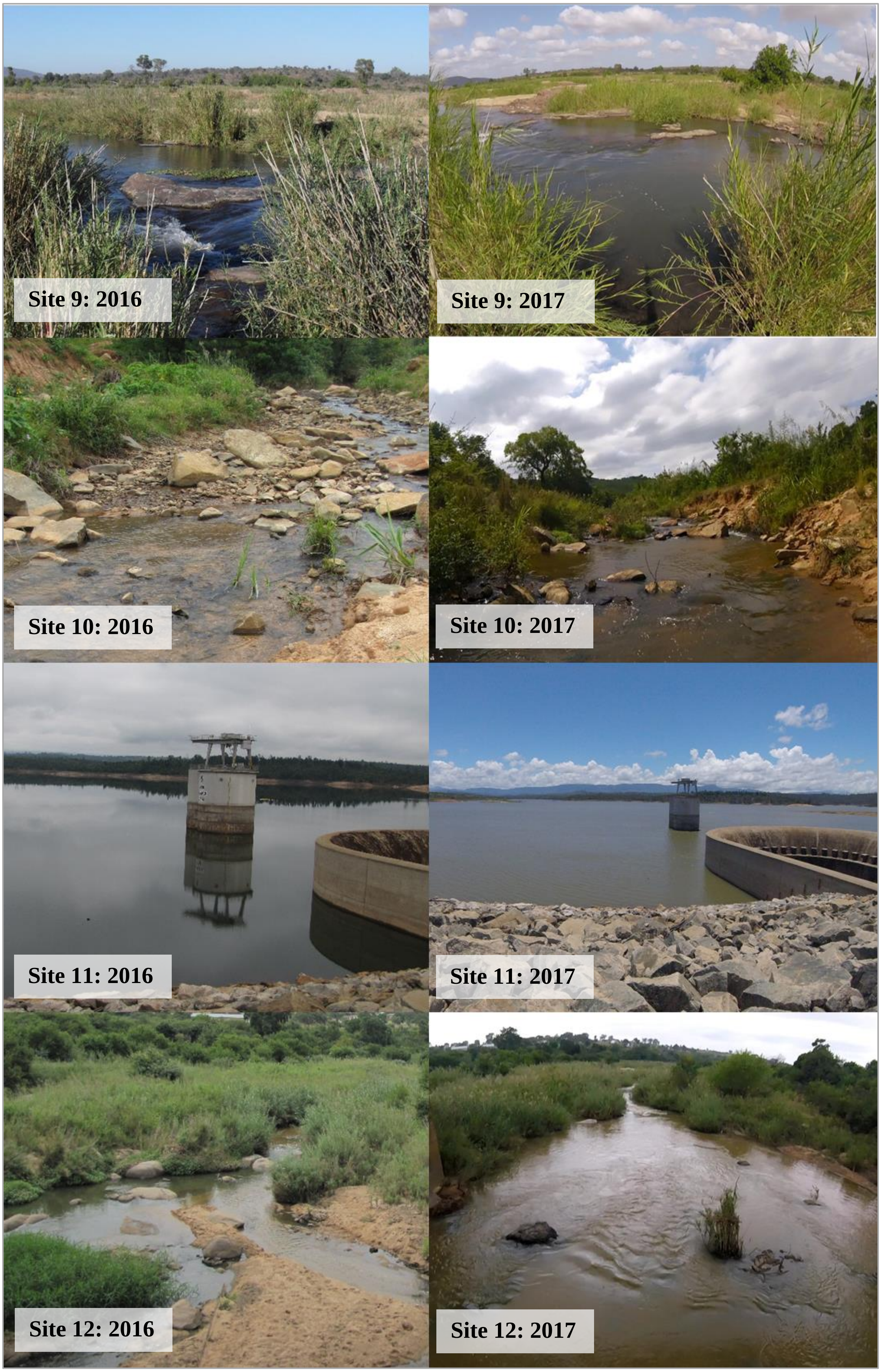

Site 5: 2016
Site 5: 2017
Site 6: 2016
Site 6: 2017
Site 7: 2016
Site 7: 2017
Site 8: 2016
Site 8: 2017

Site 9: Sabie River Mozambique;

Site 10: Marite River;

Site 11: Inyaka Dam;

Site 12: Sand River Thulamahashe.


Site 9: 2016
Site 9: 2017
Site 10: 2016
Site 10: 2017
Site 11: 2016
Site 11: 2017
Site 12: 2016
Site 12: 2017

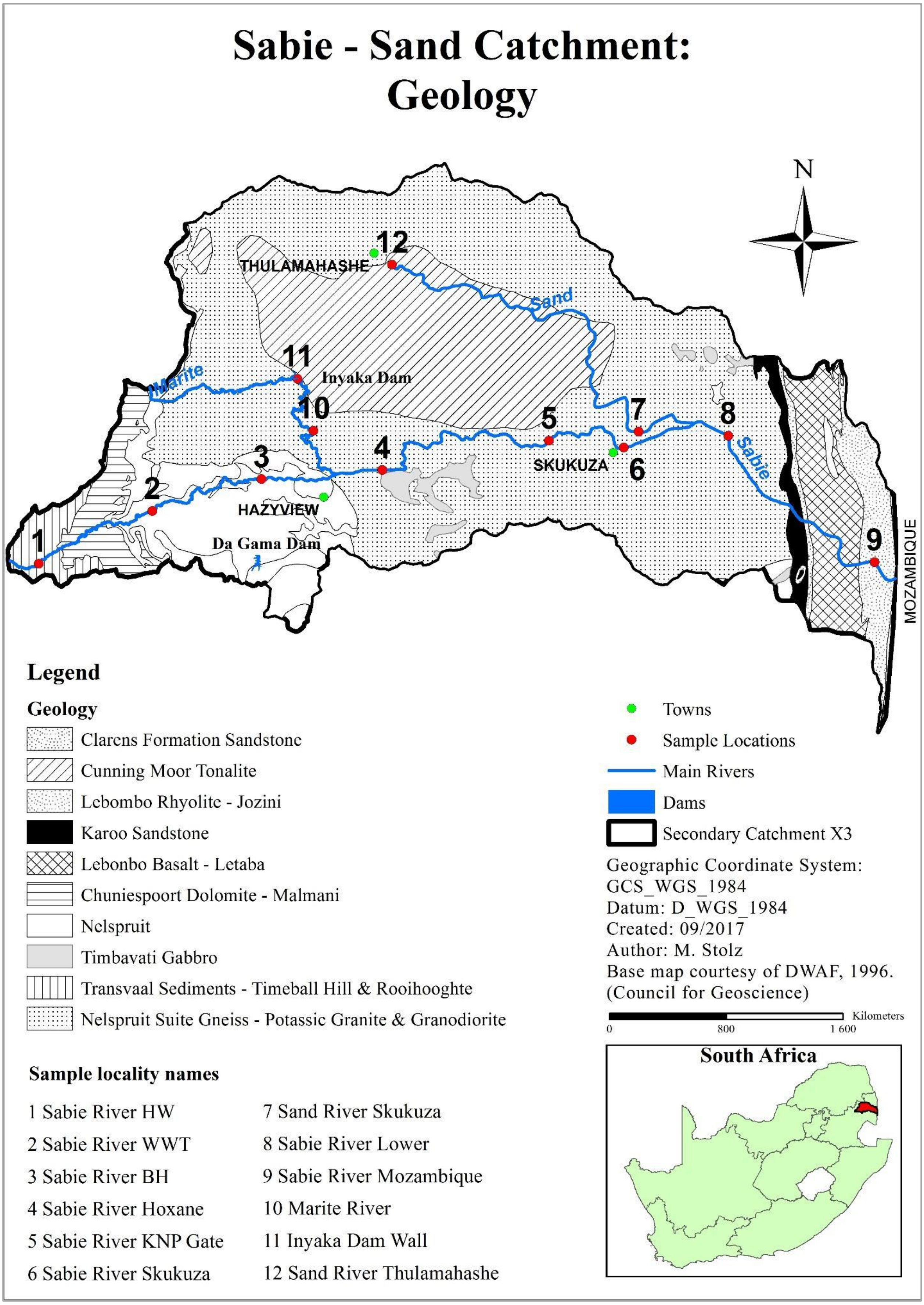


Figure 3-3: A simplified geological map of the Sabie-Sand catchment area.

3.3 Invasive water plant species

Invasive water plants, such as *Pistia stratiotes* and *Azolla filiculoides,* were found during 2016 sampling occasions. *Pistia stratiotes* (water lettuce) was present at site 9 during the April and July sampling (Figure 3-4, A & B), producing mats that cover entire surfaces. This is a cause for concern as site 9 is situated close to the Mozambique border and the invasive plant species can cross the border. The water lettuce can cause problems such as clogging waterways which reduces natural water flow and reduce the light penetration and oxygen levels in water, thereby threatening the aquatic life living in these ecosystems (EPPO (European and Mediterranean Plant Protection Organization), 2017). *Azolla filiculoides* (Figure 3-4, C & D) was present at site 7. These plants can also form mats on slow-moving water surfaces that can increase the siltation of water bodies and clog canals. Invasive species replace the natural aquatic plants, impact the biodiversity of the system and decrease the oxygen levels when it decomposes due to the increase in microbial activities (McConnachie *et al.*, 2003).

Figure 3-4: Invasive species present during 2016. *Pistia stratiotes* (A-B, site 9) at the top and the bottom photo *Azolla filiculoides* (C-D, site 7).

CHAPTER 4 METHODOLOGY

This study is a collaborative project between the North-West University (NWU), Inkomati-Usuthu Catchment Management Agency, Rand Water and South African National Parks (SANParks). Sampling commenced in January 2016 and continued until July 2017. Four sampling occasions were undertaken per year, to occur seasonally (four times in 2016 and three times in 2017). Sampling took place during the 3rd week of each of the following months; January, April, July and October in 2016, and January, April and July of 2017.

4.1 Collection of samples

A surface grab sample of nine litres of water was taken at each sampling site. The samples were collected using a bucket fixed to a rope to allow the collection of water from bridges. The bucket was rinsed with river water at each site to avoid cross-contamination between the sites. The water was then transferred to the different allocated containers. The following variables were measured *in situ* at each sampling site with a YSI multi-meter (YSI 556 handheld field instrument): pH, temperature (°C), dissolved oxygen (%), dissolved oxygen (mg/L) and specific conductivity (mS/m). All chemical and biological analyses were carried out by Rand Water's Analytical Services. Concurrently with the water quality parameter determinations, planktonic algal cell identification and enumeration were done at the North-West University.

4.2 Algal sample preparation

The sample preparation was done according to the standard laboratory techniques described in Swanepoel *et al.* (2008). The samples were preserved on site to prevent any changes in the algal composition, using 5:250, formaldehyde: sample ratio (final formaldehyde concentration of 2%). Formaldehyde poses a health hazard as it is carcinogenic and can cause changes in the structure of algal cells such as distortions of the chloroplasts (John *et al.*, 2002), but it is still preferred to Lugol's solution, because the use of Lugol's solution results in a discolouration of the cell contents, which complicates correct identification.

The sedimentation technique, as described in Utermöhl (1958) and Swanepoel *et al.* (2008), was used. The gas vacuoles of cyanobacteria were pressure-deflated in a special container using a mechanical deflation tool. After the deflation of the gas vacuoles, up to 6 ml of a sample was transferred into marked sedimentation chambers, depending on the density of the algae and cyanobacteria present. The remainder of the sedimentation tube was filled with distilled water, covered with a coverslip and left for at least 3 days in a desiccator to allow the cells to settle to the bottom. Algae and cyanobacteria were identified to genus level and enumerated using an inverted microscope at 400 times magnification.

The Whipple-grid method described in Swanepoel *et al.* (2008) was used to enumerate the samples. The enumeration was initiated in the middle of the left side of the sedimentation chamber the Whipple-grid was moved in a straight line to the right side of the chamber counting all the species that fall inside the grid, the chamber was then turned 90° and enumeration continued from the left side to the right until 200 cells were counted. A complete grid was used to enumerate the entire surface when the sample had fewer than 200 cells. Literature used for algal identification was: Croasdale *et al*. (1994): Ettl *et al.* (1999): Hindák (2008): Hüber-Pestalozzi (1961): John *et al.* (2002): Komárek and Anagnostidis (2005): Oyadomari (2001): Prescott (1964): Taylor *et al.* (2007b): Taylor and Cocquyt (2016): Tsarenko (1990) and Wehr and Sheath (2003).

4.3 Diatom sample preparation

Selected samples were prepared for the hot-potassium permanganate/hydrochloric-acid method described in Taylor *et al.* (2007a). This method removes organic material and facilitates the identification of diatoms. The samples were allowed to settle and the supernatant removed without disturbing the diatoms at the bottom. Each sample was mixed and 5-10 ml transferred to a beaker. Ten ml saturated potassium permanganate ($KMnO_4$) solution was added and the mixture was left to stand for 24 hours. Using a fume cabinet, 5-10 ml concentrated HCl (32%) was subsequently added and heated on a hot plate (90°C) for 1-2 hours until the solution was clear. One ml hydrogen peroxide was then added to determine if any organic matter remained. The sample was then transferred to centrifuge tubes and rinsed by centrifuging with distilled water at 2500 rpm for one minute and repeated four times.

A drop ammonium chloride (NH_4Cl: 10% solution) was added to decrease the electrostatic charges on the diatoms to ensure decreased aggregation and even diatom distribution. The sample was placed on a coverslip using a pipette and allowed to dry at room temperature (23°C). A few drops of Pleurax mountant were placed on the diatom-coated coverslip and a clean glass microscope slide was then lowered onto the coverslip. The slide was heated on a hot plate at 90-120°C until the Pleurax boiled and the solvent evaporated. It was allowed to cool and then examined using a differential interference contrast (DIC) light microscope at 1000 times magnification. All diatoms were identified to genus level.

4.4 Physical-Chemical variables

The physical-chemical analyses were carried out according to SANAS (South African National Accreditation System – affiliated at ILAC), accredited standard methods (APHA (American Public Health Association), 2013) by Rand Water’s Analytical Services. All containers except those allocated for algal and microbiological analyses, were rinsed with the river water before sampling. The samples allocated for inorganic analyses were collected in 1 L white plastic bottles and filled to the shoulder. The samples allocated for organic analyses were collected using 1.5 L glass bottles filled to the brim. The samples for microbiological analyses were collected in clear 500 ml bottles filled to the shoulder of the bottles. The bottles were sealed and only opened immediately before sampling to reduce contamination risk. The microbiology samples were immediately put in a fridge at 4 degrees Celsius after sampling until analyses no longer than 3 days later. Dark brown plastic containers were used for the hydro-biological samples. The 1.5 L bottles were rinsed with the river water before collection and were filled to the shoulder of the container.

The physical-chemical variables measured are listed in Table 4-1 with the method number, unit and reporting limit of each variable.

4.5 Statistical analyses

Statistical analyses were performed with Statistica Dell Statistica (data analysis software system), version 13. Basic Statistics were used to determine the normality of the data. The Kolmogorov-Smirnov & Lilliefors test indicated that the data did not meet the assumption of parametric data. Therefore, non-parametric statistics were used for the data analyses. Non-parametric statistics, such as the Spearman Rank test, were used to determine the correlations between the data. Descriptive statistics were used to determine the valid N, mean, minimum, maximum values and standard deviation of the data. The Kruskal-Wallis ANOVA (non-parametric statistics) for comparing multiple independent groups was used to determine differences between concentrations of determinants measured at the different sampling sites. Results below the reporting limit were divided by two and included in the data analyses. The results of the correlations and Kruskal Wallis analyses can be found in Appendix 3-A, B.

Table 4-1: Summary of the Physical-Chemical variables, measured by Rand Water's Analytical Services.

Method No.	Quality Variable	Unit	Reporting Limit	Method No	Quality Variable	Unit	Reporting Limit
112011	Chlorophyll-a	µg/l	<2	214031	Nickel	µg/l	<10
112091	Microcystin	µg/l	<0.36	214031	Phosphorus	mg/l	<0.5
122091	Coliforms	MPN/100 ml	0	214031	Lead	µg/l	<8
122091	*E. coli*	MPN/100 ml	0	214031	Sulphur	mg/l	<5
212021	Turbidity	NTU	<0.25	214031	Selenium	µg/l	<0.5
212041	Total Dissolved Solids	mg/l	<15	214031	Silicon	mg/l	<1
212051	Suspended Solids	mg/l	<15	214031	Strontium	µg/l	<1.0
213012	Conductivity at 25°C	mS/m	<1.0	214031	Tellurium	µg/l	<0.5
213012	M Alkalinity	mg/l CaCO3	<5	214031	Titanium	µg/l	<0.5
213012	pH	-	<0.01	214031	Thallium	µg/l	<0.5
213012	Temperature	°C	0	214031	Total Silica	mg/l	<0.15
213031	Chemical Oxygen Demand	mg/l	<10	214031	Uranium	µg/l	<0.2
214031	Aluminium	µg/l	<25	214031	Vanadium	µg/l	<10
214031	Boron	µg/l	<25	214031	Zinc	mg/l	<15
214031	Barium	µg/l	<1.0	217011	Bromide	mg/l	<0.1
214031	Beryllium	µg/l	<0.1	217011	Chloride	mg/l	<0.5
214031	Calcium	mg/l	<0.90	217011	Fluoride	mg/l	<0.15
214031	Cadmium	µg/l	<2.5	217011	Nitrate	mg/l as N	<0.1
214031	Cobalt	µg/l	<10	217011	Sulphate	mg/l	<1
214031	Chromium	µg/l	<15	218012	Nitrite	mg/l as N	<0.03
214031	Copper	µg/l	<10	218022	Total Kjeldahl Nitrogen	mg/l as N	<1
214031	Iron	µg/l	<5	218032	Ortho-Phosphate	mg/l	<0.2
214031	Hardness	mg/l CaCO3	<5	218042	Ammonia	mg/l as N	<0.2
214031	Mercury	µg/l	<0.8	218052	Silicon Dioxide	mg/l	<0.5
214031	Potassium	mg/l	<1.5	2.1.8.06.2*	Total Phosphate	mg/l	<0.036
214031	Magnesium	mg/l	<1.5	221012	Dissolved Organic Carbon	mg/l as C	<0.2
214031	Manganese	µg/l	<10	2.2.2.02.10*	2-Methylisoborneol	ng/l	<0.5
214031	Molybdenum	µg/l	<10	2.2.2.02.10*	Geosmin	ng/l	<0.5
214031	Sodium	mg/l	<2.0	223021	Total Organic Carbon	mg/l as C	<0.2

4.6 Diversity indices

Indices use numbers or scores obtained from quantitative data and can be a valuable tool for monitoring changes in the ecosystem (Fedor & Spellerberg, 2013). Several indices can be used to determine the health or state of a specific source or system, for instance, the Shannon-Wiener index, that determines diversity, the Margalef index that determines species richness (Davari *et al.*, 2011) and the Pielou index that determines species evenness (Peet, 1974).

4.6.1 The Shannon-Wiener Index

The Shannon-Wiener index is based on the number of species and their equability, therefore, representing each species in a sample (Fedor & Spellerberg, 2013). The Shannon-Wiener index is easy to use and is widely applicable for animal and plant communities. It uses the species richness as well as the evenness to determine the biodiversity of a system and is directly proportional to the evenness and the species richness.

Shannon-Wiener index (Shannon & Wiener, 1949) is determined as follows:

$$\boxed{H = -\sum_{i=1}^{n} p_i \ln p_i}$$

Where H is the index of species diversity,

Pi – S/N

S – Total number of individuals of one species in a sample

N – Total number of all the individuals in the sample

In – The logarithm to base

The index is difficult to use with different communities if the species richness varies but can be used for ecological monitoring of any changes in a system (Spellerberg, 2008). According to Fedor & Spellerberg (2013) this index captures a broad range of information in a single image and is not affected by the size of the sampling, which can be a problem with other ecological indices.

4.6.2 The Margalef Index

The Margalef index was developed by Ramon Margalef López, an ecologist, in the 1950's. This index focuses on the species richness and attempts to address the problematic effect of the sample size on the index, by dividing the number of species in the sample by the natural log of the number of organisms collected. The Margalef index (Margalef, 1958) is determined as follows:

$$D = \frac{S-1}{\ln(N)}$$

S – Represents the number of species

N – Represents the number of organisms in the sample

In – Natural logarithm

The Margalef index is a helpful index for ecologists to determine diversity; it is easy to use and relatively easy to interpret. This index can be applied to marine, freshwater and terrestrial samples and has value in the fields of genetics and sociology (Death, 2008).

4.6.3 The Pielou Index

The Margalef and Pielou indices are dual diversity approaches and focus mainly on distribution and number of species to determine the richness and evenness (Peet, 1974). The Pielou index (Pielou, 1966) is determined by the following equation:

$$\boldsymbol{e} = \boldsymbol{H/In\,S}$$

H – Shannon-Wiener Diversity index

S – Total number of species present in the sample

The application of the above methods will be presented in the following chapter.

CHAPTER 5 RESULTS

Chapman (1996) specified that "Water bodies can be fully characterised by the three major components: hydrology, physical-chemistry, and biology". Physical and chemical parameters provide data on the presence of pollutants and degradation of an ecosystem but do not reflect the environmental stress on the living organisms present in the system. Monitoring biological indicators such as algae can be used, together with the chemical and physical measurement, to determine the ecological changes or stress of a system (Omar, 2010).

Chapter 5 is the presentation and discussion of the data obtained from sampling during the year 2016.

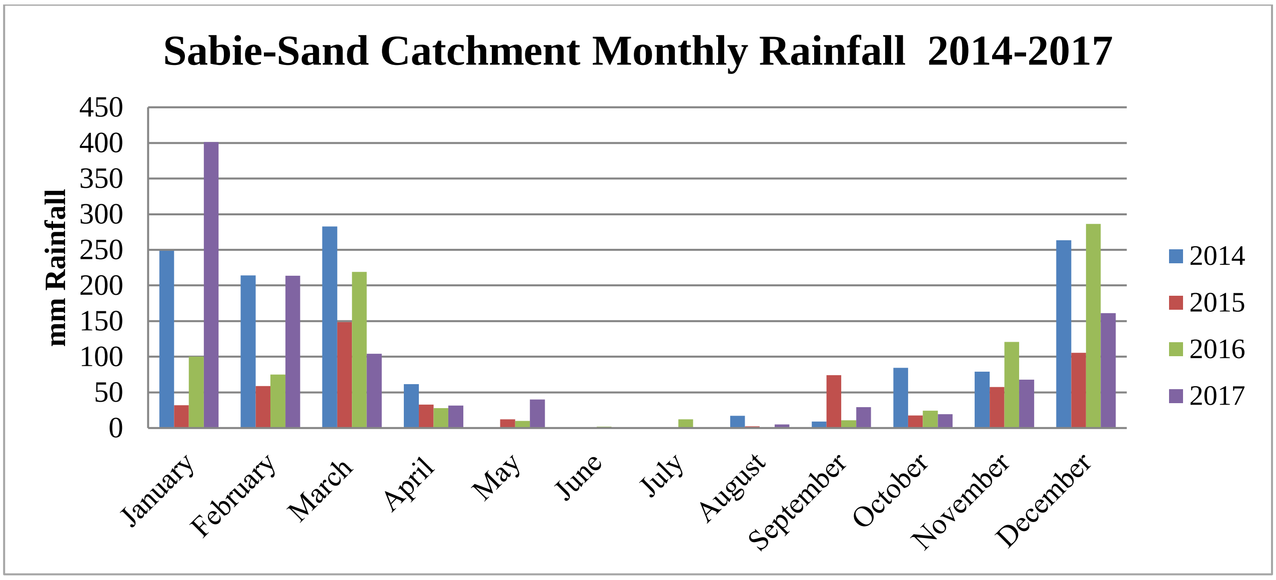
5.1 Section 1: Results of 2016

5.1.1 Rainfall of study area

Figure 5-1 illustrates the annual rainfall received during 2014-2017. The Sabie-Sand catchment received less rain during 2015-2016 rainfall season compared to 2016-2017 rainfall season. The Sabie-Sand catchment receives most of its rain during the months of November to March. The highest rainfall area of the Sabie River is closest to the Drakensberg with 2000 mm/a but the rainfall declines towards the Mozambican border, where an annual rainfall of 450 mm/a is received (Van Niekerk & Heritage, 1993). The Sand River has an annual rainfall of 400-1200 mm, partly due to the topography that ranges from 400-1500m above sea level (Van Niekerk & Heritage, 1993). Monthly rainfall data was obtained from DWS (2017) and the monthly data was used for final analysis. Only one of the rainfall stations available in the catchment was regularly updated by DWS during this study – the rainfall station (X3E005) at Inyaka Dam. The total rainfall for 2016 at this station was 888 mm compared to a total of 1073 mm during 2017.

The rainfall station does not accurately represent the rainfall of all the sites, some sites especially in the KNP received below average rainfall during the 2015/2016 rainfall season. According to Izak Smith, the Skukuza area received for the first time less than 200 mm within a climatic year (Anon, 2017). According to the SANParks programme manager in fire ecology and biogeochemistry, Navashni Govener "The current drought had drastically reduced dam levels and forced water restrictions around the country. It was being compared to the worst on record in the country (1991/92)" (Pretorius, 2016).

It was therefore decided to compare the data sampled during the dry year of 2016 to those collected during the high rainfall year of 2017.



(DWS), 2008)(http://www.dwa.gov.za/Hydrology/)

Figure 5-1: Rainfall (mm) for the Sabie-Sand catchment area for 2014 to 2017.

5.1.2 Diversity and abundance of algae and cyanobacteria

A complete list of genera can be found in Appendix 1-A. This includes 14 genera from the phylum Cyanophyta; 33 genera from the Bacillariophyta; 32 genera from the Chlorophyta; 1 genus from the Chrysophyta; 3 genera from the Dinophyta and 3 from the Euglenophyta. Thus, a total of 86 genera were observed. In general, the concentration of the different algal groups observed were very low at all the sites and the genera that occurred at < 1 cell/ml are listed in Table 5-1. However, all the genera noted through the enumeration process were included in the statistical analyses.

Table 5-1: List of all algal genera found during the first year of sampling (2016) that occurred in an abundance less than 1 cell/ml.

Bacillariophyta	Chlorophyta	Dinophyta
Aulacoseira	*Euastrum*	*Ceratium*
Luticola	*Selenastrum*	
Mayamaea		
Pinnularia		

Cyanobacteria genera such as *Leptolyngbya* (site 6), *Snowella* (site 9) and *Spirulina* (site 4) were observed only once during the sampling period (Table 5-2). The highest concentration of cyanobacteria cells (7522 cells/ml) was observed at site 12 (Thulamahashe), with the filamentous *Phormidium* as the dominant organism at this site. *Komvophoron* (Figure 5-4) was the only cyanobacteria observed in the headwaters of the Sabie River (site 1) at a low concentration of 2 cells/ml. Inyaka Dam (site 11) contained high concentrations of only *Aphanocapsa* (total of 801 cells/ml).

The Chlorophyta and Bacillariophyta were the most diverse phyla during 2016 with 32 and 33 genera, respectively, phytoplankton genera from these groups were present at all the sites during all the sampling occasions. Bacillariophyta g such as *Achnanthes*, *Achnanthidium, Cocconeis, Cymbella, Gomphonema, Gyrosigma, Navicula* and *Nitzschia* were usually present in all of the samples and examples are shown in Figure 5-2. Genera such as *Aulacoseira* (site 4), *Frustulia* (site 1), *Luticola* (sites 2 & 10), *Mayamaea* (site 2), *Pinnularia* (site 1) and *Staurosira* (site 10) all occurred in concentrations lower than 1 cell/ml. The highest concentration of Bacillariophyta (926 cells/ml) was observed at Thulamahashe (site 12), with *Gomphonema* as the dominant genus with333 cells/ml. The headwaters of the Sabie River (site 1) had the lowest concentration Bacillariophyta with a total of 11 cells/ml.Chlorophyta genera such as *Chlamydomonas, Scenedesmus* and *Treubaria* (Figure 5-3) occurred in most of the samples. Genera such as *Euastrum* (sites 4 and 7) and *Selenastrum* (sites 5, 6 & 10) occurred in concentrations lower than 1 cell/ml. The Marite River (site 10) had the highest Chlorophyta diversity with a total of 19 different genera present but again Thulamahashe had the highest concentration of 7592 cells/ml with *Pandorina* the dominant genus with 4440 cells/ml. The headwaters of the Sabie River had the lowest concentration with *Monoraphidium*, *Oocystis* and *Schroederia* occurring at this site at concentrations of 1 cell/ml each.

Only one genus of the Chrysophyta, namely *Dinobryon (*Figure 5-4), was observed at site 5 (<1 cell/ml), site 10 (9 cells/ml) and site 11 (3041 cells/ml) during the 2016 study period. Site 11 is the Inyaka Dam and the presence of *Dinobryon* can be an indication of good water quality. Only three Dinophyta genera were found, namely *Ceratium*, *Peridiniopsis* and *Peridinium* and these genera were only present at sites 8-11 and were absent during the July 2016 sampling occasion. *Ceratium* occurred at site 9 at a concentration of less than 1 cell/ml. *Euglena, Phacus* and *Trachelomonas* from the Euglenophyta were present at most sites at concentrations lower than 1 cell/ml but were completely absent at site 1(Table 5-2). Higher concentrations were observed at Thulamahashe where the concentrations of both *Euglena* and *Trachelomonas* (Figure 5-4) were 526 cells/ml.

Table 5-2: Total concentrations (cells/ml) of the algae and cyanobacteria observed at the different sampling sites during the 2016 study period.

	Site											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	Bacillariophyta											
Achnanthes	2	21	24	8	7	7	1	4	2	2	0	3
Achnanthidium	3	33	27	9	20	11	0	6	4	3	0	7
Caloneis	0	0	0	0	0	0	0	1	0	0	0	0
Capartogramma	0	0	0	0	0	1	0	0	0	0	0	0
Cocconeis	2	18	9	5	14	6	0	4	8	1	0	0
Craticula	0	0	0	0	0	0	0	0	0	0	0	5
Cyclotella	0	0	1	0	1	0	6	1	1	6	55	51
Cymatopleura	0	6	0	6	0	0	0	0	0	0	0	0
Cymbella	1	23	47	17	20	65	1	69	5	6	0	15
Diatoma	0	1	3	0	0	0	0	0	0	0	0	0
Diploneis	0	0	3	1	0	0	13	2	2	0	0	0
Encyonopsis	0	4	6	5	0	1	0	3	0	1	0	0
Eunotia	1	0	0	0	0	0	0	0	0	0	0	0
Fragilaria	0	18	6	5	5	6	12	11	1	7	0	0
Frustulia	0	0	0	0	0	0	0	0	0	0	0	0
Geissleria	0	1	1	0	0	2	1	2	1	0	0	3
Gomphonema	1	66	66	20	14	14	1	10	5	17	1	333
Gyrosigma	0	1	3	10	2	3	14	4	4	1	0	10
Hippodonta	0	1	3	0	0	0	0	0	0	0	0	0
Melosira	0	11	23	10	1	0	0	0	8	0	0	7
Navicula	1	20	43	24	19	25	5	14	21	10	35	88
Nitzschia	0	10	14	11	13	25	12	11	8	9	5	215
Plagiotropis	0	0	0	0	0	0	0	0	0	0	0	10
Rhoicosphenia	0	3	1	0	0	0	0	0	0	0	0	0
Rhopalodia	0	0	0	0	0	0	2	0	0	0	0	0
Sellaphora	0	1	1	1	6	4	0	4	6	1	0	179
Surirella	0	0	2	3	1	2	0	2	1	1	0	0
Synedra	0	31	50	7	1	1	2	6	0	0	0	0
Total cells/ml	**11**	**269**	**333**	**142**	**124**	**173**	**70**	**154**	**77**	**65**	**96**	**926**

	Site											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	Chlorophyta											
Actinastrum	0	0	0	0	0	0	0	1	0	0	0	0
Acutodesmus	0	0	0	1	0	1	0	4	1	3	0	61
Ankistrodesmus	0	0	0	0	0	0	2	0	0	1	15	0
Chlamydomonas	0	0	0	0	1	1	0	1	0	1	1	619
Chlorella	0	0	0	1	0	0	1	1	0	2	87	21
Chlorococcum	0	0	0	3	0	0	0	0	0	0	212	1669
Closterium	0	0	1	0	0	1	1	0	0	1	0	9
Coelastrum	0	0	0	0	0	0	1	0	0	0	0	164
Cosmarium	0	1	0	0	0	0	0	0	0	0	0	0
Crucigenia	0	0	0	0	0	0	0	0	0	11	0	0
Crucigeniella	0	0	0	1	0	0	0	0	0	0	0	0
Desmodesmus	0	0	0	1	2	1	0	3	0	4	0	14
Elakatothrix	0	0	0	0	0	0	0	0	0	0	1	0
Eudorina	0	0	0	0	0	0	0	1	0	0	0	0
Microspora	0	1	0	0	2	0	0	0	0	0	0	0
Monoraphidium	1	2	2	1	1	1	1	0	0	2	205	0
Mougeotia	0	0	0	0	0	0	9	0	0	0	1	0
Nephrocytium	0	0	0	0	0	0	0	0	0	1	0	0
Oedogonium	0	0	3	1	0	0	0	0	1	0	0	0
Oocystis	1	1	0	1	0	0	0	0	0	6	0	0
Pandorina	0	0	0	0	0	0	2	4	0	0	0	4440
Pediastrum	0	0	0	0	0	0	0	3	0	3	0	0
Scenedesmus	0	0	0	2	4	10	11	11	10	7	1	590
Schroederia	1	6	9	0	0	0	0	2	0	1	0	0
Spirogyra	0	0	0	0	0	0	0	7	0	0	0	0
Staurastrum	0	0	0	0	0	0	0	0	0	1	61	0
Stigeoclonium	0	0	0	0	2	0	0	0	0	0	0	0
Tetraedron	0	0	0	0	0	0	0	0	0	0	3	5
Tetrastrum	0	0	0	0	0	0	0	0	0	0	1	0
Treubaria	0	3	3	0	0	0	0	0	0	0	0	0
Total cells/ml	**3**	**14**	**18**	**12**	**12**	**15**	**28**	**38**	**12**	**44**	**588**	**7592**

	Site											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Cyanophyta												
Anabaena	0	0	0	0	0	0	138	0	4	0	0	0
Aphanocapsa	0	8	6	2	0	0	27	3	2	6	801	727
Arthrospira	0	0	2	6	0	0	17	10	0	0	0	0
Chroococcus	0	0	0	0	0	0	4	0	0	7	136	3
Geitlerinema	0	1	0	0	1	0	0	12	0	0	0	0
Johannesbaptistia	0	2	0	0	0	0	2	0	0	0	0	0
Komvophoron	2	0	1	0	0	1	11	8	0	10	0	0
Leptolyngbya	0	0	0	0	0	1	0	0	0	0	0	0
Merismopedia	0	0	0	1	3	7	24	55	0	1	8	109
Oscillatoria	0	1	0	471	0	0	6	0	0	0	0	164
Phormidium	0	0	0	13	5	0	137	4	34	0	0	6519
Pseudanabaena	0	0	0	0	0	0	5	1	5	5	0	0
Snowella	0	0	0	0	0	0	0	0	2	0	0	0
Spirulina	0	0	0	2	0	0	0	0	0	0	0	0
Total Cyanophyta cells/ml	**2**	**12**	**9**	**495**	**9**	**9**	**371**	**93**	**47**	**29**	**945**	**7522**
Chrysophyta												
Dinobryon	0	0	0	0	0	0	0	0	0	9	3041	0
Total Chrysophyta cells/ml	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**9**	**3041**	**0**
Dinophyta												
Peridiniopsis	0	0	0	0	0	0	0	0	0	2	106	0
Peridinium	0	0	0	0	0	0	0	0	0	2	135	0
Total Dinophyta cells/ml	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**241**	**0**
Euglenophyta												
Euglena	0	0	0	0	1	1	0	0	1	3	0	526
Phacus	0	0	0	0	0	0	0	0	0	0	0	66
Trachelomonas	0	0	0	1	0	2	1	1	1	2	11	526
Total Euglenophyta cells/ml	**0**	**0**	**0**	**1**	**1**	**3**	**1**	**1**	**2**	**5**	**11**	**1118**

Figure 5-2: Light microscopy photos (1000x magnification) of samples collected during 2016: Bacillariophyta.

Achnanthes (A), *Achnanthidium* (B), *Cymbella* (C), *Sellaphora* (D), *Gyrosigma* (E), *Cocconeis* (F), *Gomphonema* (G), *Nitzschia* (H), *Navicula* (I) and *Synedra* (J), uncommon genera were *Capartogramma* (K) and *Diploneis* (L).

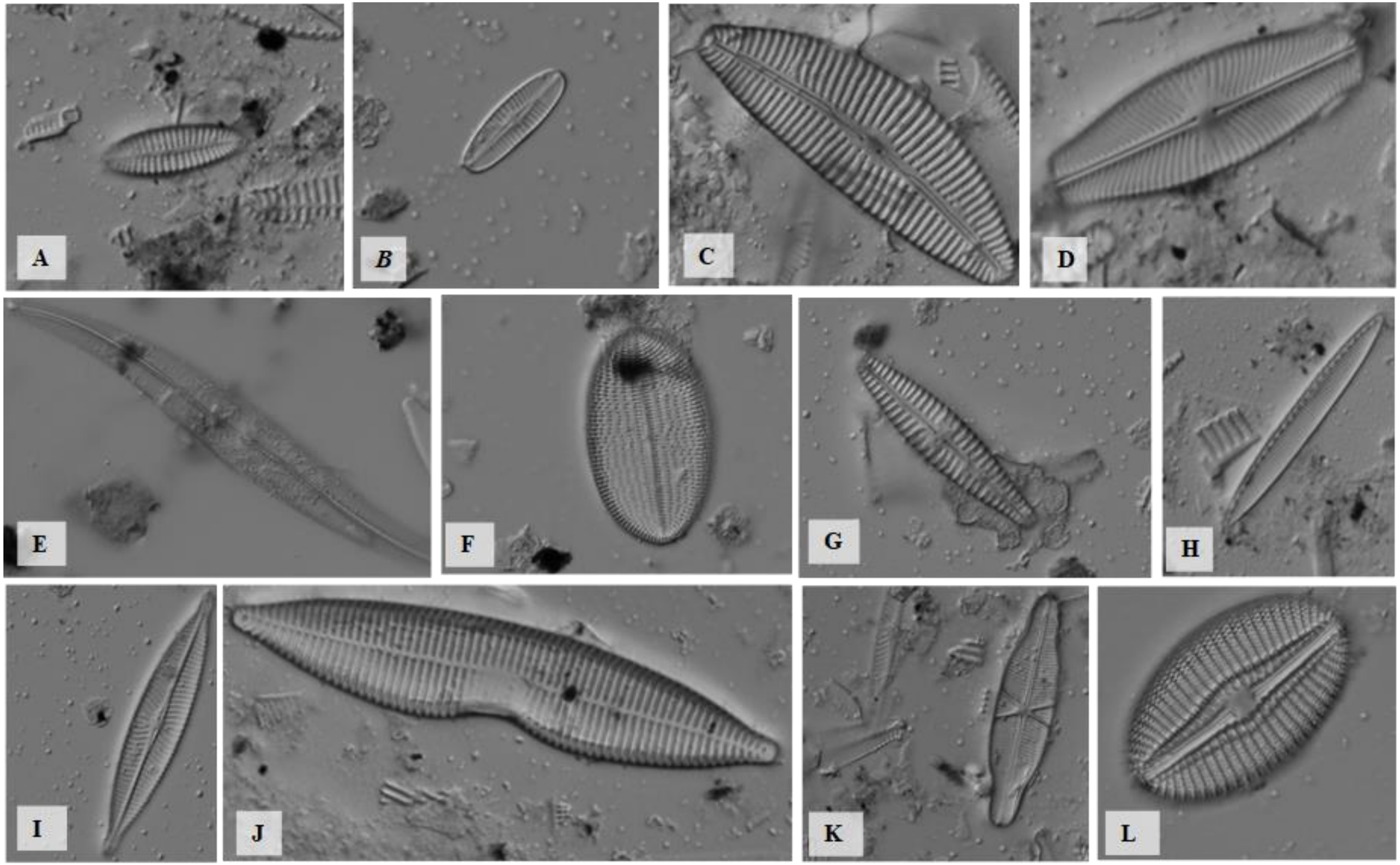

A
B
C
D
E
F
G
H
I
J
K
L

Figure 5-3: Light microscopy photos (400x magnification) of samples collected during 2016: Chlorophyta.

Scenedesmus (A), *Desmodesmus* (B), *Acutodesmus* (C), *Schroederia (*D), *Cosmarium* (E), *Treubaria* (F), *Closterium* (G), *Pediastrum* (H), *Nephrocytium* (I), *Selenastrum* (J), *Pandorina* (K) *and Oocystis* (L).

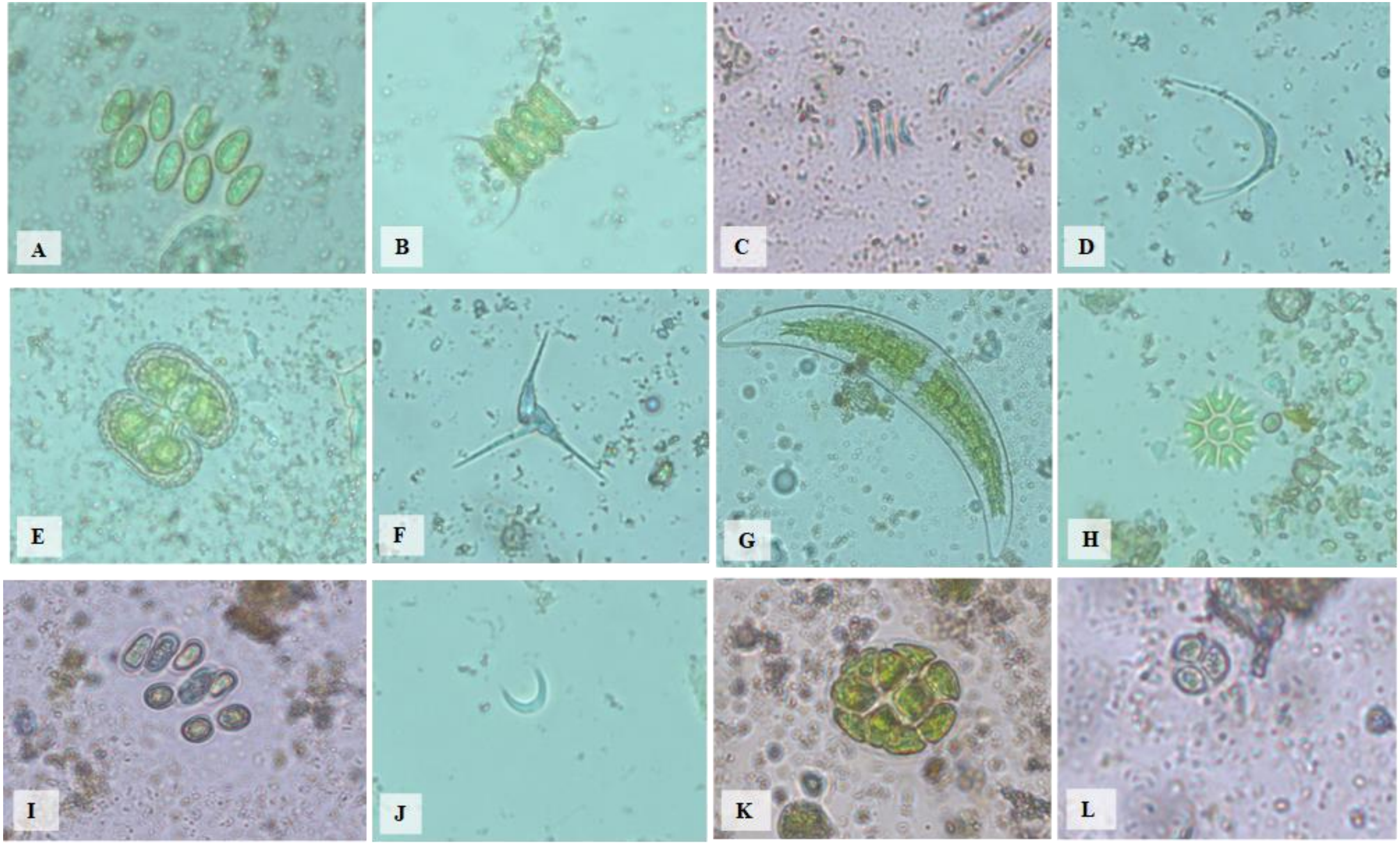

A
B
C
D
E
F
G
H
I
J
K
L

Figure 5-4: Light microscopy photos (400x magnification) of samples collected during 2016. Cyanophyta (A-C), Dinophyta (D-E), Euglenophyta (F-G) and Chrysophyta (H-I).

The genera found in the Cyanophyta group include *Merismopedia* (A), *Komvophoron* (B), and *Anabaena* (C). The Dinophyta includes *Peridiniops*is (D), and *Peridinium* (E). The Euglenophyta includes *Trachelomonas* (F), and *Strombomonas* (G) and one genus of the Chrysophyta: *Dinobryon* (H-I).

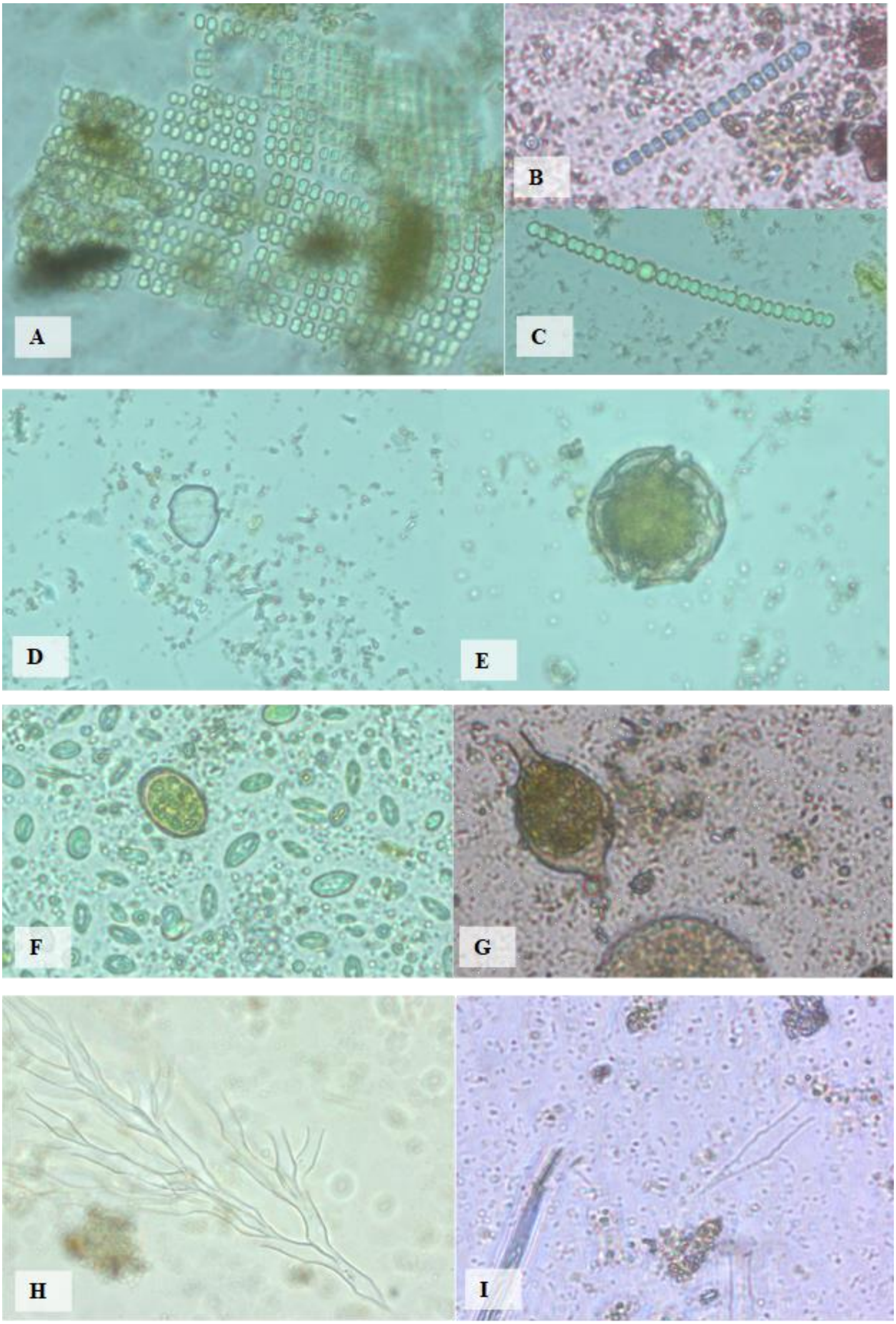

A
B
C
D
E
F
G
H
I

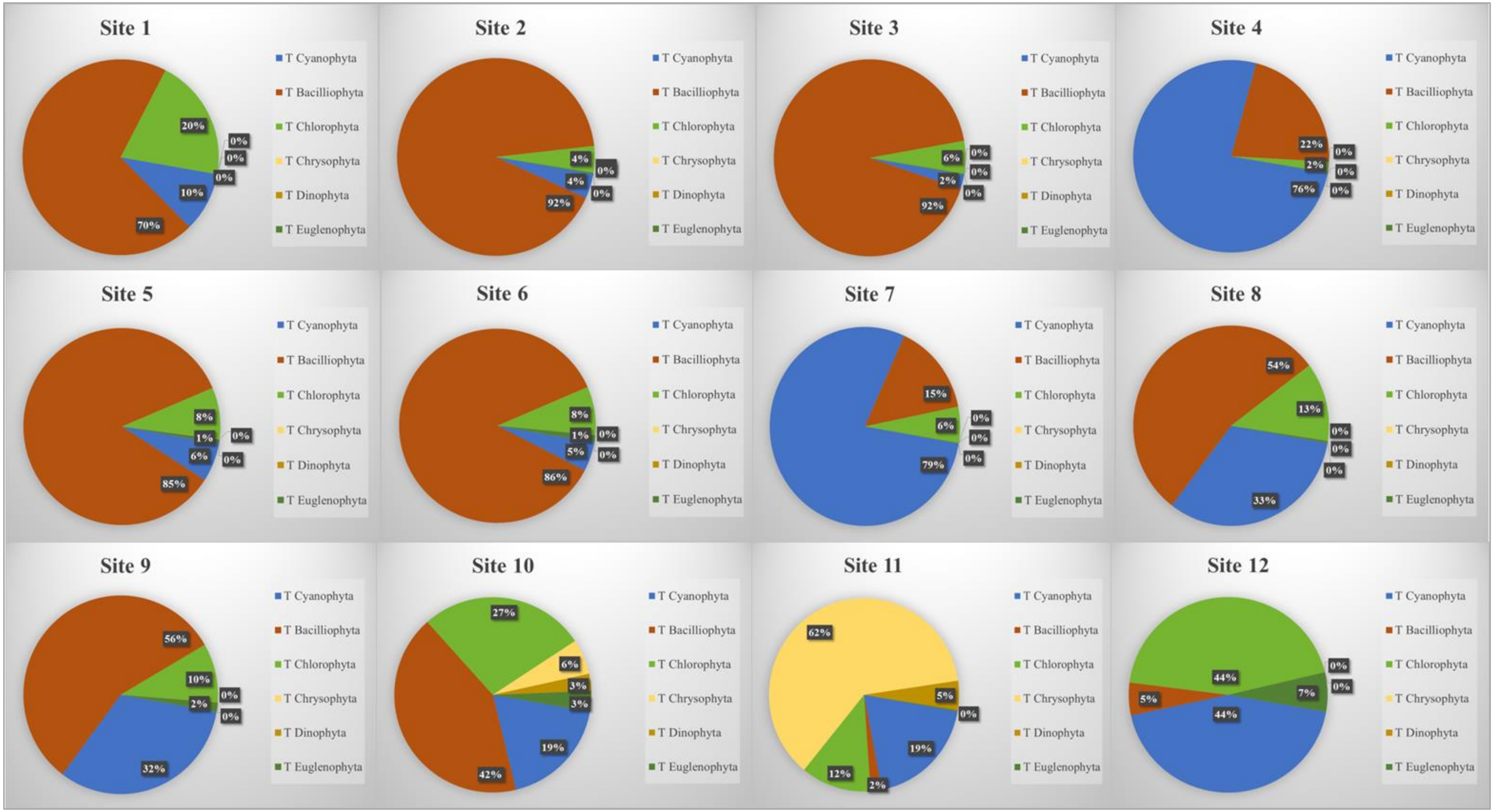
Figure 5-5 shows the percentage abundance of the different taxa as observed during the 4 sampling occasions of 2016 for each of the sites. The Cyanophyta was the most dominant group at both sites 4 near Hoxane in the Sabie River and site 7 located in the Sand River within the Kruger National Park. *Oscillatoria* was the dominant genus at site 4 with a concentration of 471 cells/ml. Site 7 had 2 prominent cyanobacteria genera namely *Anabaena* and *Phormidium* with a total concentration of 138 cells/ml and 137 cells/ml respectively. Thulamahashe (site 12 in the Sand River) had the highest concentrations (cells/ml) of both algae and cyanobacteria (Table 5-2). This site had similar concentrations of both Cyanophyta (7522 cells/ml) and Chlorophyta (7592 cells/ml). *Phormidium* accounted for most of the Cyanophyta at this site and *Pandorina* for most of the Chlorophyta.

Bacillariophyta was clearly the dominant group in the Sabie River with the exception of site 4 where the Cyanophyta was dominant. Sites 8 and 9 are situated after the Sabie-Sand Rivers' confluence and have similar phytoplankton and cyanobacteria compositions. The Sabie River had a total of 1283 Bacillariophyta cells/ml and genera such as *Cymbella*, *Gomphonema, Navicula* and *Synedra* occurred at high concentrations. Bacillariophyta was also dominant in the Marite River (site 10) with a total of 65 cells/ml. *Gomphonema* (17 cells/ml) and *Navicula* (10 cells/ml) were the most dominant genera at this site (Table 5-2). Site 10 also had a diverse Chlorophyta population of which most occurred at concentrations lower than 1 cell/ml. Amongst these Chlorophyta genera, *Crucigenia* occurred at the highest concentration (11 cells/ml) at site 10.

Chrysophyta was the dominant group at site 11. Only one genus, *Dinobryon*, with a total concentration of 3041 cells/ml was observed at this site. The Chrysophyta was also present at sites 10 at a considerably lower concentration compared to site 11, with a total of only 9 cells/ml during 2016. The Dinophyta group was also present at both the Inyaka Dam and the Marite River sites with 241 cells/ml and 4 cells/m respectively. *Peridiniopsis* and *Peridinium* were present at both site 10 and 11. The Chrysophyta and Dinophyta phyla were both absent in the Sabie River and Sand River sites (Figure 5-5). Thulamahashe (site 12) in the Sand River had the highest Euglenophyta concentration with a total of 1119 cells/ml. *Euglena* and *Trachelomonas* were dominant at this site with a total concentration of 526 cells/ml for both genera (Table 5-2). Euglenophyta was absent or occurred at concentrations lower than 1 cell/ml in the Sabie River.

Figure 5-5: Percentage abundance (cells/ml) of the different algal phyla at each of the sites observed during the 4 sampling occasions of 2016.

Site 1: Sabie River Head Waters; Site 2: Sabie River Waste Water Treatment; Site 3: Sabie River Before Hazyview; Site 4: Sabie River Hoxane; Site 5: Kruger Gate Bridge; Site 6: Sabie Skukuza; Site 7: Sand River Skukuza; Site 8: Sabie River lower; Site 9: Sabie River Mozambique; Site 10: Marite River; Site 11: Inyaka Dam and Site 12: Sand River Thulamahashe.


Site 1
20%
0%
0%
0%
10%
70%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 2
4%
0%
4%
0%
92%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 3
6%
0%
0%
2%
0%
92%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 4
22%
0%
2%
0%
76%
0%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 5
8%
1%
0%
6%
0%
85%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 6
8%
1%
0%
5%
0%
86%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 7
15%
0%
6%
0%
79%
0%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 8
54%
13%
0%
0%
0%
33%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 9
56%
10%
0%
2%
0%
32%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 10
27%
6%
3%
3%
19%
42%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 11
62%
5%
0%
19%
12%
2%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 12
0%
0%
44%
7%
5%
44%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta

5.1.3 Diversity Indices

According to Magurran (2004), the Shannon-Wiener index score (Table 5-3) varies between 1.5 and 3.5 and is very rarely higher than 4. Sites 4, 11 and 12 had the lowest scores during 2016. Site 4 and 11 had the lowest Shannon-Wiener and Pielou scores of 1.40 and 1.42 respectively and site 11 and 12 the lowest Margalef scores 2.82 and 3.08 respectively. This is due to one or two dominant genera found at these sites. Site 4 scored higher than site 11 and 12 with a Margalef score of 6.49 and thus the lowest species diversity, richness and species evenness compared to the other sites. Site 12 had high algal concentrations for most of the sampling occasions. Site 10 had the highest Shannon-Wiener Index score (3.35) and therefore the highest species diversity. The other sites had an-unexceptional species diversity. Overall site 10 scored the highest in all the indices, indicating that the diversity, richness and evenness are all high, indicating a healthy system.

Table 5-3: Shannon-Wiener, Margalef and Pielou Indices Scores during 2016.

Site	Shannon-Wiener Index Score	Margalef Index Score	Pielou Index Score
1	2.46	5.40	0.89
2	2.66	6.33	0.74
3	2.62	6.12	0.73
4	1.40	6.49	0.37
5	2.72	7.42	0.75
6	2.44	7.17	0.66
7	2.29	6.18	0.62
8	2.81	8.50	0.72
9	2.77	8.28	0.74
10	3.35	9.64	0.86
11	1.42	2.82	0.44
12	1.96	3.08	0.57

5.1.4 Physical-Chemical Variables of the Sabie-Sand River Catchment

Table 5-4, Table 5-5 and Table 5-6 is a summary of the most relevant physical-chemical variables of the Sabie-Sand catchment. This includes the mean, minimum and maximum for each variable compared to the target range or natural range where the target was unavailable. A full list of all the measured variables is available in Appendix 2-A.

Table 5-4: A comparison of the mean, minimum and maximum values of the physical and chemical parameters determined in the Sabie River during 2016 and the TWQR of each parameter (n=4).

Variable	Range	Site 1			Site 2			Site 3			Site 4		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
pH	6.5-9.0	6.18	5.9	6.55	7.37	6.53	8.16	7.23	6.6	8.2	6.93	6.6	7.37
M Alkalinity (mg/l CaCO3)	> 20	14.5	14	15	59.5	54	64	56.5	51	61	45.25	39	50
Hardness (mg/l CaCO3)	<75 >120	10.05	8.2	11	58.5	51	63	54.75	51	59	39	31	48
Specific conductance (mS/m)	5-150	46.77	41.4	49.4	143.375	122.2	157.5	130.67	115	142	124.62	119.2	132.6
Turbidity (NTU)	<5 > 55	0.70	0.45	1.1	1.028	0.6	1.6	1.045	0.72	1.6	2.6	1.4	4.5
Dissolved Oxygen (%)	>80%	82.25	76.2	93.4	83.65	74.1	94.2	88.15	72.3	102.2	85.4	66	105.3
Total Nitrogen (mg/l as N)	<0.35	1.82	0.59	4.69	2.038	0.59	4.59	2.08	0.925	4.32	2.14	0.66	4.82
Nitrate - Nitrite (mg/l as N)	0.3	0.065	0.065	0.065	0.32	0.065	0.465	0.368	0.22	0.52	0.17	0.065	0.29
Ammonia (mg/l as N)	0,1	0.062	0.025	0.1	0.063	0.025	0.1	0.063	0.025	0.1	0.063	0.025	0.1
Total Phosphorus (mg/l)	<0.03	0.33	0.3	0.35	0.33	0.3	0.35	0.338	0.3	0.35	0.33	0.3	0.35
Ortho-Phosphate (mg/l)	<0.01	0.08	0.05	0.1	0.088	0.05	0.1	0.088	0.05	0.1	0.08	0.05	0.1
Dissolved Organic Carbon (mg/l)	0-5	0.96	0.5	1.6	0.903	0.52	1.6	1.22	0.72	2.4	1.525	1.3	1.9
Total Organic Carbon (mg/l)	<30	0.81	0.56	1.3	0.93	0.65	1.4	1.093	0.8	1.7	1.7	1.4	2.1
Aluminium (µg/l)	5	12.5	12.5	12.5	17.37	12.5	32	15.875	12.5	26	83	66	110
Iron (µg/l)	<10%	20.12	2.5	34	77.25	65	89	125	105	140	338.75	220	395
Zinc (mg/l)	<0.002	0.0075	0.0075	0.008	0.008	0.008	0.008	0.198	0.0075	0.77	0.008	0.0075	0.008
Chlorophyll-*a* (µg/l)	<100 mg/l	2.35	1	4.4	2.92	1	5.4	3.15	1	6.2	1.97	1	3.6
Coliforms (MPN/100 ml)	0-130	507	31	1145	2065	1789	2420	2099.66	727	3790	1230.33	727	1664
E. coli (MPN/100 ml)	0-130	9.75	0	17	225.25	4	548	35	3	67	69.75	9	93
2-Methylisoborneol (ng/l)	4 - 20	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Geosmin (ng/l)	4 - 20	0.76	0.25	1.5	1.45	0.91	2.4	2.8	2	3.8	4.1	2.9	5.3

The following references were used for the TWQR: (DWAF, 1996a,b,c; South Africa, 2016; US-EPA, 2012).

Variable	Range	Site 5			Site 6			Site 8			Site 9		
		Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
pH	6.5-9.0	6.96	6.58	7.25	6.81	6.55	7.1	7.11	6.59	7.7	6.74	6.57	6.9
M Alkalinity (mg/l CaCO3)	> 20	55	45	66	61.75	45	81	56	44	66	60.5	49	72
Hardness (mg/l CaCO3)	<75 >120	33.37	7.5	47	49	36	59	47	35	59	50.25	37	63
Specific conductance (mS/m)	5-150	126.9	71.1	159	155.92	148.1	170.1	148.62	130.7	158.3	161.87	133.9	177.2
Turbidity (NTU)	<5 > 55	2.8	1.8	3.5	2.788	0.85	6.2	2.25	1.6	3.9	7.15	2.6	15
Dissolved Oxygen (%)	>80%	82.92	77.8	85	85.4	63.8	98.1	91.9	87.4	98.8	76.32	62.8	83.3
Total Nitrogen (mg/l as N)	<0.35	2.44	1.86	3.93	4.33	1.93	10.23	2.75	1.89	3.89	4.77	1.89	8.95
Nitrate - Nitrite (mg/l as N)	0.3	0.13	0.065	0.205	0.14	0.065	0.23	0.12	0.065	0.28	0.21	0.065	0.65
Ammonia (mg/l as N)	0,1	0.063	0.025	0.1	0.063	0.025	0.1	0.063	0.025	0.1	0.063	0.025	0.1
Total Phosphorus (mg/l)	<0.03	0.33	0.3	0.35	0.33	0.3	0.35	0.33	0.3	0.35	0.33	0.3	0.35
Ortho-Phosphate (mg/l)	<0.01	0.088	0.05	0.1	0.088	0.05	0.1	0.088	0.05	0.1	0.088	0.05	0.1
Dissolved Organic Carbon (mg/l)	0-5	1.85	1.4	2.5	1.62	0.88	2.8	1.85	1.3	2.3	2.45	1.9	2.8
Total Organic Carbon (mg/l)	<30	2	1.5	2.4	1.9	1.3	2.9	1.95	1.4	2.3	2.65	2	3.2
Aluminium (µg/l)	5	41.375	12.5	83	61.375	12.5	105	54.875	12.5	100	118.25	45	190
Iron (µg/l)	<10%	153.62	2.5	285	172.5	135	245	142.5	115	195	318.75	270	400
Zinc (mg/l)	<0.002	0.331	0.008	1.3	0.008	0.0075	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Chlorophyll-*a* (µg/l)	<100 mg/l	1.8	0.5	4.7	3.45	1	5.3	2.87	1	6.9	1.77	1	2.8
Coliforms (MPN/100 ml)	0-130	1719.66	1187	1986	2360	866	3990	4670	1203	6867	4962.33	1450	6867
E. coli (MPN/100 ml)	0-130	356	63	866	207.75	32	365	387.25	241	613	273.75	185	461
2-Methylisoborneol (ng/l)	4 – 20	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Geosmin (ng/l)	4 – 20	4.88	0.25	15	2.68	0.52	8.8	3.32	0.99	7.1	7.85	1.7	17

The following references were used for the TWQR: (DWAF, 1996a,b,c; South Africa, 2016; US-EPA, 2012).

	Health risk
	Exceeded TWQR
	Higher than natural ranges
	Lower than recommended
	Taste and odour problems

Table 5-5: A comparison of the mean, minimum and maximum values of the physical and chemical parameters determined in the Marite River and Inyaka Dam during 2016 with the TWQR (n=4).

Variable	Range	Site 10			Site 11		
		Mean	Min	Max	Mean	Min	Max
pH	6.5-9.0	6.52	5.9	7.47	6.49	5.96	7.25
M Alkalinity (mg/l CaCO3)	> 20	24	21	28	21.5	20	24
Hardness (mg/l CaCO3)	<75 >120	13.75	10	18	11.5	11	13
Specific conductance (mS/m)	5-150	76.92	58.6	100.4	62.05	57.3	71.1
Turbidity (NTU)	<5 > 55	7.47	1.5	21	9.95	1.7	34
Dissolved Oxygen (%)	>80%	79.42	70.2	95.6	75.42	62.4	89.4
Total Nitrogen (mg/l as N)	<0.35	3.90	1.69	5.39	3.91	1.46	7.23
Nitrate- Nitrite (mg/l as N)	0.3	0.16	0.065	0.37	0.065	0.065	0.065
Ammonia (mg/l as N)	0,1	0.063	0.025	0.1	0.19	0.1	0.37
Total Phosphorus (mg/l)	<0.03	0.33	0.3	0.35	0.33	0.3	0.35
Ortho-Phosphate (mg/l)	<0.01	0.08	0.05	0.1	0.08	0.05	0.1
Dissolved Organic Carbon (mg/l)	0-5	2.05	1.5	2.7	2.2	1.6	2.9
Total Organic Carbon (mg/l)	<30	2	1.6	2.2	2.2	1.9	2.5
Aluminium (µg/l)	5	132.75	56	185	34.125	12.5	61
Iron (µg/l)	<10%	545	280	640	540	200	1440
Zinc (mg/l)	<0.002	0.01	0.008	0.019	0.78	0.0075	3.1
Chlorophyll-*a* (µg/l)	<100 mg/l	1.82	1	2.8	3.87	2.5	7.5
Coliforms (MPN/100 ml)	0-130	2779	2430	2987	326.33	99	554
E. coli (MPN/100 ml)	0-130	125.25	68	231	1.5	0	2
2-Methylisoborneol (ng/l)	4 - 20	0.25	0.25	0.25	0.25	0.25	0.25
Geosmin (ng/l)	4 - 20	3.85	1.8	7.3	2.125	1.5	3.4

The following references were used for the TWQR: (DWAF, 1996a,b,c; US-EPA, 2012)

	Health risk
	Exceeded TWQR
	Higher than natural ranges
	Lower than recommended
	Taste and odour problems

Table 5-6: A comparison of the mean, minimum and maximum values of the physical and chemical parameters determined in the Sand River during 2016 with the TWQR (n=4).

Variable	**Range**	**Site 7**			**Site 12**		
		Mean	Min	Max	Mean	Min	Max
pH	6.5-9.0	7.24	6.59	7.58	6.9	6.56	7.1
M Alkalinity (mg/l CaCO3)	> 20	66.25	55	83	105.3	68	150
Hardness (mg/l CaCO3)	<75 >120	48.5	44	58	62	46	86
Specific conductance (mS/m)	5-150	292.62	243.5	329.4	389.2	276.2	602
Turbidity (NTU)	<5 > 55	3.35	2	5.9	3.7	1.5	6.9
Dissolved Oxygen (%)	>80%	86	76	95.6	40.2	21.1	69
Total Nitrogen (mg/l as N)	<0.35	2.30	1.29	3.39	18.7	3.15	38.4
Nitrate- Nitrite (mg/l as N)	0.3	0.065	0.065	0.065	0.6	0.07	1.6
Ammonia (mg/l as N)	0,1	0.063	0.025	0.1	5	0.1	11
Total Phosphorus (mg/l)	<0.03	0.33	0.3	0.35	1.1	0.3	2.4
Ortho-Phosphate (mg/l)	<0.01	0.088	0.05	0.1	0.5	0.05	1.1
Dissolved Organic Carbon	0-5	2.57	1.7	4.2	6.2	4.2	9.6
Total Organic Carbon (mg/l)	<30	2.8	1.9	4.6	8.2	4	16
Aluminium (µg/l)	5	158.75	12.5	460	31.3	12.5	60
Iron (µg/l)	<10%	288.75	105	680	161	24	300
Zinc (mg/l)	<0.002	0.008	0.0075	0.008	1.9	0.01	7.6
Chlorophyll-*a* (µg/l)	<100	3.75	1	7.2	62.2	6.7	170
Coliforms (MPN/100 ml)	0-130	1195.5	435	1956	143593.7	15531	241960
E. coli (MPN/100 ml)	0-130	83.66	4	236	26425.3	1986	98040
2-Methylisoborneol (ng/l)	4 - 20	0.25	0.25	0.25	5.7	0.25	22
Geosmin (ng/l)	4 - 20	1.255	0.25	3.5	6.8	4.1	8.2

The following references were used for the TWQR: (DWAF, 1996a; DWAF, 1996b; DWAF, 1996c; US-EPA, 2012)

	Health risk
	Exceeded TWQR
	Higher than natural ranges
	Lower than recommended
	Taste and odour problems

During 2016 the study area experienced lower rainfall (see section 5.1.1) compared to the average annual rainfall of the region (Mucina & Rutherford, 2006). The relevant data regarding the water quality can be found in Appendix 2-A. Low turbidity values were observed at all sites and none of the mean values exceeded the clarity ranges for turbidity as stated in MELP (1998). There was also no indication of a downstream increase in turbidity in the Sabie River, although the highest mean annual turbidity was measured at the Sabie River Mozambique site (site 9; 7.15 NTU). According to Wetzel (2001) turbidity is usually much higher in rivers than in lakes or impoundments, but Inyaka Dam had the highest average turbidity of 9.95 NTU with a maximum of 34 NTU (Table 5-5) measured during the July 2016.

The total dissolved solids in water are usually measured as TDS or as specific conductance (SPC) or as salinity in most waters. There is a close correlation between these values (Weiner, 2008). The majority of the ionic substances dissolved in most waters are the cations such as Na^+ K^+ Ca^{2+} and Mg^{2+}, while the anions are composed of HCO_3^-, CO_3^{2-}, Cl^- and SO_4^{2-}(Dallas & Day, 2004; Weiner, 2008). During this study, there was a significant positive correlation (p<0.05) between turbidity, TDS and SPC. SPC was significantly correlated to all the dissolved ions measured during 2016, namely: Na^+ K^+ Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-}.

The mean annual composition of the major ions in the Sabie, Sand and Marite Rivers has been determined as $Na^+ > Cl^- > Ca^{2+} > SO_4^{2-} > K^+$. The SPC concentrations of the Sabie River was similar to natural conditions and only the means at sampling sites in Skukuza (site 6) and near Mozambique (site 9) exceeded the ranges of natural water (>150 mS/m; MELP, 1998). The sampling sites in the Sand River (sites 7 & 12) exhibited the highest mean SPC values of 292.62 and 389.20 mS/m respectively. These two sites (7 &12) also showed the highest concentrations of Na^+ K^+, Cl^-, and total silica (Appendix 2-A;MELP, 1998).

The pH of natural waters ranges from 6.5 to 9.0 (Dallas & Day, 2004). Site 1 had a mean pH of 6.1 with a minimum pH of 5.9, which is slightly lower than the range for natural water (Table 5-4). A minimum pH of 5.9 was also observed for the Marite River (site 10) and the Inyaka Dam (site 11;Table 5-5). The pH of the remaining Sabie River sites (2-6, 8 and 9) was highest at site 2 with a mean pH of 7.3. The Sand River had a mean value pH of 7.2 at site 7 and 6.9 at site 12.

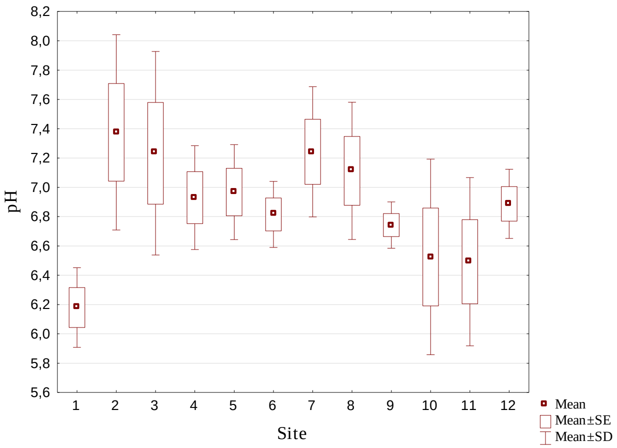
Both the Marite River and Inyaka Dam had an alkalinity greater than 20 mg/l and therefore a higher buffering capacity to withstand changes in the pH. However, the alkalinity of the Sand River was higher than all the sites with a mean concentration of 66 mg/l at Skukuza (site 7) and 105 mg/l at Thulamahashe (site 12).

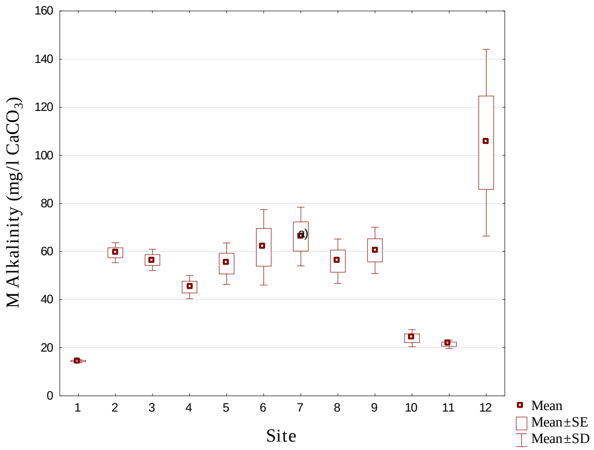
Dissolved oxygen (DO) can be influenced by many factors such as temperature, atmospheric pressure and an increase in salinity (Dallas & Day, 2004). The mean annual percentage dissolved oxygen (Figure 5-6) of the Sabie River was above 80% and thus meets the TWQR (DWAF, 1996c). The minimum concentrations were above 70% for sites 1, 2, 3, 5 but sites 4, 6 and 9 had minimum values around 60%. The mean annual dissolved oxygen levels were 79% and 75% for site 10 and 11, respectively, which are slightly below the TWQR.

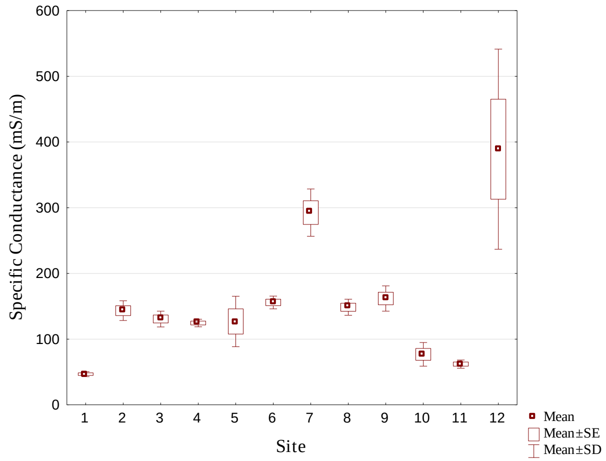
The minimum %DO of the Inyaka Dam was observed during July (Table 5-5). The dissolved oxygen levels at Skukuza site in the Sand River (site 7) were similar to that of the Sabie River, but critically low levels were observed at Thulamahashe (site 12). The mean annual %DO at site 12 was 40% which is well below the requirements of the TWQR (Dallas & Day, 2004).

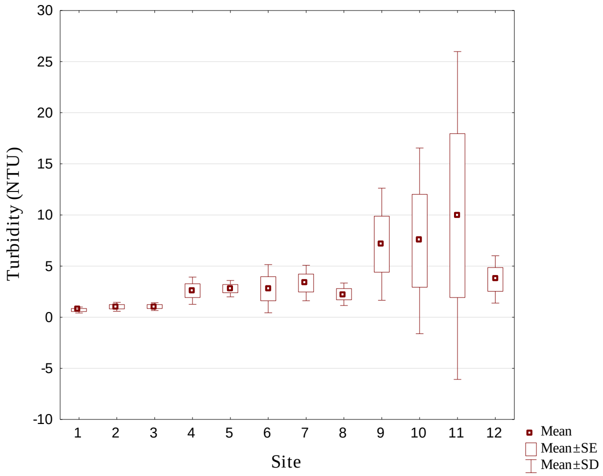
Figure 5-6: Box and Whiskers plots illustrating the mean annual measurements of pH, alkalinity, SPC, Turbidity and %DO, for the different sampling sites as determined during the 2016 study period.

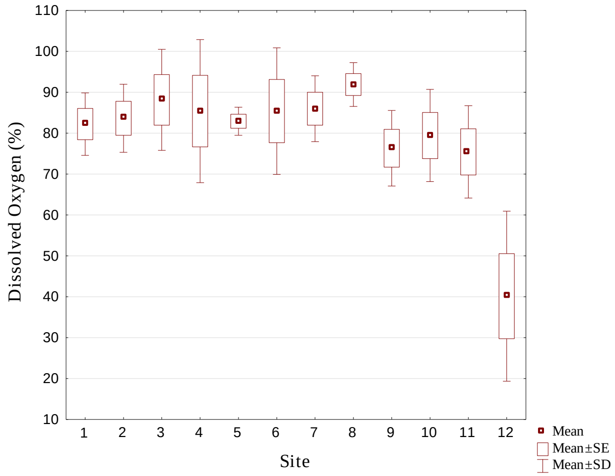
SE (Standard Error) SD (Standard Deviation) n= 4. Site 1: Sabie River Head Waters; Site 2: Sabie River Waste Water Treatment; Site 3: Sabie River Before Hazyview; Site 4: Sabie River Hoxane; Site 5: Kruger Gate Bridge; Site 6: Sabie Skukuza; Site 7: Sand River Skukuza; Site 8: Sabie River lower; Site 9: Sabie River Mozambique; Site 10: Marite River; Site 11: Inyaka Dam and Site 12: Sand River Thulamahashe.


pH
Site
Mean
Mean±SE
Mean±SD


M Alkalinity (mg/l $CaCO_3$)
Site
Mean
Mean±SE
Mean±SD


Specific Conductance (mS/m)
Site
Mean
Mean±SE
Mean±SD


Turbidity (NTU)
Site
Mean
Mean±SE
Mean±SD


Dissolved Oxygen (%)
Site
Mean
Mean±SE
Mean±SD

The total nitrogen concentration (total kjeldahl nitrogen, nitrate, nitrite, ammonia) (Figure 5-7) in the Sabie River was relatively low compared to that in the Sand River. The Sabie River had a mean concentration of 2 mg/l at most sites with a mean concentration of 4.4 mg/l at site 6 and 4.7 mg/l at site 9. The nitrate-nitrite (Figure 5-7) concentrations in the Sabie River (Sites 1, 4, 5, 6, 8 and 9) were similar to that found in natural systems (<0.1 mg/l; MELP, 1998; Weiner, 2008). Sites 2 and 3 of the Sabie River had concentrations slightly higher than that found in natural systems with a mean concentration of 0.3 mg/l. The ortho-phosphate concentrations (Table 5-4) of all the Sabie River sites were 0.088 mg/l, this is slightly higher than in non-polluted waters (<0.01 mg/l; MELP, 1998) Ammonia (Table 5-4) concentrations of the entire Sabie River, were lower than the range found in natural waters (<0.1 mg/l) with a mean of 0.06 mg/l (Dallas & Day, 2004). The dissolved inorganic nitrogen (DIN = $NH_3^+N^+$ NO_3^--N+NO_2^--N) concentration ratio to dissolved inorganic phosphate (DIP=PO_4^- P) is lower than the Redfield ratio of 16:1 at all the sampling sites in the Sabie River. However according to Reynolds (1992) whether a nutrient is limiting or not is immaterial if the nutrient concentrations are already in excess. The mean DIN:DIP ratio ranged from of 0.38 at site 1 to 0.88 at site 9, while the mean TN:TP ratio ranged from 5.38 at site 1 to 14.72 at site 9. This implies that nitrogen could possibly be limiting to plant and algal growth (Dallas & Day, 2004). The average TN:TP ratio is much higher but it should be taken into consideration that not all the N and P are available for metabolic use. Again sites 1-4 exhibited the lowest TN:TP ratios. The minimum and maximum values for Si ranged from a maximum of 6.8 mg/l at site 6 to a minimum of 0.5mg/l at site 5. There was however very little difference in the average Si:DIP ratio down the length of Sabie River and no significant correlation between algal groups and Si:DIP was evident.

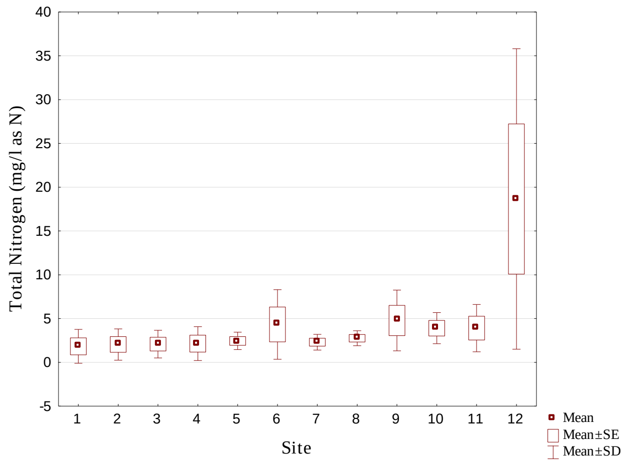
The Marite River and Inyaka Dam had total nitrogen concentrations slightly higher than that observed in the Sabie River with a mean concentration of 3.9 mg/l for both the sites nitrate-nitrite (Figure 5-7) concentrations of both the Marite River (site 10), and Inyaka Dam (site 11) was similar to a natural system (<0.1 mg/l; MELP, 1998; Weiner, 2008). The ortho-phosphate concentrations (Figure 5-7) were the same as in the Sabie River with a mean of 0.088 mg/l. This is slightly higher than non-polluted waters (<0.01 mg/l; MELP, 1998). The ammonia concentrations (Table 5-5) in the Marite River were lower than the natural waters (<0.1 mg/l; Dallas & Day, 2004) but that of the Inyaka Dam was higher with a mean concentration of 0.19 mg/l. The DIN to DIP concentration ratio is lower than the Redfield ratio of 16:1 at both the Marite and Inyaka Dam with a mean DIN:DIP ratio of 0.69 at site 10 and 0.76 at site 11. The TN:TP ratio was lower than that observed in the Sabie River at site 9 with a mean of 11.76 in both the Marite River and Inyaka Dam. The Inyaka Dam had a higher Si: DIP ratio compared to the Sabie River sites with a mean of 75. The Marite River had a Si:DIP ratio lower than the Inyaka Dam and similar to the Sabie River sites with a mean of 57.

Site 7, located in the Sand River, had a similar mean total nitrogen concentration when compared to the other sites located in the Sabie River. However, site 12 had excessively higher total nitrogen concentrations with a mean concentration of 18 mg/l and a maximum of 38.4 mg/l.

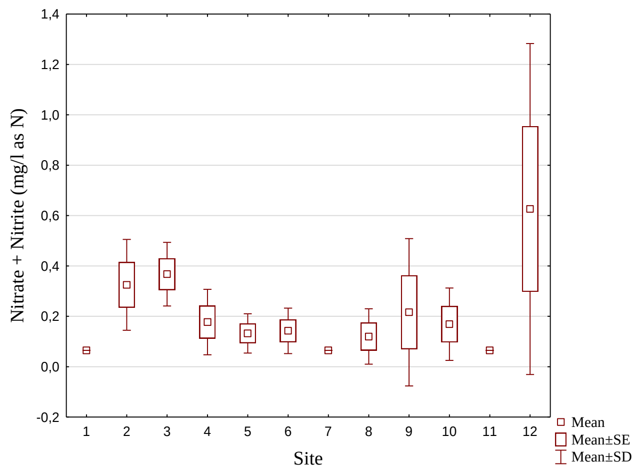
The nitrate-nitrite (Figure 5-7) concentrations of the Sand River (site 7) were similar to that of a natural system (<0.1 mg/l;MELP, 1998), while site 12 had the highest nitrate-nitrite concentration with a mean concentration of 0.6 mg/l. The ortho-phosphate concentrations (Figure 5-7) of Sand River site 7 was the same as in the Sabie River, the Marite River and Inyaka Dam with a mean concentration of 0.088 mg/l (Table 5-6). However, again site 12 exhibited a higher mean concentration compared to the rest of the sites with a mean of 0.5 mg/l and a maximum of 1.1 mg/l. Ammonia (Figure 5-5) concentrations at site 7 were lower than that of natural waters (<0.1 mg/l;Dallas & Day, 2004), while the levels at site 12 exceeded that of the TWQR. Increased ammonia concentrations varied during the year from 1.4 mg/l measured in January, to 0.1 mg/l in April, and then increased to 7.3 mg/l in July, and 11 mg/l in October. The Sand River (site 7) had a DIN: DIP ratio of 0.38, a TN:TP ratio of 6.88 and a Si: DIP ratio of 84.50. The DIN:DIP and TN:TP ratios were relatively low and similar to Sabie River (site 1), but the Si: DIP ratio was higher than that of all the other sites. Sand River site 12 had the highest DIN:DIP and TN:TP ratios compared to the other sites with a mean DIN:DIP of 5.00 and TN:TP of 16.00. The Si:DIP ratio at site 12 was similar to the Sabie River sites with a mean of 54.90.

Figure 5-7: Box and Whiskers plots illustrating the mean concentrations of the total nitrogen, nitrate-nitrite, orthophosphate, DOC and TOC , for the different sampling sites as determined during the 2016 study period.

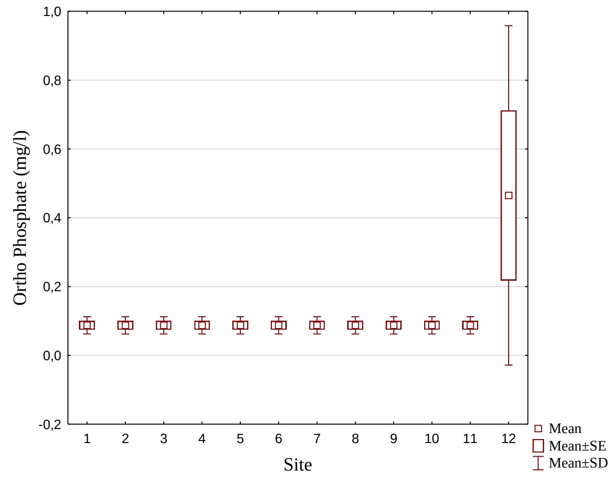
SE (Standard Error) SD (Standard Deviation) n=4. Site 1: Sabie River Head Waters; Site 2: Sabie River Waste Water Treatment; Site 3: Sabie River Before Hazyview; Site 4: Sabie River Hoxane Dumping site; Site 5: Kruger Gate Bridge; Site 6: Sabie Skukuza; Site 7: Sand River Skukuza; Site 8: Sabie River lower; Site 9: Sabie River Mozambique; Site 10: Marite River; Site 11: Inyaka Dam and Site 12: Sand River Thulamahashe.



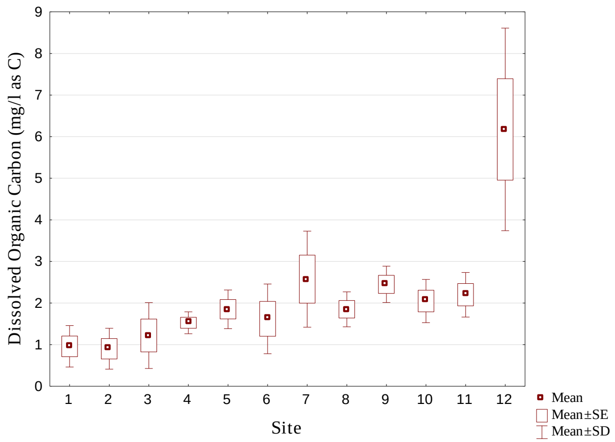
Total Nitrogen (mg/l as N)
Site
Mean
Mean±SE
Mean±SD



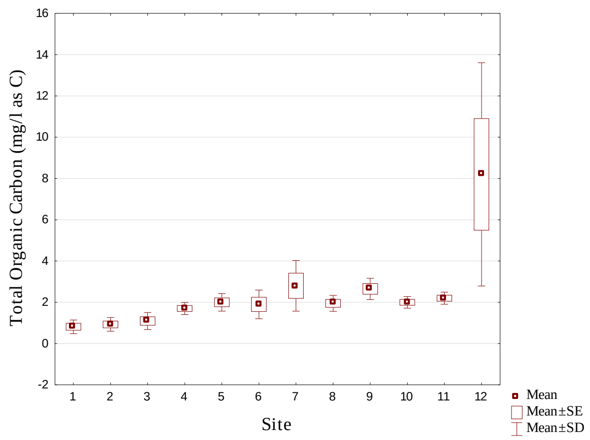
Nitrate + Nitrite (mg/l as N)
Site
Mean
Mean±SE
Mean±SD



Ortho Phosphate (mg/l)
Site
Mean
Mean±SE
Mean±SD



Dissolved Organic Carbon (mg/l as C)
Site
Mean
Mean±SE
Mean±SD



Total Organic Carbon (mg/l as C)
Site
Mean
Mean±SE
Mean±SD

Considering the Sabie River, the zinc concentrations were similar for all the sites with a mean concentration of 0.008 mg/l at most sites except for sites 3 and 5. Site 3 had a mean concentration of 0.198 mg/l, and site 5 had the highest zinc concentration compared to the other sites located in Sabie River with a mean of 0.331 mg/l. The mean zinc concentrations for all sites located in the Sabie River exceeded the TWQR of 0.002 mg/l for zinc (Dallas & Day, 2004; DWAF, 1996c). Iron concentrations were different at all the Sabie River sites. The lowest mean iron concentration was at site 1 (20.12 µg/l) and it increased to reach the highest mean concentration at site 4 (338.75 µg/l). The Sabie River exhibited iron concentrations lower than 1000 µg /l which is the range of natural water (Xing & Liu, 2011). Aluminium concentrations were high for all the Sabie River sites exceeding the TWQR of 5 µg/l (Table 5-4;Dallas & Day, 2004; DWAF, 1996c). The lowest concentration was measured at the headwaters of the Sabie (site 1) with a mean concentration of 12 µg/l and it increased to a mean concentration of 118.25 µg/l at site 9, which is 23 times higher than the TWQR.

The zinc concentrations determined in the Marite River site and the Inyaka Dam were slightly higher than the Sabie River, with a mean concentration of 0.10 mg/l and 0.78 mg/l respectively, both exceeding the TWQR (Dallas & Day, 2004; DWAF, 1996c). Iron concentrations were much higher in both the Sabie and the Sand Rivers, with a mean concentration of 545 µg/l in the Marite River and 540 µg/l for the Inyaka Dam (Table 5-5). The Inyaka Dam had the highest maximum iron concentrations compared to the other sites. The maximum iron concentration of 1440 µg/l occurred during July 2016. Site 11 (Inyaka Dam), was the only site with an iron concentration greater than that expected for natural ranges (Xing & Liu, 2011). The mean and maximum manganese concentrations at this site were also higher than all of the other sites (10 µg/l) and (435 µg/l) respectively, and the maximum concentration exceeded the TWQR (Dallas & Day, 2004; DWAF, 1996c) (Appendix 2-A).

The zinc concentrations at site 7 in the Sand River was similar to that of the Sabie River (mean concentration of 0.008 mg/l; Figure 5-8), but site 12 had the highest zinc concentrations with a mean of 1.9 mg/l which are almost a 1000 times higher than the prescribed TWQR (Dallas & Day, 2004; DWAF, 1996c). The iron concentration was higher at site 7 compared to site 12 with a mean concentration of 288.70 µg/l and 161.0 µg/l respectively. Aluminium concentrations were highest at site 7 compared to all the other sites, with a mean concentration of 158.7 µg/l, and the mean aluminium concentration at site 12 was 31µg/l. The aluminium levels at these sites exceeded the TWQR, as was the case in the Sabie River (Dallas & Day, 2004; DWAF, 1996c).

The Chlorophyll-*a* concentrations of the Sabie River were lower than those measured in the Sand River. The Sabie River near Mozambique (site 9) had the lowest chlorophyll-*a* concentration and the Sabie River near Skukuza (site 6) the highest concentration with a mean of 3.45 µg/l and a maximum of 5.30 µg/l. The Sabie River sites showed low concentrations of 2-Methylisoborneol (2-MIB); mean of 0.25 ng/l at all sites, compared to that of the Sand River sites.

The Sabie River sites had low geosmin (GM) concentrations which varied at the different sites, with sites 5 and 9 exhibiting the highest concentrations. The mean concentration at site 5 was 4.88 ng/l but it did experience a maximum of 15.00 ng/l. Likewise site 9 had a mean concentration of 7.85 ng/l and a maximum of 17.00 ng/l.

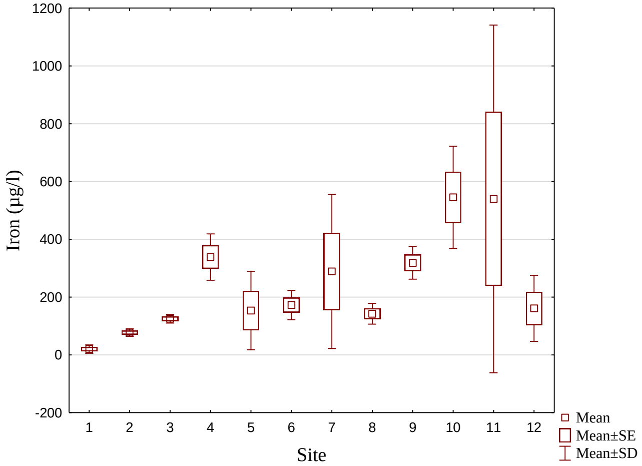
Chlorophyll-*a* concentrations were relatively low in the Marite River compared to the Sabie and Sand Rivers with a mean concentration of 1.82 µg/l at site 10 and 3.87 µg/l at site 11. The Marite River and Inyaka Dam had 2-MIB concentrations similar to the Sabie River sites (Figure 5-8), with a mean of 0.25 ng/l for both sites. The Marite River (site 10) had a geosmin concentration higher than the Inyaka Dam with a mean of 3.8 ng/l at site 10 and 2.12 ng/l at site 11.

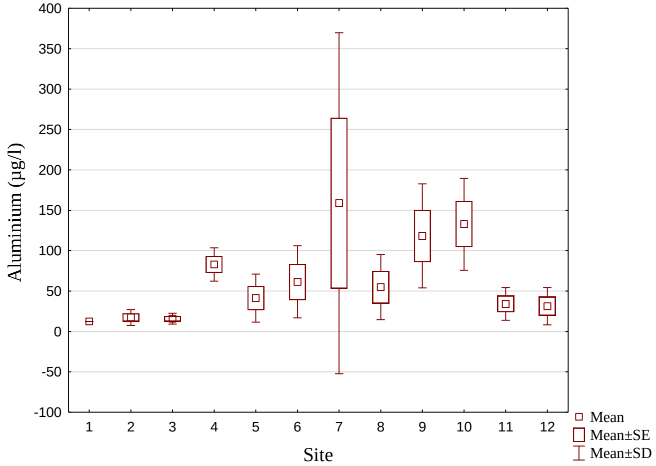
Site 12 had the highest chlorophyll-*a* concentration (62.20 µg/l) and this was concurrent with the highest Cyanophyta cell concentration. This was also the site that had the highest 2-MIB concentration with a mean of 5.7 ng/l and a maximum concentration of 22 ng/l. Site 12 had a higher geosmin concentration than site 7 (1.25 ng/l) but a lower concentration than Sabie River site 9 with a mean of 7.85.8 ng/l.

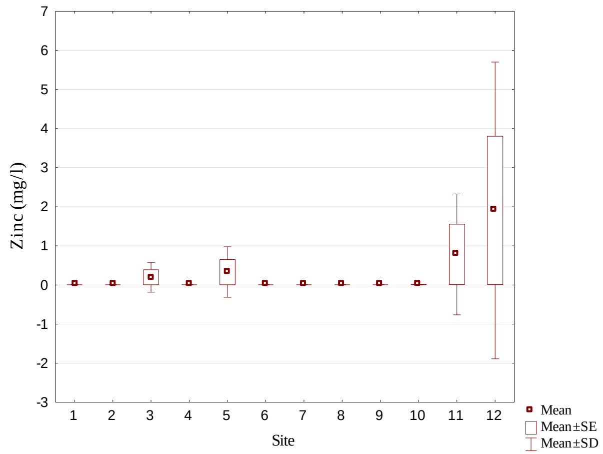
Although the coliform concentrations were lower at sites 1-11 it was still much higher than the TWQR for this parameter. Site 12 had considerably higher coliform concentrations than all the other sites with a mean concentration of 143593 MPN/100 ml and a maximum concentration of 241960 MPN/100 ml. Coliforms are an indication of the potential presence of pathogens. The *E. coli* concentrations were also lower at sites 1-11 and showed a noteworthy increase at site 12. The maximum concentration for *E. coli* at site 12 was 98040.0 MPN/100 ml with a mean concentration of 26425.3 MPN/100 ml and the minimum concentration was 1986.00 MPN/100 ml. Site 12 had alarmingly high coliform and *E. coli* concentrations. The entire Sabie-Sand catchment exceeded both natural and TWQR for both coliforms and *E. coli* (Table 5-4, Table 5-5, Table 5-6) and had critical levels during the entire sample period (Weiner, 2008).

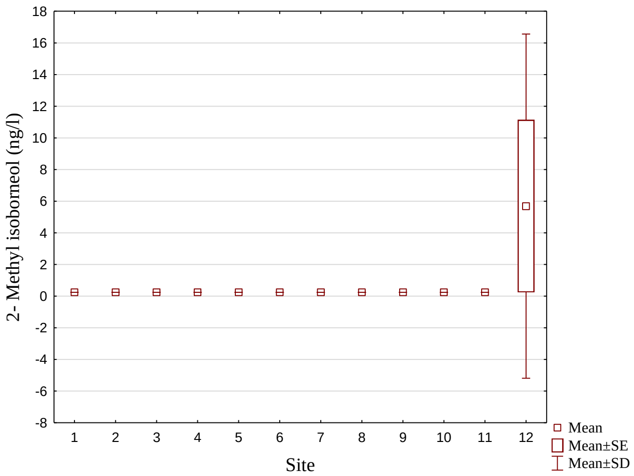
Figure 5-8: Box and Whiskers plots illustrating the mean concentrations of iron, aluminium, zinc, 2-MIB, GM and Chlorophyll-*a* for the different sampling sites, during 2016.

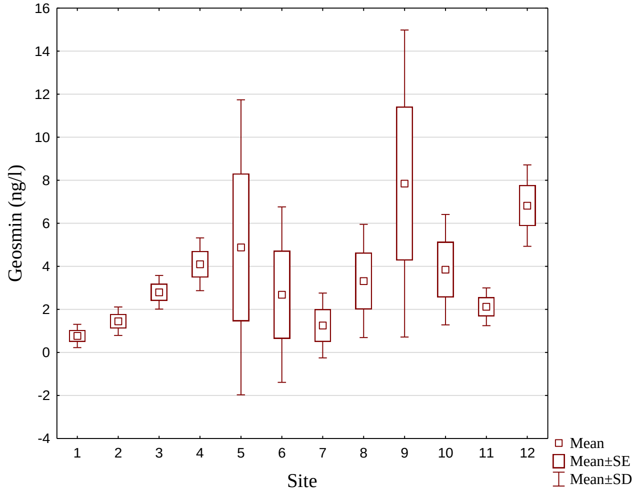
SE (Standard Error) SD (Standard Deviation) n=4. Site 1: Sabie River Head Waters; Site 2: Sabie River Waste Water Treatment; Site 3: Sabie River Before Hazyview; Site 4: Sabie River Hoxane Dumping site; Site 5: Kruger Gate Bridge; Site 6: Sabie Skukuza; Site 7: Sand River Skukuza; Site 8: Sabie River lower; Site 9: Sabie River Mozambique; Site 10: Marite River; Site 11: Inyaka Dam and Site 12: Sand River Thulamahashe.

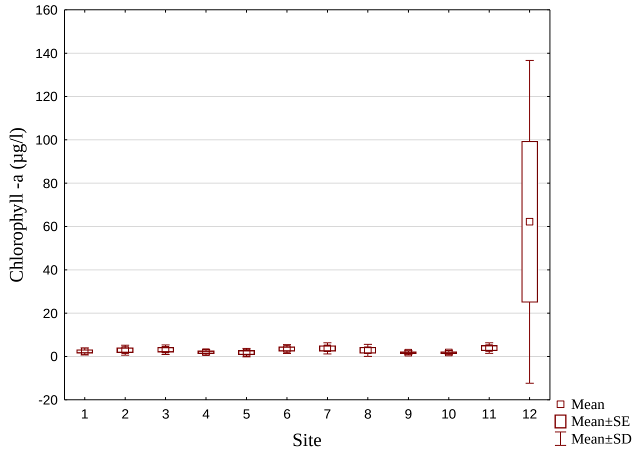

Iron (µg/l)
Site
Mean
Mean±SE
Mean±SD


Aluminium (µg/l)
Site
Mean
Mean±SE
Mean±SD


Zinc (mg/l)
Site
Mean
Mean±SE
Mean±SD


2- Methyl isoborneol (ng/l)
Site
Mean
Mean±SE
Mean±SD


Geosmin (ng/l)
Site
Mean
Mean±SE
Mean±SD


Chlorophyll -a (µg/l)
Site
Mean
Mean±SE
Mean±SD

5.2 Section 1: Summary of 2016 Results

The chemical and physical variables of the Sabie River indicate that it is in a better condition than the Sand River. The biggest problem in the Sand River is the poor water quality observed at site 12. Values measured in the Sabie River mirror values of natural waters with regard to pH, alkalinity, hardness, EC, and turbidity, with the exception of the headwaters, where anomalous pH values were measured. When the mean %DO is considered only site 9 had values below the TWQR. The nutrient ranges were slightly higher than the natural ranges and the total nitrogen and orthophosphate concentrations exceeded the TWQR and RQO respectively. High orthophosphate concentrations of 0.88 mg/l are a cause for concern from a resource quality perspective as are the high aluminium and zinc concentrations exceeded the TWQR for all the Sabie River sites. There was a clear indication of faecal matter pollution in the Sabie River as the *E. coli* and coliforms concentrations exceeded the drinking water as well as recreational use ranges.

Overall the algal assemblages, indices and physical-chemical variables indicated that the Marite River had the greatest diversity, species richness and evenness. The chemical-physical variables of this river were mostly below the TWQR but the total nitrogen, total phosphorus (phosphorus & ortho-phosphate), aluminium and zinc concentrations exceeded the TWQR as well as the RQO's set. The Marite River also showed faecal contamination as the *E. coli* and coliforms exceeded the water quality ranges.

The physical-chemical variables can be an indication that the Inyaka Dam can develop an increased taste and odour problem in the future, especially considering the 2-MIB and GM concentrations. The indices revealed that this site had low species diversity, richness and evenness indicating that this site was dominated by one or more species. The Inyaka Dam had aluminium, iron and zinc concentrations higher than the recommended TWQR but did have the lowest *E. coli* concentrations compared to the other sites. However, these concentrations still exceeded the drinking water quality standards as well as RQO set for the Marite River.

The Sand River showed signs of sewerage pollution as made apparent by high concentrations of ammonia and extremely high concentrations of coliforms, and *E. coli* at site 12. This site was also the site where both 2-MIB and GM were present in high concentrations. This correlates with higher chlorophyll-*a* concentrations and Cyanophyta abundance. The %DO was also always critically low during all the sampling occasions but January was the lowest and this correlates with higher concentrations of nutrients and organic matter. Downstream at site 7, signs of sewerage pollution were absent and variables were similar to that of the Sabie River. The only difference was the high silica concentration at site 7. The aluminium, iron and zinc concentrations of the Sand River also exceeded the TWQR.

5.3 Section 2: Comparison of 2016/2017 results

This section compares the water quality variables measured during 2016 to that of 2017. The environmental conditions differed visibly as 2016 was a drier year and 2017 started with flash floods and received a higher rainfall compared to 2016 (Figure 5-1). The average rainfall was 74.06 mm for the entire year, 2017 surpassed that with 112.91 mm from January until July.

5.3.1 Diversity and abundance of algae and cyanobacteria

A complete list of genera observed during 2017 can be found in Appendix 1-B which includes 15 genera from the phylum Cyanophyta; 35 genera from the Bacillariophyta; 30 genera from the Chlorophyta; 1 genus from the Chrysophyta; 3 genera from the Dinophyta and 4 from the Euglenophyta. Thus, a total of 88 genera were observed. The total diversity of the algae and cyanobacteria remained the same as in the drier season of 2016 (86 genera) but the total cell concentrations of the different algal groups and cyanobacteria were much lower (compared Table 5-2) during the wetter season of 2017. Table 5-7 gives a list of genera found at a concentration of less than 1 cell/ml and Table 5-8 shows only the genera that occurred at a concentration of 1 cell/ml or more during the 2017 sampling period.

Table 5-7: List of all the algal and Cyanophyta genera found during the second year of sampling (2017) in an abundance of <1 cell/ml.

Bacillariophyta	Chlorophyta	Euglenophyta	Dinophyta	Cyanophyta	Chrysophyta
Craticula	*Euastrum*	*Euglena*	*Peridiniopsis*	*Chroococcus*	*Dinobryon*
Cymatopleura	*Tetraedron*	*Trachelomonas*	*Peridinium*		
Diatoma					
Geissleria					
Neidium					
Placoneis					
Rhopalodia					
Tryblionella					

Cyanophyta genera such as *Chroococcus*, *Geitlerinema*, *Pseudanabaena*, *Snowella and Spirulina* were observed during the 2016 sampling period, but not during the 2017 sampling period. *Aphanothece*, *Cylindrospermopsis*, *Gloeocapsa*, *Radiocystis* and S*ynechocystis* were only found during the 2017 sampling period. Thulamahashe (site 12) contained high concentrations of *Phormidium* (6519 cells/ml) in 2016 but none was found during 2017.

In 2016 this sampling site in the Sand River had the highest cyanobacteria diversity (10 genera) but in 2017 the cyanobacteria diversity at this, and all the other sites, were low (5 or less; Table 5-8). The Bacillariophyta and Chlorophyta were still the most diverse groups, with 35 and 30 genera observed respectively, during the 2017 study period. Bacillariophyta genera such as *Aulacoseira*, *Caloneis*, *Luticola* and *Mayamaea* were only found during the 2016, while *Fallacia*, *Hantzschia*, *Neidium*, *Placoneis*, *Planothidium*, *Surirella*, *Tryblionella* and *Urosolenia* were only found during 2017. The cell concentrations of the Bacillariophyta were lower in 2017 compared to 2016. Chlorophyta genera such as *Microspora*, *Mougeotia*, *Nephrocytium*, *Schroederia*, *Selenastrum* and *Spirogyra* were only observed during the 2016 sampling period while *Dictyosphaerium*, *Kirchneriella*, *Tetrastrum*, *Treubaria* and *Ulothrix* were only found during the 2017 sampling period. Thulamahashe (site 12) had a high concentration of *Pandorina* (4440 cells, Table 5-2) in 2016 but only 92 cells/ml were found in 2017. Only one genus of the Chrysophyta, *Dinobryon* was observed during 2016 as well as 2017 (at sites 5, 10 & 11). The three genera from the Dinophyta, *Ceratium* (sites 4, 8 & 12), *Peridiniopsis* (site 11) and *Peridinium* (site 11) were also present during both 2016 and 2017. *Euglena* and *Trachelomonas* from the Euglenophyta were present in low concentrations at most sites during both 2016 and 2017 but *Phacus* occurred only at sites 4 and 5 during 2017. *Strombomonas* was only found in 2017 at sites 2, 7, 9 and 10.

Table 5-8: Total cell concentrations (cells/ml) of algal and cyanobacteria genera found at >1 cell/ml at the sampling sites during 2017 (n=3).

	Site											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Bacillariophyta												
Achnanthes	3	8	6	4	3	2	2	3	2	2	0	2
Achnanthidium	5	6	5	5	3	2	5	4	6	2	0	2
Capartogramma	0	0	5	0	1	1	0	1	1	0	0	1
Cocconeis	11	5	4	4	4	2	11	2	4	1	0	1
Cyclotella	0	0	0	2	2	7	4	2	1	3	49	3
Cymbella	0	23	13	14	25	18	4	27	9	3	0	10
Diploneis	0	0	0	0	0	0	9	2	0	0	0	0
Encyonopsis	0	12	8	6	4	3	1	4	1	3	0	1
Eunotia	1	0	1	0	0	0	0	0	0	1	0	1
Fragilaria	0	3	2	2	0	0	1	0	0	3	0	0
Frustulia	1	0	0	0	0	0	1	0	0	0	0	0
Gomphonema	2	27	39	20	16	12	6	8	5	12	0	10
Gyrosigma	0	0	1	4	1	2	16	11	8	1	0	5
Hantzschia	0	0	0	0	0	0	13	3	1	0	0	0
Hippodonta	0	0	1	0	0	0	0	0	0	0	0	0
Melosira	1	2	3	8	1	1	1	2	0	0	0	2
Navicula	1	7	13	10	12	9	23	20	25	8	1	9
Nitzschia	0	2	3	3	5	6	7	14	9	4	3	3
Pinnularia	0	0	0	0	1	0	2	1	1	1	0	1
Plagiotropis	0	0	0	0	0	0	2	1	1	0	0	1
Planothidium	1	0	0	0	0	0	0	0	0	0	0	0
Rhoicosphenia	0	1	1	0	0	0	0	0	0	0	0	0
Sellaphora	0	0	0	0	1	1	1	1	1	0	0	3
Surirella	0	0	0	0	1	1	5	4	1	0	0	0
Synedra	0	3	13	6	7	5	0	5	1	1	0	0
Urosolenia	0	0	0	0	0	0	0	0	0	0	4	0
Total cells/ml	**26**	**99**	**118**	**88**	**87**	**72**	**114**	**115**	**77**	**45**	**57**	**55**

Site												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Chlorophyta												
Actinastrum	0	0	0	0	2	0	0	0	0	0	9	0
Acutodesmus	0	0	0	2	0	1	2	3	1	2	1	2
Ankistrodesmus	0	0	0	0	0	0	0	0	0	0	3	0
Chlamydomonas	0	0	0	1	1	1	1	2	2	1	1	1
Chlorella	0	0	0	1	1	0	0	1	1	1	3	29
Chlorococcum	0	0	0	0	0	0	0	0	0	1	1	1
Closterium	0	0	0	0	0	0	1	0	0	0	0	0
Coelastrum	0	0	0	0	0	0	1	0	0	0	0	0
Cosmarium	0	1	0	0	0	0	0	0	0	1	0	0
Crucigenia	0	0	0	0	0	1	0	0	0	13	5	0
Crucigeniella	0	0	0	2	1	0	0	0	0	0	7	0
Desmodesmus	0	0	0	1	0	0	5	2	5	1	0	0
Dictyosphaerium	0	0	2	2	0	1	1	0	0	0	2	0
Elakatothrix	0	0	0	0	0	0	0	0	0	1	3	0
Eudorina	0	0	0	0	0	0	0	1	0	0	0	32
Kirchneriella	0	0	0	0	0	0	0	0	0	1	0	0
Monoraphidium	0	3	1	1	1	1	0	1	0	1	3	5
Oedogonium	0	2	0	1	0	0	0	1	0	0	0	0
Oocystis	0	1	2	0	1	0	0	0	0	0	0	1
Pandorina	1	0	0	1	4	1	2	2	1	3	0	92
Pediastrum	0	0	0	0	0	0	1	2	0	5	0	0
Scenedesmus	0	0	1	2	5	7	11	6	3	4	5	10
Schroederia	3	4	4	1	0	0	0	0	0	0	0	0
Staurastrum	0	0	0	0	0	0	0	0	0	0	2	0
Stigeoclonium	4	0	0	0	0	0	0	0	0	0	0	0
Tetrastrum	0	0	0	0	0	1	0	1	0	1	2	5
Treubaria	0	3	2	1	0	0	0	0	0	0	0	0
Ulothrix	0	0	1	0	0	0	0	0	0	0	0	0
Total cells/ml	**8**	**14**	**13**	**16**	**16**	**14**	**25**	**22**	**13**	**36**	**47**	**178**

Site												
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Cyanophyta												
Anabaena	0	0	0	0	0	0	2	0	0	0	0	0
Aphanocapsa	0	0	0	0	2	0	0	2	2	0	33	4
Aphanothece	0	0	0	0	0	0	0	0	1	0	0	0
Arthrospira	0	0	0	0	2	0	0	0	3	0	0	0
Cylindrospermopsis	0	0	0	2	0	1	0	0	0	0	0	0
Gloeocapsa	0	0	0	0	0	0	0	0	0	0	19	0
Johannesbaptistia	0	4	0	0	0	0	0	0	0	0	0	0
Komvophoron	0	0	3	0	0	1	1	4	3	1	0	0
Leptolyngbya	0	0	0	2	0	0	0	0	0	0	0	0
Merismopedia	4	0	0	1	0	0	8	6	1	1	0	2
Oscillatoria	0	0	0	0	0	0	3	0	0	0	0	0
Phormidium	0	0	0	0	0	2	6	4	8	15	0	0
Radiocystis	0	0	0	0	0	0	0	0	0	0	27	0
Synechocystis	0	0	0	0	0	1	0	1	0	2	7	0
Total Cyanophyta cells/mℓ	**4**	**4**	**3**	**5**	**4**	**5**	**20**	**17**	**18**	**19**	**86**	**6**
Chrysophyta												
Dinobryon	0	0	0	0	0	0	0	0	0	2	46	0
Total Chrysophyta cells/ml	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2**	**46**	**0**
Dinophyta												
Dinophyta												
Peridiniopsis	0	0	0	0	0	0	0	0	0	0	8	0
Peridinium	0	0	0	0	0	0	0	0	0	0	1	0
Total Dinophyta cells/ml	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**9**	**0**
Euglenophyta												
Euglena	0	0	0	0	0	1	1	0	0	2	0	2
Trachelomonas	0	0	0	1	0	1	1	1	1	2	0	2
Total Euglenophyta cells/mℓ	**0**	**0**	**0**	**1**	**0**	**2**	**2**	**1**	**1**	**4**	**0**	**4**

Figure 5-9 shows the percentage abundance (cells/ml) of the different algal phyla and cyanobacteria observed during 2017. There were some similarities between compositions of the algal assemblages of the two different study years. The abundance of the Cyanophyta decreased from 2016 to 2017 and the Cyanophyta was no longer dominant group at sites 4 and 7 but shifted to Bacillariophyta in 2017. There was an overall decrease in the total cell concentrations (cells/ml) of the Cyanophyta at all sites except site 1 with similar cell concentration during 2017 from 2 cells/ml to 4 cells/ml. Site 4, 5, 7, 11 and 12 experienced a considerable decrease during 2017 (Table 5-9). Site 12 showed the greatest decrease compared to all the other sites with 7522 cells/ml in 2016 and only 6 cells/ml in 2017.

Table 5-9: Comparison of 2016 and 2017, showing the total Cyanophyta cells/ml.

Total Cyanophyta cells/ml	**2016**	**2017**
Site 4	495	5
Site 7	371	20
Site 11	945	86
Site 12	7522	6

The Bacillariophyta remained the dominant group in the Sabie River in 2017, both in terms of cell number and diversity. The Bacillariophyta numbers also showed a general decrease at all the sampling sites except for site 1, and 7 where it increased from 11 cells/ml to 26 cells/ml at site 1 and 70 cells/ml to 114 cells/ml at site 7, during 2017. Sites 2, 3, 6 and 11 showed a noteworthy decrease in Bacillariophyta numbers and the comparison can be found in Table 5-10. Once again site 12 had the greatest decrease from 2016 to 2017 with a total Bacillariophyta cell concentration of 926 cells/ml in 2016 to only 55 cells/ml and 2017.

Table 5-10: Comparison of the total Bacillariophyta cells/ml during 2016 and 2017.

Total Bacillariophyta cells/ml	**2016**	**2017**
Site 2	269	99
Site 3	333	118
Site 6	173	72
Site 11	96	57
Site 12	926	55

The Chlorophyta was present at all the sites but was dominant at site 12 during 2017. Site 12 had an equal percentage abundance of Cyanophyta and Chlorophyta during 2016, but the Cyanophyta made a much smaller contribution during 2017. Sites 1, 4, 5 and 9 showed minor increases in the total Chlorophyta cell concentrations (cells/ml) in 2017 and site 11 and 12 showed a large decrease in 2017. Site 11 and 12 had a total of 588 cells/ml and 7592 cells/ml respectively in 2016 and that decreased to 47 cells/ml at site 11 and 178 cells/ml at site 12.

During the study the Chrysophyta and Dinophyta mainly occurred at site 10 in the Marite River and site 11 in the Inyaka Dam. The Chrysophyta also decreased from 9 cells/ml and 3041 cells/ml respectively, to 2 cells/ml at site 10 and 46 cells/ml at site 11 during 2017.The Dinophyta decreased from 4 cells/ml in 2016 to less than 1 cell/ml in 2017 at site 10 and from 241 cells/ml to 9 cells/ml at site 11. The cell concentrations observed at the sites for the Euglenophyta showed a decrease but only site 12 had a marked decrease from 1118 cells/ml to 4 cells/ml during 2017.

Figure 5-9: Percentage abundance (cells/ml) of the different algal phyla at each site during 2017.

Site 1: Sabie River Head Waters; Site 2: Sabie River Waste Water Treatment; Site 3: Sabie River Before Hazyview; Site 4: Sabie River Hoxane Dumping site; Site 5: Sabie River Kruger Gate; Site 6: Sabie River Skukuza; Site 7: Sand River Skukuza; Site 8: Sabie River lower; Site 9: Sabie River Mozambique; Site 10: Marite River; Site 11: Inyaka Dam and Site 12: Sand River Thulamahashe.

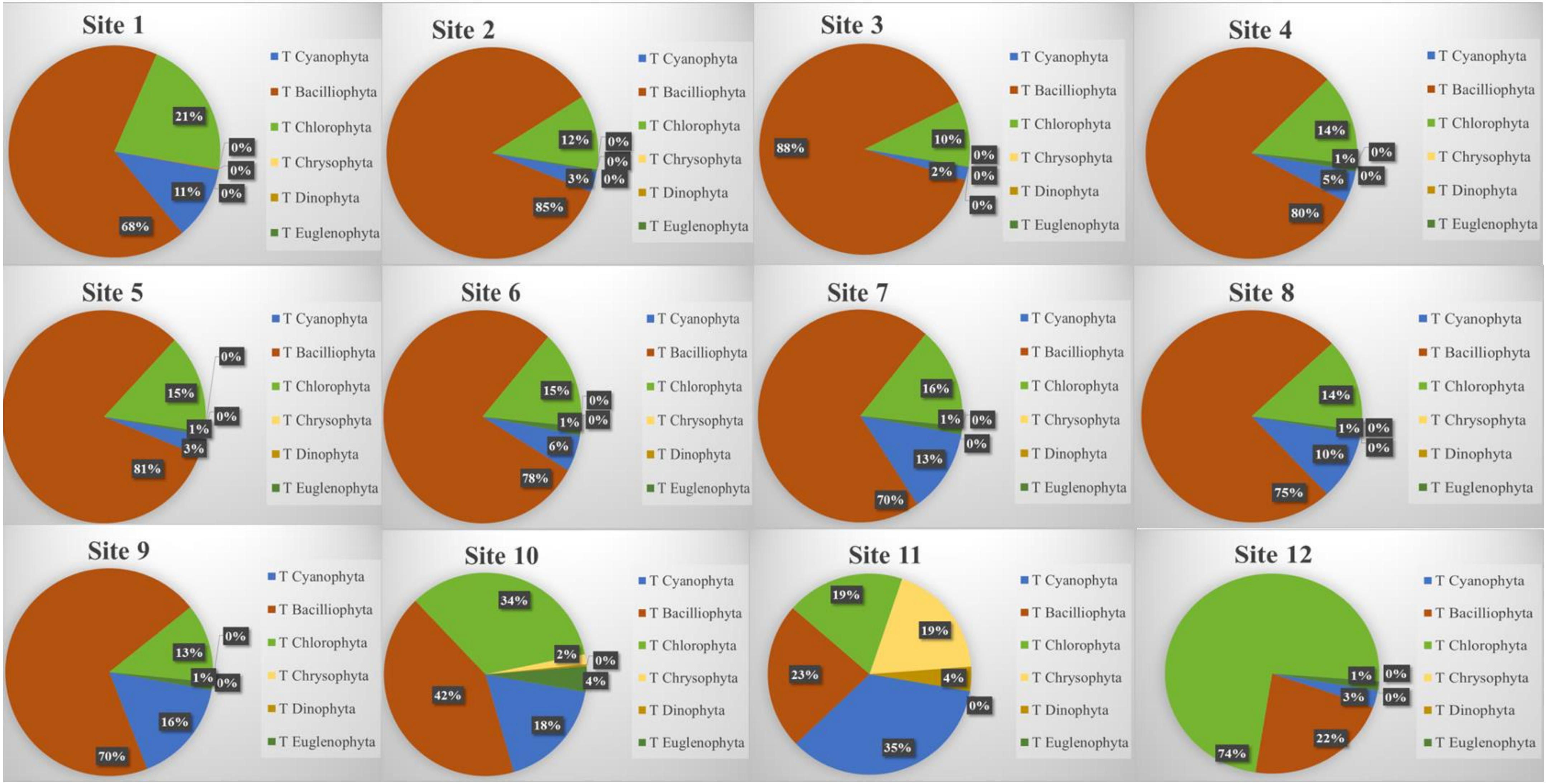

Site 1
21%
0%
0%
11%
0%
68%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 2
12%
0%
0%
3%
0%
85%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 3
88%
10%
0%
2%
0%
0%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 4
14%
1%
0%
5%
0%
80%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 5
0%
15%
0%
1%
3%
81%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 6
15%
0%
1%
0%
6%
78%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 7
16%
1%
0%
0%
13%
70%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 8
14%
1%
0%
0%
10%
75%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 9
0%
13%
1%
0%
16%
70%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 10
34%
2%
0%
4%
42%
18%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 11
19%
19%
23%
4%
0%
35%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta
Site 12
1%
0%
3%
0%
22%
74%
T Cyanophyta
T Bacilliophyta
T Chlorophyta
T Chrysophyta
T Dinophyta
T Euglenophyta

Figure 5-10: Light microscopy photos (1000x magnification) of samples collected during 2017: Bacillariophyta.

The Bacillariophyta genera commonly found include: *Navicula* (A), *Navicula* (B), *Cocconeis* (C), *Nitzschia* (D), *Capartogramma* (E), *Planothidium* (F), *Fallacia* (G), *Fragilaria* (H), *Hantzschia* (I) and *Encyonopsis* (J).

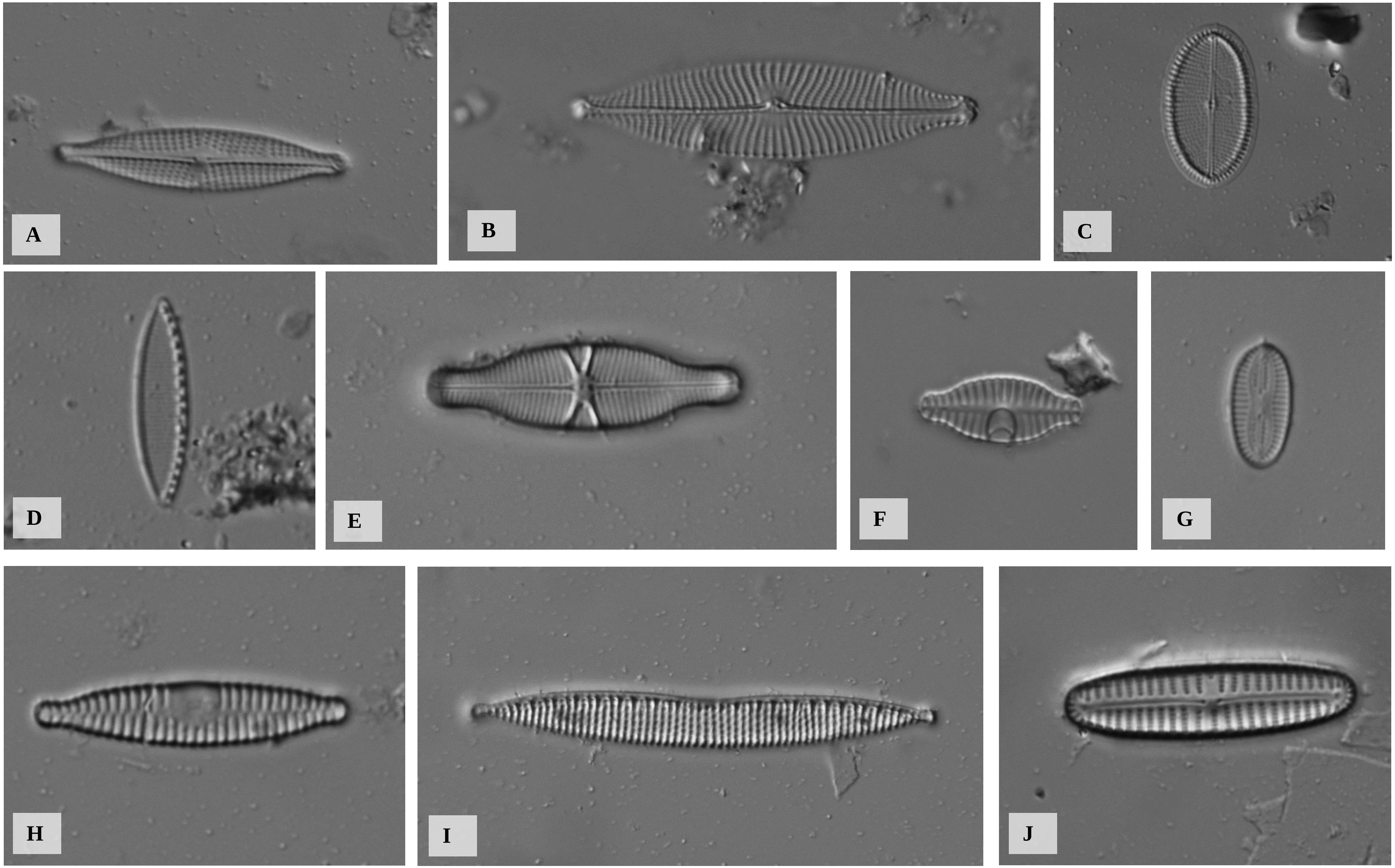

A
B
C
D
E
F
G
H
I
J

Figure 5-11: Light microscopy photos (400x magnification) of samples collected during 2017: Chlorophyta.

The genera commonly found of the Chlorophyta group includes: *Crucigeniella* (A), *Treubaria* (B), *Monoraphidium* (C), *Scenedesmus* (D), *Closterium* (E), *Ankistrodesmus* (F), *Dictyosphaerium* (G), *Acutodesmus* (H), *Cosmarium* (I), *Elakatothrix* (J), *Pediastrum* (K), and *Pandorina* (L).

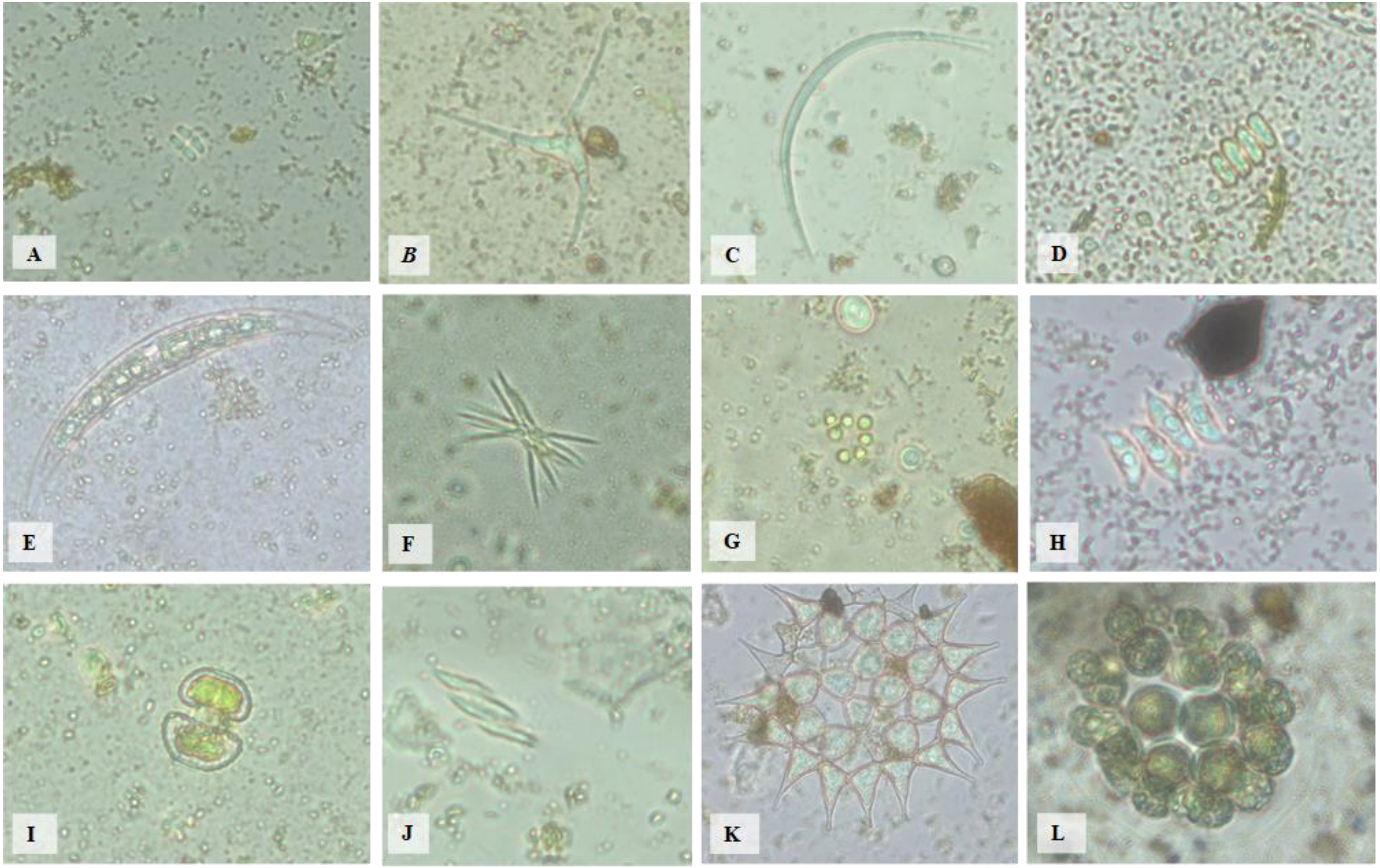
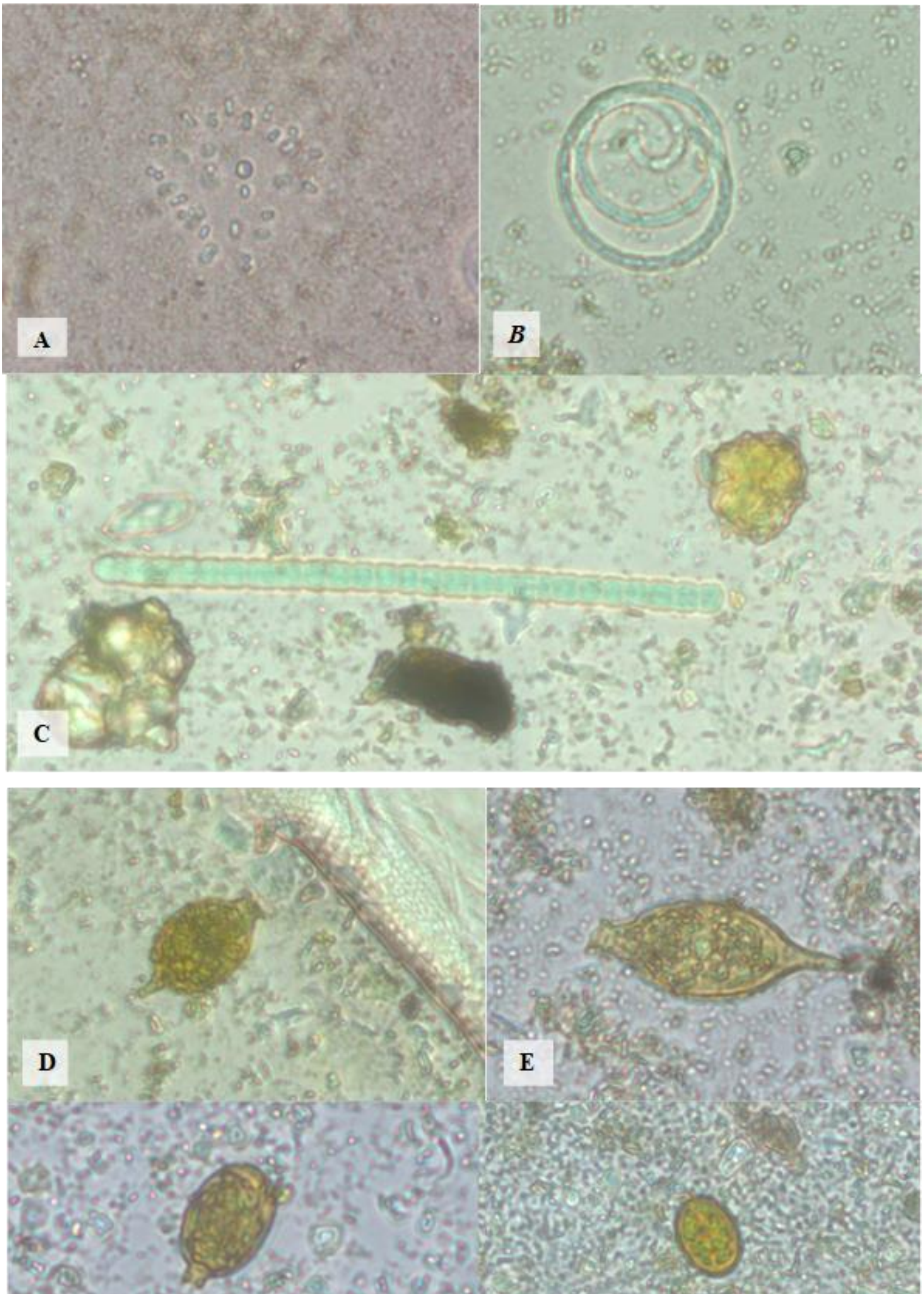
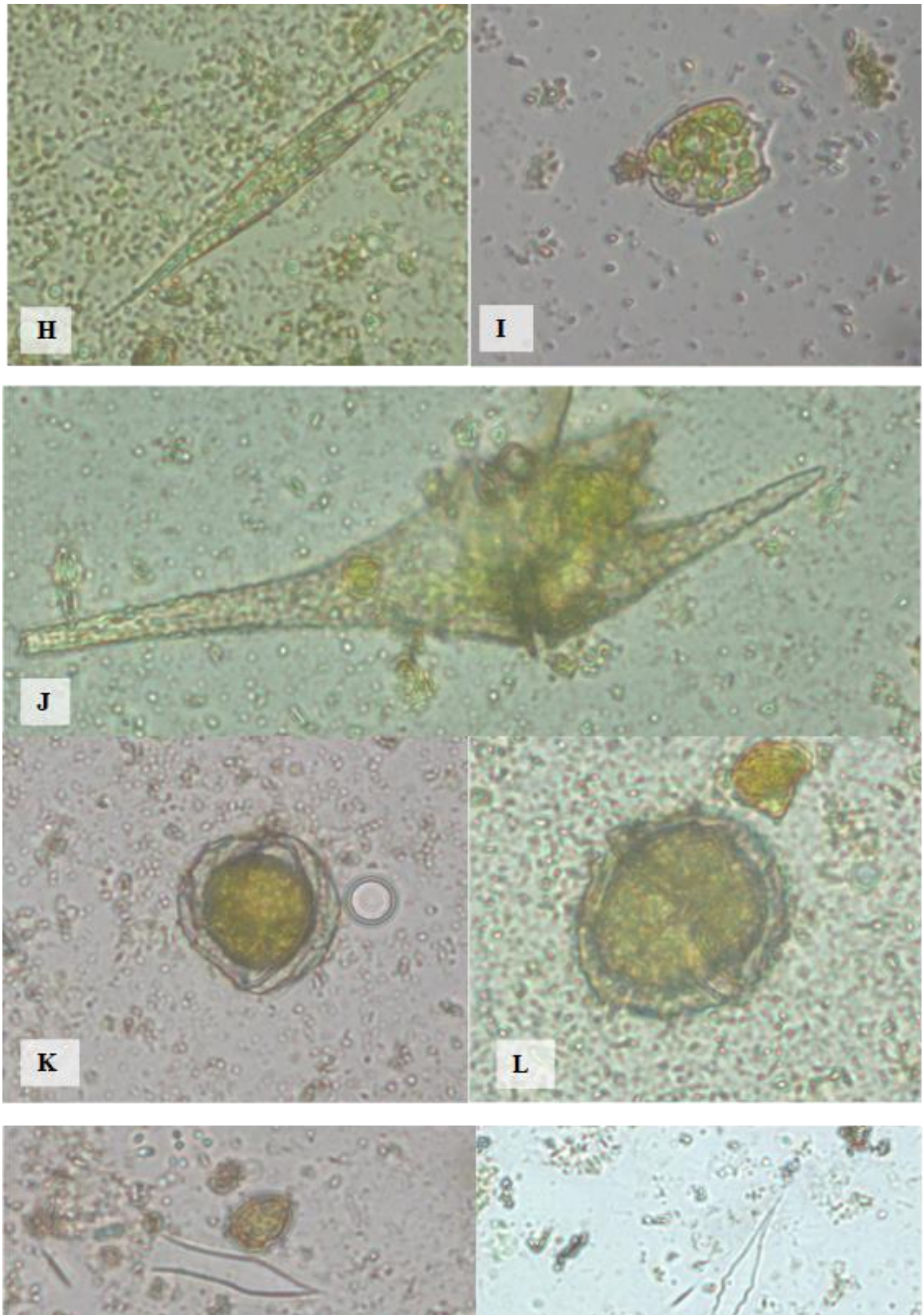

A
B
C
D
E
F
G
H
I
J
K
L

Figure 5-12: Light microscopy photos (400x magnification) of samples collected during 2017: Cyanophyta (A-C), Euglenophyta (D-I), Dinophyta (J-L) and Chrysophyta (M-N).

The Cyanophyta genera include: *Radiocystis* (A), *Komvophoron* (B), and *Phormidium* (C). The Euglenophyta includes: *Strombomonas* (D-E), *Trachelomonas* (F-G), *Euglena* (H), and *Phacus* (I). The Dinophyta includes: *Ceratium* (J) and *Peridinium* (K-L). Chrysophyta: *Dinobryon* (M-N).


A
B
C
D
E
F
G


H
I
J
K
L
M
N

5.3.2 Diversity Indices

Site 10 had the highest Shannon-Wiener, Margalef and Pielou index scores for both 2016 and 2017, indicating that this site had the highest diversity, richness and evenness (Table 5-11). Sites 4, 11 and 12 had the lowest scores in 2016 and sites 11 and 12 again had the lowest scores during 2017. However, these sites did show an increase in the Shannon-Wiener and Pielou index scores (1.4 increased to 2.5) and (2.8 increased to 5.2) for site 11 and (1.9 increased to 2.3) and (3 increased to– 7.1) for site 12 respectively. Site 4 showed an increase in the species evenness (Pielou scores) and richness (Shannon-Wiener) which increased from a score of 0.37 in 2016 to a score of 0.79 in 2017 (Pielou) and 1.4 in 2016 to 3 in 2017 (Shannon-Wiener).

Table 5-11: The Shannon-Wiener, Margalef and Pielou Indices scores for each site during 2017.

Site	Shannon-Wiener Index Score	Margalef Index Score	Pielou Index Score
1	2.439	7.105	0.740
2	2.571	6.895	0.729
3	2.619	7.760	0.715
4	3.026	9.523	0.790
5	2.753	8.802	0.737
6	2.882	9.292	0.766
7	3.120	8.852	0.815
8	3.055	8.585	0.807
9	2.915	8.533	0.785
10	3.301	12.037	0.820
11	2.527	5.272	0.743
12	2.315	7.134	0.628

5.3.3 Water quality comparison

Table 5-12: A comparison of the mean, minimum and maximum values of the physical and chemical parameters determined in the Sabie River during 2017 and the TWQR of each parameter (n=3).

	Range	Site 1			Site 2			Site 3			Site 4		
Variable		**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
pH	6.5-9.0	6.6433	6.17	6.92	7.223	6.48	7.62	6.91	6.37	7.23	6.87	6.67	6.99
M Alkalinity (mg/l CaCO3)	> 20	15	10	21	45.333	31	61	39.333	28	51	38	30	45
Hardness (mg/l CaCO3)	<75 >120	9.4	7.5	13	40	26	51	36.667	24	47	33.33	24	39
Specific conductance (mS/m)	5-150	31.1	23.6	40.6	99.467	78	120	97.933	82.1	115	102.8	90.3	111
Turbidity (NTU)	<5 > 55	0.5733	0.4	0.92	1.633	1	2.5	5.367	1.3	12	7.57	2.2	14
Dissolved Oxygen (%)	>80%	84.6	80	88.2	84.733	78	94.2	87.967	82.5	95.2	80.13	71.3	86
Total Nitrogen (mg/l as N)	<0.35	0.5567	0.28	0.8	0.75	0.36	1.08	0.7	0.37	1.02	0.63	0.37	0.86
Nitrate- Nitrite (mg/l as N)	0.3	0.1817	0.065	0.275	0.375	0.285	0.56	0.325	0.185	0.5	0.26	0.145	0.34
Ammonia (mg/l as N)	0.1	0.025	0.025	0.025	0.025	0.025	0.03	0.025	0.025	0.03	0.03	0.025	0.03
Total Phosphorus (mg/l)	<0.03	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Ortho-Phosphate (mg/l)	<0.01	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
TN:TP		1.5905	0.8	2.286	2.143	1.029	3.09	2	1.0571	2.91	1.81	1.057	2.46
Dissolved Organic Carbon (mg/l)	0-5	0.3367	0.1	0.57	0.41	0.1	0.64	0.463	0.1	0.71	1.1	0.62	1.8
Total Organic Carbon (mg/l)	<30	0.3767	0.1	0.56	0.54	0.3	0.76	0.83	0.59	1.2	1.43	1	1.9
Aluminium (µg/l)	5	12.5	12.5	12.5	60	28	92	103.667	36	165	182.67	53	365
Iron (µg/l)	<10%	17.6667	11	23	140	110	175	235	130	305	495	345	630
Zinc (mg/l)	<0.002	0.0075	0.008	0.008	0.008	0.008	0.01	0.008	0.0075	0.01	0.01	0.008	0.01
Chlorophyll-a (mg/l)	<100	1	1	1	1.633	1	2.9	1	1	1	1	1	1
Coliforms (MPN/100 ml)	0	797.6667	172	1300	8576.667	5730	10120	8006.333	579	14390	11614	1046	24196
E. coli (MPN/100 ml)	0	26.6667	2	58	1218.333	548	2420	586.667	27	1046	799.33	114	1300
2-Methylisoborneol (ng/l)	4 – 20	16.33	0.25	48	0.8	0.25	1.9	0.8	0.25	1.9	0.25	0.25	0.25
Geosmin (ng/l)	4 – 20	2.3	0.25	6.4	0.69	0.25	1	0.89	0.71	1.1	2.43	0.89	4.7

The following references were used for the TWQR: (DWAF, 1996a,b,c; US-EPA, 2012)

Variable	Range	Site 5 Mean	Site 5 Min	Site 5 Max	Site 6 Mean	Site 6 Min	Site 6 Max	Site 8 Mean	Site 8 Min	Site 8 Max	Site 9 Mean	Site 9 Min	Site 9 Max
pH	6.5-9.0	6.837	6.62	7.24	7.14	6.69	7.5	7.59	7.03	8.24	7.26	6.96	7.8
M Alkalinity (mg/l CaCO3)	> 20	45	35	54	27.41	2.5	46	50	39	61	56.66	43	74
Hardness (mg/l CaCO3)	<75 >120	38.33	28	45	39	30	45	39.333	32	45	45	35	51
Specific conductance (mS/m)	5-150	125	121	129.7	87.33	13.2	130.4	138.9	135.3	141	155.43	142.2	167.5
Turbidity (NTU)	<5 > 55	10.23	2.5	19	16.8	6.4	32	21.633	9.9	40	27.86	7.6	58
Dissolved Oxygen (%)	>80%	73.23	60.6	80.1	85.66	75	92	82.36	75	87	87.3	79.3	92.5
Total Nitrogen (mg/l as N)	<0.35	0.63	0.38	0.82	0.63	0.45	0.79	0.583	0.39	0.77	0.60	0.47	0.75
Nitrate- Nitrite (mg/l as N)	0.3	0.262	0.19	0.31	0.255	0.125	0.38	0.208	0.065	0.32	0.228	0.065	0.4
Ammonia (mg/l as N)	0.1	0.025	0.03	0.03	0.025	0.025	0.03	0.025	0.025	0.03	0.025	0.025	0.03
Total Phosphorus (mg/l)	<0.03	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Ortho-Phosphate (mg/l)	<0.01	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dissolved Organic Carbon (mg/l)	0-5	1.4	0.8	1.7	1.247	0.76	2	1.4	1.1	2	1.5	1.4	1.7
Total Organic Carbon (mg/l)	<30	1.73	1.4	2.2	1.66	1.1	2.4	2.03	1.3	2.7	2.3	1.9	2.7
Aluminium (µg/l)	5	168.67	36	290	179.67	54	375	177.33	47	320	1186	73	3170
Iron (µg/l)	<10%	415	310	510	366.67	245	570	310	175	445	370	230	530
Zinc (mg/l)	<0.002	0.008	0.01	0.01	0.008	0.008	0.01	0.008	0.008	0.01	0.008	0.008	0.01
Chlorophyll-a (mg/l)	<100	1.6	1	2.8	1.633	1	2.9	1.86	1	2.5	3.4	1	6
Coliforms (MPN/100 ml)	0-130	7375	2310	14136	7537.3	5380	10462	8458	2420	14136	9456.3	2420	17329
E. coli (MPN/100 ml)	0-130	1614	276	4106	303	144	504	226.33	107	435	240.67	75	455
2-Methylisoborneol (ng/l)	4 - 20	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Geosmin (ng/l)	4 - 20	1.25	0.56	2.2	0.55	0.25	0.82	0.98	0.65	1.6	0.85	0.25	1.8

The following references were used for the TWQR: (DWAF, 1996a, b, c; South Africa, 2016; US-EPA, 2012).

(red)	Health risk
(blue)	Exceeded TWQR
(green)	Higher than natural ranges
(orange)	Lower than recommended
(purple)	Taste and odour problems

Table 5-13: A comparison of the mean, minimum and maximum values of the physical and chemical parameters determined in the Marite River and Inyaka Dam during 2017 and the TWQR of each parameter (n=3).

	Range	**Site 10**			**Site 11**		
Variable		**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
pH	6.5-9.0	6.78	6.59	7.09	6.61	6.37	6.81
M Alkalinity (mg/l CaCO3)	> 20	24.66	24	26	16	15	17
Hardness (mg/l CaCO3)	<75 >120	14.66	11	19	10.03	8.2	13
Specific conductance (mS/m)	5-150	73.9	67.2	81.2	50.33	48.8	52.4
Turbidity (NTU)	<5 > 55	13.63	4.7	30	24.6	1.8	70
Dissolved Oxygen (%)	>80%	87.43	85.6	88.5	67.1	61.4	74.4
Total Nitrogen (mg/l as N)	<0.35	0.633	0.33	0.9	0.61	0.34	0.91
Nitrate- Nitrite (mg/l as N)	0.3	0.25	0.145	0.38	0.22	0.065	0.36
Ammonia (mg/l as N)	0.1	0.025	0.025	0.03	0.033	0.025	0.05
Total Phosphorus (mg/l)	<0.03	0.35	0.35	0.35	0.35	0.35	0.35
Ortho-Phosphate (mg/l)	<0.01	0.1	0.1	0.1	0.1	0.1	0.1
TN:TP		1.81	0.943	2.57	1.74	0.97	2.59
Dissolved Organic Carbon (mg/l)	0-5	1.96	1	2.8	1.43	1.1	1.9
Total Organic Carbon (mg/l)	<30	2.63	2	3.6	2.06	2	2.2
Aluminium (µg/l)	5	4866	115	14300	206.7	32	500
Iron (µg/l)	<10%	6240	890	16920	451.7	285	640
Zinc (mg/l)	<0.002	0.008	0.008	0.01	0.008	0.0075	0.01
Chlorophyll-a (mg/l)	<100	2.467	1	3.4	1.76	1	2.2
Coliforms (MPN/100 ml)	0	6565.7	2420	12997	904.7	173	1725
E. coli (MPN/100 ml)	0	234	107	464	71	1	189
2-Methylisoborneol (ng/l)	4 – 20	0.96	0.25	2.4	1.96	0.25	5.4
Geosmin (ng/l)	4 – 20	4.46	1.6	6	0.52	0.25	0.68

The following references were used for the TWQR: (DWAF, 1996a, b, c; South Africa, 2016; US-EPA, 2012).

(red)	Health risk
(blue)	Exceeded TWQR
(green)	Higher than natural ranges
(orange)	Lower than recommended
(purple)	Taste and odour problems

Table 5-14: A comparison of the mean, minimum and maximum values of the physical and chemical parameters determined in the Sand River during 2017 and the TWQR of each parameter (n=3).

Variable	Range	Site 7 Mean	Site 7 Min	Site 7 Max	Site 12 Mean	Site 12 Min	Site 12 Max
pH	6.5-9.0	7.63	7.13	8.19	6.83	6.58	7.2
M Alkalinity (mg/l CaCO3)	> 20	57	56	58	57.67	46	76
Hardness (mg/l CaCO3)	<75 >120	37.33	37	38	38	32	46
Specific conductance (mS/m)	5-150	187.47	174.9	202	191.83	168	234.9
Turbidity (NTU)	<5 > 55	22.9	2.7	36	19.2	3.6	28
Dissolved Oxygen (%)	>80%	83.67	76	88.3	68.63	65	73.3
Total Nitrogen (mg/l as N)	<0.35	0.47	0.14	0.68	0.74	0.19	1.5
Nitrate- Nitrite (mg/l as N)	0.3	0.1	0.065	0.16	0.29	0.07	0.7
Ammonia (mg/l as N)	0.1	0.03	0.025	0.03	0.1	0.03	0.3
Total Phosphorus (mg/l)	<0.03	0.35	0.35	0.35	0.35	0.35	0.4
Ortho-Phosphate (mg/l)	<0.01	0.1	0.1	0.1	0.1	0.1	0.1
TN/TP		1.34	0.4	1.94	2.12	0.53	4.1
Dissolved Organic Carbon (mg/l)	0-5	2.13	1.6	2.9	2.83	2.2	3.4
Total Organic Carbon (mg/l)	<30	3	1.9	4.1	3.93	3.4	4.3
Aluminium (µg/l)	5	2657	91	5350	1164	53	2740
Iron (µg/l)	<10%	636	110	930	2906	310	7390
Zinc (mg/l)	<0.002	0.01	0.008	0.01	0.02	0.01	0.03
Chlorophyll-a (mg/l)	<100	3	1	4.8	1.83	1	3.5
Coliforms (MPN/100 ml)	0-130	10526	5710	14670	73106.7	46110	111900
E. coli (MPN/100 ml)	0-130	137	86	169	6780	3282	11690
2-Methylisoborneol (ng/l)	4 - 20	0.25	0.25	0.25	1.37	0.25	3.6
Geosmin (ng/l)	4 - 20	0.33	0.25	0.5	6.42	0.96	16

The following references were used for the TWQR: (DWAF, 1996a, b, c; South Africa, 2016; US-EPA, 2012).

	Health risk
	Exceeded TWQR
	Higher than natural ranges
	Lower than recommended
	Taste and odour problems

The water quality of the Sabie -Sand rivers remained similar during the 2017 sampling period compared to the 2016 sampling period, with only the following variables that showed noteworthy changes from the drier year compared to the wetter year.

5.3.3.1 Turbidity and percentage dissolved oxygen

Most of the sampling sites showed an increase in turbidity, thus, appeared less clear than the previous sampling year. The turbidity of the Sabie River increased downstream with the most obvious increase at site 8 with 2.2 NTU in 2016 compared to 21.6 NTU in 2017. Site 9 had a maximum value of 58 NTU which can be classified as murky waters (MELP, 1998). The Marite River had a slight increase in the turbidity with a mean of 7.4 NTU in 2016 and 13.6 NTU in 2017. The turbidity of the Inyaka Dam increased from 9.9 NTU in 2016 to 24.6 NTU in 2017. Site 7 in the Sand River had a notable increase in turbidity, even more than that found at site 12 with a mean of 3.3 NTU in 2016 and 22.9 NTU in 2017. Site 12 increased from a mean of 3.7 NTU in 2016 to a mean of 19.2 NTU in 2017. The increase in turbidity is possibly due to increased runoff as a result of the rainfall.

The %DO of the Sabie River showed an overall increase from 2016 to 2017 and fewer sites had a minimum value lower than the recommended range. Sites 4 and 8 showed a slight decrease in the %DO but mean still within the TWQR. Site 5 had a substantial decrease in %DO with a mean of 82% in 2016 compared to 73% in 2017, which is no longer within the recommended target ranges. Site 9 showed an increase in %DO with a mean of 76% in 2016 and 87% in 2017, and this site is no longer below the TWQR. The %DO of the Inyaka Dam (site 11) decreased from 75% in 2016 to 67% in 2017 (Table 5-13), and the mean %DO did not meet the TWQR for both of the sampling years (Dallas & Day, 2004; DWAF, 1996c). The %DO of site 12 in the Sand River increased from a very low 40% to 65%, which is still below the TWQR but a noteworthy improvement.

5.3.3.2 Nutrients

The mean nitrate-nitrite concentrations of the sampling sites showed an overall increase at most sites, except site 3. The total nitrogen concentrations showed a decreased at most sites, but the total nitrogen, total phosphorus and orthophosphate concentrations exceeded the TWQR and natural ranges (Table 5-12; Table 5-13; Table 5-14). The Inyaka Dam and site 12 showed a substantial decrease in the ammonia concentrations with a mean concentration of 0.19 µg/l in 2016 and 0.03 µg/l in 2017 at the Inyaka Dam and 5 mg/l in 2016 compared to 0.1 mg/l in 2017 for site 12. Both these concentrations are now similar to the concentrations of natural waters. Site 12 also showed a huge decrease in the total nitrogen concentrations from a mean of 18.7 mg/l in 2016 compared to a mean of 0.74 mg/l in 2017.

5.3.3.3 Metals

All the sampling sites showed an alarming increase in the aluminium and iron concentrations. Site 1 in the Sabie River was the only site where the aluminium concentrations remained the same and where the iron concentrations of sites 1 and 11 (Inyaka Dam) decreased. The zinc concentrations of all the sites remained similar. Aluminium, iron and zinc concentrations of 2016 and 2017 all exceeded the recommended TWQR, with alarmingly high concentrations (aluminium concentrations at site 12 were 581 times more than the target). The Marite River showed a marked increase in both the aluminium and iron concentrations with a mean aluminium concentration of 132 µg/l determined in 2016 compared to a mean of 4866 µg/l determined in 2017, and a mean iron concentration 545 µg/l in 2016 to 6240 µg/l in 2017. The aluminium concentrations of the Inyaka Dam showed an increase from 34.1 µg/l in 2016 to 206.7 µg/l in 2017. The Sand River showed the greatest increase in the aluminium and iron concentrations. At site 7 the concentrations of these heavy metals increased from 158 µg/l in 2016 to 2657 µg/l in 2017 for aluminium and 288 µg/l in 2016 to 636 µg/l in 2017 for iron. Site 12 showed a mean aluminium concentration of 31 µg/l in 2016 which increased to a mean concentration of 1164 µg/l and an iron concentration of 161 µg/l in 2016 compared to 2906 µg/l in 2017.

5.3.3.4 Coliform, *E. coli*, chlorophyll-*a*, 2-MIB and geosmin

There was an overwhelming increase in both the coliform and *E. coli* concentrations at all the sites. Site 12 was the only site which showed a decrease in both the coliform and *E. coli* concentrations. Sites 8 and 9 of the Sabie River had an increase in the coliform concentrations but showed a decrease in the *E. coli* concentrations. Site 11 (Inyaka Dam) had the lowest concentrations coliform and *E. coli* but showed a general increase from 2016 to 2017. All the Sabie, Sand and Marite Rivers' sites exceeded the drinking water, recreational and aquatic ecosystem target ranges (DWAF, 1996a; Weiner, 2008) . A comparison of the mean coliform and *E. coli* concentrations of the two sampling years can be found in Table 5-15.

Table 5-15: A comparison of the mean coliform and *E. coli* concentrations (MPN/100 ml) in 2016 and 2017.

	2016		**2017**			**2016**		**2017**	
	Coliforms	***E. coli***	**Coliforms**	***E. coli***		**Coliforms**	***E. coli***	**Coliforms**	***E. coli***
Site 1	507	9.75	797	26	Site 7	1195	83	10526	137
Site 2	2065	225	8576	1218	Site 8	4670	387	8458	226
Site 3	2099	35	8006	586	Site 9	4962	273	9456	240
Site 4	1230	69	11614	799	Site 10	2779	125	6565	234
Site 5	1719	356	7375	1614	Site 11	326	1.5	904	71
Site 6	2360	207	7537	303	Site 12	143593	26425	73106	6780

The chlorophyll-*a* concentrations decreased at most sites. Site 12 had a substantial decrease from 62 µg/l (2016) to 1.8 µg/l in 2017. Site 3 of the Sabie River, site 10 in the Marite River, and site 11 in the Inyaka Dam were the only sites that showed an increase in the chlorophyll-*a* concentrations.

Site 1 showed an unexpected increase in the 2-MIB concentrations with a mean of 0.25 ng/l in 2016 compared to a mean of 16.33 ng/l in 2017. Site 9 showed a noteworthy decrease in geosmin concentrations with a mean of 7.1 ng/l in 2016 to 0.8 in 2017. Both the geosmin and 2-MIB concentrations increased at site 10 (Marite River), the 2-MIB remained lower than the palatability threshold but the geosmin concentrations exceeded the palatability ranges (Table 5-13).

The geosmin concentration detected in the Inyaka Dam decreased from 2.1 ng/l to 0.5 ng/l and the 2-MIB concentrations increased from 0.25 ng/l to 1.96 ng/l. Even though the GM and 2-MIB concentrations remained below the palatability threshold, it remains important to monitor the *E. coli*, GM and 2-MIB as the Inyaka Dam provides drinking water to the surrounding communities. The chlorophyll-*a* concentrations in the Inyaka Dam also decreased during the 2017 sampling year from a mean of 3.87 µg/l in 2016 to a mean of 1.7 µg/l in 2017.

CHAPTER 6 DISCUSSION AND CONCLUSION

6.1 Discussion

The Sabie-Sand sub-catchment is an important area for various reasons which include potable water for the community as well as recreation and tourism. This study found that although the overall water quality is good, there are certain problems that need to be addressed. During the two years of sampling the study area experienced rainfall of 888 mm during 2016 and 1073 mm/ rainfall during 2017 with the highest rainfall during January 2017 (401 mm). The study area receives higher rainfall towards the western part compared to the eastern part (Rountree *et al.*, 2000). This provided a unique opportunity to study the water quality and algal assemblages during relatively dry, as well as during higher rainfall conditions.

Algal assemblages

There was very little difference between the total number of algae genera and cyanobacteria during 2016 and 2017 (total of 86 to 88 genera, respectively). However, an overall increase in the species diversity, evenness, and richness, as indicated by the various indices, was observed for 2017. Site 4, in the Sabie River, showed an increase in both species evenness and richness while sites 11 and 12 showed greater diversity. Site 11 was dominated by the genus *Dinobryon* during 2016, but during 2017 the diversity increased considerably and Cyanophyta was most abundant. At site 12 in the Sand River, the Chlorophyta became more abundant during 2017. Site 10 in the Marite River had the highest scores for the Shannon-Wiener, Margalef and Pielou indices in both 2016 and 2017. This site showed greater algal biodiversity and evenness, although the algal cell concentrations decreased in 2017. An increase in species richness is unexpected during high rainfall episodes (Biggs and Smith,2002). This is possibly due to the downstream migration of species during conditions of high flow. The increase in species richness observed during a year of higher rainfall is possibly due to elevation of the drought conditions, accompanying lower temperatures and changes in the nutrient concentrations.

Despite the dilution effect of higher water volumes and lower cell concentrations the abundances of different groups observed at the different study sites were mostly similar between the two years of study with the exceptions of sties 4, 7 11 and 12. At both sites 4 and 7, in the Sabie and Sand Rivers respectively, dominance changed from Cyanophyta to Bacillariophyta. Site 11 (Inyaka Dam) showed an overall decrease in the Chrysophyta and increase in Cyanophyta in 2017. Katsiapi *et al.* (2012) stated that a population shift to less Chrysophyta and more Cyanophyta can be an indication of eutrophic conditions increasing in the system. However, there was no change in the concentration of orthophosphate in the water and chlorophyll-*a* concentrations decreased from 2016 (3.87 µg/l) to 2017 (1.7 µg/l) at this site. Although changes in orthophosphate concentrations could not be conclusively determined, due to the reporting limit as discussed earlier, there was an increase in orthophosphate at most sampling sites during 2017.

Based on chlorophyll-*a* levels site 11 can be classified as oligotrophic according to Van Ginkel (2011) but has the potential for increased algal productivity (total phosphorus > 0.13 mg/l). Site 12, in the Sand River showed a decrease in Cyanophyta and an increase in Chlorophyta during 2017. As stated by Chinyama *et al.* (2016) cyanobacteria are associated with eutrophic waters containing high nutrient concentrations, as was seen at site 12 during 2016. The shift in dominance can be due to the higher rainfall and decreased nutrient concentrations. Site 12 showed changes in the trophic status and was no longer hypertrophic but rather had indications of oligotrophic conditions, however since the data only represents single measurements every three months the potential effects it may have on the aquatic environment can be modified by other factors. It's therefore still important to monitor the changes in the total phosphorus and ortho-phosphate concentrations as it can indicate potential future growth of algae and cyanobacteria.

During this study all, chemical analyses were done by Rand Water Analytical Services. The reporting limit for the methods used to determine: (i) Phosphorus was <0.5 mg/l, (ii) orthophosphate was <0.2 mg/l, and (iii) and total phosphorus were <0.036 mg/l. The mean ortho-phosphate levels were always lower than the reporting limit (0.1mg/l) and therefore did not change between the two years of study and neither did the mean levels of phosphorus (0.25 mg/l). Due to the reporting limit these mean values also did not change between sites. According to the RQO (South Africa, 2016) for phosphates in the Sabie and Marite Rivers the 50th percentile of the data must be below 0.015 mg/l, which was not the case. Only sites 7 and 12 in the Sand River were compliant to the RQO which specify that the 50th percentile of the data must be below 0.125 mg/l. It will thus not be possible to clearly classify the study sites as either mesotrophic or eutrophic according to Van Ginkel (2011). According to Palmer (1980) and Van Ginkel (2012), changes in the Cyanophyta population can be an indication of seasonal changes in the physical-chemical and biological environment and can result in the formation of blooms. Monitoring Cyanophyta blooms can, therefore, be a good indicator of changing or degraded water quality (Teta *et al*., 2017). According to Wehr *et al.* (2015), cyanobacteria blooms are dependent on the total phosphate concentrations and systems with concentrations < 5µg/l will not be able to support harmful bloom-forming cyanobacteria. The Cyanophyta population in the study area had 14 genera in total and did not occur in very high concentrations. Ndlela *et al.* (2016) also reiterate *Microcystis*, *Oscillatoria*, *Cylindrospermopsis* and *Anabaena* as South Africa's greatest threat in terms of Cyanophyta blooms. According to several studies done by Harke *et al.* (2016): Mowe *et al.* (2015): Ndlela *et al.* (2016), *Microcystis* has the widest distribution and is the dominant cyanobacteria genus in South Africa, it is also known that this this genus prefers stagnant waters. *Microcystis* was not observed during this study. *Cylindrospermopsis* was however found in low abundances during 2017. The occurrence of this genus is not unusual, a study done by Mowe *et al.* (2015) confirmed that this genus can often be found in tropical regions. *Oscillatoria* was present during the 2016 sampling period with the highest abundance at sites 4 and 12. According to Ganai and Parveen (2014) and Pinedo *et al.* (2007) this genus is an indicator of organic pollution and degraded environments which correlate with its presence at sites 4 and 12, both associated with organic pollution. Although *Oscillatoria* can produce toxins, it is not usually the major toxin producing genus when a toxic bloom is present (Ndlela *et al.*, 2016).

According to Ndlela *et al.* (2016), the genus *Anabaena* is affected by phosphorus concentrations higher phosphorus concentrations will result in increasing toxicity. The *Anabaena* abundances showed a noteworthy decrease during the high rainfall season. As discussed in Chapter 2 (section 2.1.1) some Cyanophyta can produce cyanotoxins such as microcystin. The microcystin concentrations were measured at the all sampling sites, but did not exceed the detection limit. Since some of the toxic bloom-forming genera were present, monitoring the Cyanophyta abundances in the study area is vital, especially in the Inyaka Dam.

The Bacillariophyta was the dominant algal group during all the seasons, with a total of 33 different genera observed in 2016, and 35 genera during 2017. According to Taylor *et al.* (2007b) Bacillariophyta can grow in a wide range of conditions and are more abundant during the winter months. *Gomphonema* was present at most sites and was frequently dominant. *Gomphonema* is tolerant to pollution and electrolyte-rich waters and is expected to persist even when the water quality and conditions change. *Cymbella* was the second most frequently encountered diatom. *Cyclotella* can often be found in oligotrophic to mesotrophic waters. *Hippodonta* and *Geissleria* are found in eutrophic waters, *Hippodonta* is also tolerant to pollution (Taylor *et al.*, 2007b). These genera were found in low abundances at sites 2, 3 (*Hippodonta, Geissleria*) and 6, 7, 8, 9 and 12 (*Geissleria)*. During 2017 *Hippodonta* was only found at site 3 and *Geissleria* decreased to an abundance of <1 cell/ml. *Hantzschia* was only present during 2017, this genus favours dry conditions but will increase in abundance when the EC and salt concentrations increase (Taylor *et al.*, 2007). As this genus is associated with soil habitats, it is possible that this genus was transferred to the study area with increased surface runoff during the higher rainfall period (Spaulding, s.a.). *Cyclotella* and *Aulacoseira* can cause filter clogging during the water treatment process (Oosthuizen & Janse van Vuuren, 2014), however, these genera were however present in very low concentrations, with the highest abundance of *Cyclotella* at site 11. Due to its proneness to create blooms, combined with clogging of filters, it may become a possible problem in the future.

The Chlorophyta showed the highest species diversity and abundance at site 12 in the Sand River. Janse van Vuuren *et al.* (2006) stated that the presence of *Pediastrum*, *Oocystis*, *Scenedesmus* and *Coelastrum* can be used as indicators of eutrophic water conditions. There were only few *Pediastrum* and *Oocystis* cells present in the study area. *Scenedesmus* and *Coelastrum* had the highest abundance at site 12 which correlates with higher total nitrogen and in particular ammonia concentrations reported at this site during 2016.

The Chrysophyta genus *Dinobryon* was frequently present at sites 10 and 11 in the Marite River but were absent during winter (July) of 2016. A study done by Heinze (2009) found that *Dinobryon* showed high biomass production at the maximum oxygen layer (when stratification occurs) and a study done by Taş *et al*. (2010) found a positive correlation between dissolved oxygen and Chrysophyta. This can possibly explain the absence of *Dinobryon* at the lower %DO measured during July 2016.

The Chrysophyta can be used as indicators of oligotrophic waters but this can be misleading because increased Chrysophyta diversity can be an indicator of eutrophic waters as well (Bellinger & Sigee, 2010). Only one genus of the Chrysophyta *(Dinobryon)* was observed during this study and it will therefore, be more indicative of oligotrophic waters, especially when the chlorophyll-*a* concentration is considered. According to Bellinger and Sigee (2010), *Dinobryon* can cause aesthetic problems within drinking water resources when it is present in high concentrations. Sun *et al.* (2014) identified *Dinobryon* as one of the genera responsible for fishy taste and odours in water. There were no fishy odours detected at the sampling sites but taste and odour problems can occur in the future, especially at site 11(Inyaka Dam).

The Euglenophyta was present at most sites except site 1. The genera found were *Euglena*, *Phacus* and *Trachelomonas* (2016 Table 5-2) and in addition to *Strombomonas* during 2017. Variables such as coliforms, chemical oxygen demand, dissolved carbon and total organic carbon had a significant positive correlation (p<0.05) with Euglenophyta (Appendix 3-A). The high cell concentrations of this group during 2016 was expected as the Euglenophyta are present in waters with increased organic matter. *Euglena* is generally used as an indicator genus of higher nutrient concentrations (Bellinger & Sigee, 2010). The higher abundance of the Euglenophyta at site 12 compared to other sites during 2016 could be an indication or result of higher concentrations of organic matter. This was supported by the high TOC, DOC and ammonia concentrations determined at this site. Again, this was no longer the case during 2017 and the total cell concentrations of this grouped decreased from 1118 cells/ml in 2016 to only 4 cells/ml in 2017.

Water quality

The physical and chemical water quality parameters determined during this study were compared to the TWQR (DWAF, 1996b,c) as well as the RQO for this study area (South Africa, 2016). According to standards discussed in Dallas and Day (2004), all the sites had relatively low turbidity values during 2016. During the higher rainfall period of 2017 a general increase in the turbidity was observed for all sites, except site 1. According to Dallas and Day (2004) turbidity represents the suspended particles present in a water source, and increased turbidity can be caused by increased erosion and sediment runoff. Harvesting of the commercial plantations as was observed at site 2 can also account for the increased erosion and runoff and thus higher turbidity of the system (Rountree *et al.*, 2000).

High %DO is crucial for good quality water, and all aquatic life is dependent on these levels (Weiner, 2008). During 2016, site 9 of the Sabie River, site 10 in the Marite River, site 11 in the Inyaka Dam and site 12 in the Sand River had low %DO considered harmful for any aquatic ecosystem and organisms present in the water. The %DO at sites 9 and 12 showed an improvement during 2017. Site 9 was no longer below TWQR, probably due to the absence of the invasive plant species (*Pistia stratiotes*) during 2017. Site 12 is no longer acute low in DO possibly due to increased water levels, decreased COD, and lower decomposition rate of cyano-blooms. Site 5 in the Sabie River and site 11 in the Inyaka Dam were the only sites where the %DO decreased during 2017.

All the study sites showed *Escherichia coli* and coliform cell concentrations were well above the concentrations of the recommended TWQR. Site 12 in the Sand River had the highest *E. coli* and coliform concentrations in both 2016 and 2017. This site also had the highest DOC, TOC and COD concentrations. There was a significant correlation ($p<0.05$) between the COD and *E. coli,* which can explain the low DO percentages observed at this site. The *E. coli* and coliform concentrations in the Sand River decreased downstream from site 12 site 7, suggesting that the conservation areas may have a restorative effect. The *E. coli* and coliform concentrations increased at all the sites, except site 12 during 2017. However, the concentrations at this site remained higher than at the other sites. The high coliform and *E. coli* concentrations at site 12 may be the result of the densely populated surroundings, that include the urban village of Thulamahashe. The wastewater treatment plant situated 500m upstream of this sampling site was also not functional during the study period (Rand Water, 2017). Livestock was also observed roaming in the river at this site. A combination of all these factors may have contributed to high *E. coli* and coliform concentrations.

According to Srinivasan and Sorial (2011), 2-MIB and GM can be detected by the human palate in concentrations ranging from 4-20 ng/l. Some sites located in the Sabie River, particularly sites 4, 5 and 9experienced taste and odour related problems during the period of low flow (2016). During the period of higher rainfall (2017) 2-MIB and GM concentrations no longer exceeded the TWQR. Site 12 in the Sand River had 2-MIB and GM concentrations (both mean and maximum) that exceeded the palatable concentration guidelines and this site experienced taste and odour problems during the whole study period. Site 11 (Inyaka Dam), which forms part of the Inyaka Water supply scheme that provides potable water to the surrounding areas, never experienced 2-MIB and GM concentrations above the TWQR.

The GM concentrations were highest at sites 4, 5, 9 and 12, but the Cyanophyta genera associated with geosmin production (*Anabaena* and *Oscillatoria*) were only present at sites 4 and 12. This suggests that Actinomycetes may be present in the water, since this group of organisms can also contribute to the geosmin concentrations (Zaitlin *et al.,* 2003), especially at sites 5 and 9. During 2017 the 2-MIB concentration increased at site 1 and decreased at site 9. Site 1 only had 4 cells/ml Cyanophyta (*Merismopedia*) and it suggests that the Cyanophyta cannot be the source of increased concentration of 2-MIB observed.

Zaitlin and Watson,(2006 stated that increased concentrations of tastes and odours can also be due to surface runoff. The marked increase of tastes and odours at this site can be a result of the increased runoff due to harvesting of forestry plantations observed as well as the influence of increased rainfall during 2017.

Iron plays an important role in photosynthesis and electron transport in algae (Xing & Liu, 2011). Natural concentrations in freshwater usually do not exceed 1 mg/l, but anthropogenic activities, such as urbanisation and industrialisation, have greatly increased the iron concentration in freshwater systems (Xing & Liu, 2011). Xing and Liu (2011) further stated that there can be a shift from Chlorophyta to Cyanophyta as the dominant group if the iron concentrations range from 0.1 to 1.0 mg/l.

Site 11 had a mean and maximum concentration of 0.5 mg/l and 1.4 mg/l respectively and it was the only site that exceeded the natural ranges during 2016. Contrary to the results of Xing and Liu (2011) neither Chlorophyta nor Cyanophyta were dominant at this site, and no shift between these group was observed. A shift from Chrysophyta to Cyanophyta as the dominant was observed at this site during 2017 even though the maximum iron concentrations decreased drastically (0.6 mg/l). Contrary to the findings of Xing and Liu (2011) site 10 and 12 showed a shift from Cyanophyta to Chlorophyta together with a striking increase in the iron concentrations during 2017. According to Dallas and Day (2004) high iron concentrations can be oxidised and cause oxygen depletion. This is a great concern considering the high iron concentrations present in the study area. Site 5 was the only site that showed a decrease in %DO during 2017.

The aluminium concentrations determined in all sites were extremely high, this may also be due to natural background values which is related to the regions geology. Increased aluminium concentrations can have severe impacts if the pH of the system reaches acidic conditions as the aluminium concentrations are dependent on the pH ranges of the system and are insoluble in natural pH ranges. Under low pH conditions, aluminium is both soluble and toxic, at low pH conditions, aluminium can also form a complex with iron or sulphates, these complexes can become unavailable and non-toxic to the aquatic system. At high pH conditions aluminium occurs in a biologically unavailable complex (DWAF, 1996c).

6.2 Conclusion

A clear difference was observed in the abundance of the different algal groups during low and higher rainfall periods. At site 4 in the Sabie River and site 7 in the Sand River (within the confines of the KNP) the dominant phyla changed from Cyanophyta to Bacillariophyta and at site 11 in the Inyaka Dam dominance changed from Chrysophyta to Cyanophyta. The dominant phylum at site 12 in the Sand River shifted from Cyanophyta/ Chlorophyta co-dominance to Chlorophyta dominance. There was also a decrease in the abundance of harmful bloom-forming genera such as *Anabaena* and *Oscillatoria* at site 12. The genus *Cylindrospermopsis* was only observed during 2017 and fortunately *Microcystis* was absent from the study area. The number of genera observed did not change significantly between the two years and high cell concentrations and bloom formation were absent. A general increase in the species diversity, richness and evenness was observed during the wetter year, (2017).

The higher rainfall experienced during 2017 relieved the critical conditions caused by the drought, the water levels improved at all the sites and invasive species (*Pistia stratiotes* and *Azolla filiculoides*) were flushed downstream. The total nitrogen and ammonia concentrations decreased and there were clear improvements in the %DO at most sites. The turbidity measured at all sites were higher during the higher rainfall period possibly due to increased runoff. The aluminium and iron concentrations increased significantly in the sites located in the Sand River as well as the site located in the Marite River.

This may be reason for concern since these metals can become toxic to users. High *E. coli* concentrations observed at all sites (apart from sites 1 & 11) are reason for concern as it poses a serious health risk, especially to the surrounding rural communities that may come in contact with these bacteria.

The sites located in the Sabie River have relatively good water quality. Most of the physical and chemical water quality parameters determined complied with the recommended TWQR. The chlorophyll-*a* concentrations were low at all Sabie River sites and harmful potential bloom-forming genera only occurred in low cell concentrations at site 4. The turbidity of these sites was low even after the higher rainfall period. All the sites showed %DO higher than the 80% recommended range, site 5 was the only Sabie River site that showed a decrease in the %DO during 2017 that no longer met the TWQR. Nutrients such as total nitrogen, total phosphorus (phosphorus & ortho-phosphate) did not comply with the set RQO's for the Sabie River. This may however be because of the method used to determine the different variables. Heavy metals, such as, aluminium and zinc concentrations, exceeded the TWQR. The Sabie River also experienced slight taste and odour problems at sites 1, 5 and 9.

Site 10 located in the Marite River also had relatively good water quality. Most of the physical and chemical water quality parameters determined complied with the recommended TWQR. The sampling site in the Marite River showed the greatest species diversity, evenness and richness of all sites, and none of the known harmful potentially bloom-forming genera were present at this site during the study. The turbidity of site was low even after the higher rainfall period. The %DO measured at site 10 did not comply with the TWQR during the drier sampling period but did improve to greater than 80% after higher rainfall. Total nitrogen and total phosphorus (phosphorus & ortho-phosphate) concentrations were higher than those set by the RQO's. The concentrations of heavy metals aluminium and zinc also exceeded the TWQR. The Marite River also indicated a slight increase in taste and odour compounds but it remained lower than the palatability ranges.

The Inyaka Dam is the most important site when the aesthetic value of drinking water is considered. This site can face taste and odour problems in the future due to high iron concentrations as well as emergent chlorophyll-*a* and possible related geosmin and 2-MIB concentrations. Even though the site showed a decrease in Chrysophyta abundance and increase in Cyanophyta during 2017, harmful bloom-forming genera such as *Anabaena*, *Cylindrospermopsis*, *Oscillatoria* and *Phormidium* were detected, but all genera occurred in very low concentrations. The %DO at the Inyaka Dam did not comply with the TWQR during both years of study. The total nitrogen and total phosphorus (phosphorus & ortho-phosphate) concentrations, were higher than the RQO's set for the Marite River. The heavy metals concentrations of aluminium and zinc also exceeded the TWQR.

Site 7, located in the Sand River experienced very low flow conditions during 2016. The higher rainfall and increased flow conditions did improve the overall water quality and the invasive plant *Azolla filiculoides* was no longer present during 2017. Site 12, also located in the Sand River, had the poorest water quality of all the sites. Many of the physical and chemical parameters measured did not comply with the TWQR as well as the RQO's, set for this river. Extremely high *E. coli* concentrations were observed. Site 12 also showed the best improvement during the higher rainfall year. The %DO increased from acute low to sub-lethal and the nutrient concentrations showed a noteworthy decrease. Although the *E. coli* concentrations decreased considerably during 2017 it could still be considered extremely high.

According to Van Ginkel (2011), the study area can be classified as an oligotrophic system based on the chlorophyll- *a* concentrations. However due to high concentrations of ortho-phosphate observed, the potential for increased algal productivity exists. Site 12 was the only site that showed a noteworthy decreased algal productivity and varied from mesotrophic to hypertrophic in 2016 and oligotrophic in 2017 (January to July) based on chlorophyll-*a* concentrations.

CHAPTER 7 REFERENCES

Anon. 2017. After the drought: What is the future for Kruger's waterholes? http://www.wildcard.co.za/drought-future-krugers-waterholes/. Date of access: June 2018.

APHA (American Public Health Association). 2013. Standard methods for the examination of water and wastewater (22nd ed.): American Public Health Association.

Bellinger, E.G. & Sigee, D.C. 2010. Freshwater algae: identification and use as bioindicators. West Sussex, UK: Wiley-Blackwell.

Biggs, B.J. & Smith, R.A. 2002. Taxonomic richness of stream benthic algae: effects of flood disturbance and nutrients. *Limnology and Oceanography*, 47(4):1175-1186.

Bond, N.R., Lake, P.S. & Arthington, A.H. 2008. The impacts of drought on freshwater ecosystems: an Australian perspective. *Hydrobiologia*, 600(1):3-16.

Chapman, D.V. 1996. Water quality assessments: a guide to the use of biota, sediments and water in environmental monitoring. 2nd ed. London: Chapman & Hall.

Chinyama, A., Ochieng, G.M., Snyman, J. & Nhapi, I. 2016. Occurrence of cyanobacteria genera in the Vaal Dam: implications for potable water production. *Water SA*, 42(3):415-420.

Croasdale, H., Flint, E. A., Racine, M. M. 1994. Flora of New Zealand: Desmids volume 3. New Zealand: Manaaki Whenua Press.

Dallas, H.F. & Day, J.A. 2004. The effect of water quality variables on aquatic ecosystems: a review. Pretoria: Water Research Commission.

Daneshvar, F., Nejadhashemi, A.P., Herman, M.R. & Abouali, M. 2017. Response of benthic macroinvertebrate communities to climate change. *Ecohydrology & Hydrobiology*, 17(1):63-72.

Davari, N., Jouri, M.H. & Ariapour, A. 2011. Comparison of Measurement Indices of Diversity, Richness, Dominance, and Evenness in Rangeland Ecosystem (Case Study: Jvaherdeh-Ramesar). *Journal of Rangeland Science*, 2(1).

Death, R. 2008. Margalef's Index. Encyclopedia of Ecology. New Zealand: Elsevier p. 2209-2210).

DWA (Department of Water Affairs), S.A. 2002. State of the rivers report (pp. 41): Department of Water Affairs. https://www.dwa.gov.za/iwqs/rhp/state_of_rivers/limpopo/Sand_2002_report_without_pics.pdf. Date of access 12 Apr 2017.

DWA (Department of Water Affairs), S.A. 2010. Comprehensive Reserve determination study for selected water resources (rivers, groundwater and wetlands) in the Inkomati Water Management Area, Mpumalanga. Sabie and Crocodile systems: EcoSpecs report. In Louw, M., D. & Koekemoer, S. (Eds.). Pretoria: Department of Water Affairs.

DWA (Department of Water Affairs), S.A. 2011a. Bushbuckridge Local Municipality: First order reconciliation strategy for the Inyaka Regional Water Supply Scheme area. Author: Tlou, T. https://www6.dwa.gov.za/iwrp/DSS/UserFiles/IWRP/Documents/MP_DC32_MP325_Inyaka_F.pdf. Date of access 22 Feb 2016.

DWA (Department of Water Affairs), S.A. 2011b. Green Drop Report 2011 Mpumalanga. http://www.dwa.gov.za/Documents/BD/BDMP.pdf.Date of access 22 Feb 2016.

DWA (Department of Water Affairs), S.A. 2012. Blue Drop Report 2012. http://www.gov.za/sites/www.gov.za/files/blue%20drop%20report.pdf. Date of access 24 Feb 2016.

DWA (Department of Water Affairs), S.A. 2013. The determination of water resource classes and associated resource quality objectives in the Inkomati Water Management Area.: Status quo assessment, IUA delineation and biophysical node identification. Author: Mallory, S.L., D. Deacon, A. Huggins, G. Kotze, P. Mackenzie, J. Scherman, P. Van Jaarsveld, P. http://www.dwa.gov.za/rdm/WRCS/doc/Draft%20Status%20Quo%20Report.pdf. Date of access 12-03-2016.

DWA (Department of Water Affairs), S.A. 2014a. Blue Drop Report 2014. https://www.green-cape.co.za/assets/Water-Sector-Desk-Content/DWS-2014-Blue-Drop-report-national-overview-part-1-of-2-2016.pdf. Date of access 12 Aug 2017.

DWA (Department of Water Affairs), S.A. 2014b. Green Drop Progress Report Mpumalanga 2014. file:///E:/Chapters%20nuutse/chapters%20final/1/Chapter%209%20MP%20GD.pdf. Date of access: Feb 2016.

DWAF (Department of Water Affairs and Forestry), S.A. 1996a. Sabie Sand IRF Workshop Starter Document. Author: Deacon, A.R.

DWAF (Department of Water Affairs and Forestry), S.A. 1996b. South African Water Quality Guidelines: Volume 1: Domestic use. (pp. 190): Department of Water Affairs and Forestry.

DWAF (Department of Water Affairs and Forestry), S.A. 1996c. South African Water Quality Guidelines: Volume 6: Agriculture use: Aquaculture. (pp. 185). South Africa DWAF (Department of Water Affairs and Forestry).

DWAF (Department of Water Affairs and Forestry), S.A. 1996d. South African Water Quality Guidelines: Volume 7: Aquatic Ecosystems (pp. 145). Pretoria: Department of Water Affairs and Forestry.

DWAF (Department of Water Affairs and Forestry), S.A. 2000. Zoning for Inyaka Dam for Recreation, Development and Nature Conservation. In Ackerman, P.B.I. (Ed.).

DWAF (Department of Water Affairs and Forestry), S.A. 2006. Status of the Water Sector in Mpumalanga, Mpumalanga water summit. Author: Van Zyl, F., Marais, S.https://www.dwaf.gov.za/Documents/Other/WS/MpumWaterSummitJan06full.pdf. Date of access 23 Feb 2016.

DWS (Department of Water and Sanitation), S.A. 2008. Hydrological Services - Surface Water (Data, Dams, Floods and Flows). http://www.dwa.gov.za/Hydrology/. Date of access: 22 Aug 2017.

EPPO (European and Mediterranean Plant Protection Organization). 2017. Pistia stratiotes L. *Bulletin EPPO* (47:537-543).

Esfahanian, E., Nejadhashemi, A.P., Abouali, M., Adhikari, U., Zhang, Z., Daneshvar, F. & Herman, M.R. 2017. Development and evaluation of a comprehensive drought index. *Journal of environmental management*, 185(2017):31-43.

Ettl, H., Gärtner, G., Heynig, H., Mollenhauer, D., Komárek, J. & Anagnostidis, K. 1999. Süsswasser von Mitteleuropa: Cyanoprokaryota, Teil 1: Chroococcales. Stuttgart: Gustav Fisher Verlag.

Falconer, I.R. & Humpage, A.R. 2005. Health risk assessment of cyanobacterial (blue-green algal) toxins in drinking water. *International Journal of Environmental Research and Public Health*, 2(1):43-50.

Fedor, P.J. & Spellerberg, I.F. 2013. Shannon–Wiener Index☆. Reference Module in Earth Systems and Environmental Sciences. Amsterdam: Elsevier. p. 3249-3252).

Ganai, A.H. & Parveen, S. 2014. Effect of physico-chemical conditions on the structure and composition of the phytoplankton community in Wular Lake at Lankrishipora, Kashmir. *International Journal of Biodiversity and Conservation*, 6(1):71-84.

Giorgio, A., De Bonis, S. & Guida, M. 2016. Macroinvertebrate and diatom communities as indicators for the biological assessment of river Picentino (Campania, Italy). *Ecological Indicators*, 64(2016):85-91.

Harding, W.R., Archibald, C.G.M. & Taylor, J.C. 2005. The relevance of diatoms for water quality assessment in South Africa: A position paper. *Water SA*, 31(1):41-46.

Harke, M.J., Steffen, M.M., Gobler, C.J., Otten, T.G., Wilhelm, S.W., Wood, S.A. & Paerl, H.W. 2016. A review of the global ecology, genomics, and biogeography of the toxic cyanobacterium, Microcystis spp. *Harmful Algae*, 54(2016):4-20.

Heinze, A.W. 2009. The role of temperature in the distribution of mixotrophic protists of the genus Dinobryon. Philadelphia: Temple University.

Henderson, R., Parsons, S.A. & Jefferson, B. 2008. The impact of algal properties and pre-oxidation on solid–liquid separation of algae. *Water Research*, 42(8-9):1827-1845.

Heritage, G. & Moon, B.P. 2000. The contemporary geomorphology of the Sabie River in the Kruger National Park. *Koedoe*, 43(1):39-55.

Heritage, G., Moon, B.P., Jewitt, G.P., Large, A.R.G. & Rountree, M. 2001. The February 2000 floods on the Sabie River, South Africa: an examination of their magnitude and frequency. *Koedoe*, 44(1):37-44.

Heritage, G., Tooth, S., Entwistle, N. & Milan, D. 2015. Long-term flood controls on semi-arid river form: evidence from the Sabie and Olifants rivers, eastern South Africa. *Proceedings of the International Association of Hydrological Sciences*, 367:141.

Hindák, F. 2008. Colour Atlas of Cyanophytes. Bratislava: VEDA, Publishing House of the Slovak Academy of Sciences.

Hitzfeld, B.C., Höger, S.J. & Dietrich, D.R. 2000. Cyanobacterial toxins: removal during drinking water treatment, and human risk assessment. *Environmental health perspectives*, 108(Suppl 1):113.

Hüber-Pestalozzi, G. 1961. Das Phytoplankton des Süsswassers: Systematik und Biologie. Tiel 5: Chlorophyceae (Grünalgen). Ordnung: Volvocales. Stuttgart: E Schweizerbart'sche Verlagbuchhandlung.

Janse van Vuuren, S., Taylor, J.C., Gerber, A. & Van Ginkel, C.E. 2006. Easy identification of the most common freshwater algae: a guide for the identification of microscopic algae in South African freshwaters. Potchefstroom: North-West University.

John, D.M., Whitton, B.A. & Brook, A.J. 2002. The freshwater algal flora of the British Isles: an identification guide to freshwater and terrestrial algae. Cambridge: Cambridge University Press.

Katsiapi, M., Mazaris, A.D., Charalampous, E. & Moustaka-Gouni, M. 2012. Watershed land use types as drivers of freshwater phytoplankton structure. *Hydrobiologia*, 698(1):121-131.

Komárek, J. & Anagnostidis, K. 2005. Cyanoprokaryota: Oscillatoriales. In Büdel B., G.G., Krienitz L., Schagerl M. (Ed.). *Freshwater Flora of Central Europe, Part 2* (pp. 758). Jena: Spektrum Akademischer Verlag.

Kshirsagar, A.D. 2013. Use of Algae as a Bioindicator to Determine Water Quality of River Mula from Pune City, Maharashtra (India). *Universal Journal of Environmental Research & Technology*, 3(1):79-85.

Lake, P.S. 2000. Disturbance, patchiness, and diversity in streams. *Journal of the North American Benthological society*, 19(4):573-592.

Lanciotti, E., Santini, C., Lupi, E. & Burrini, D. 2003. Actinomycetes, cyanobacteria and algae causing tastes and odours in water of the River Arno used for the water supply of Florence. *Journal of Water Supply: Research and Technology-Aqua*, 52(7):489-500.

Magurran, A. 2004. Measuring biological diversity. Blackwells: Oxford, UK.

Maponya, P., Mpandeli, S. & Oduniyi, S. 2013. Climate Change Awareness in Mpumalanga Province, South Africa. *2013*, 5(10): 273-282.

Margalef, R. 1958. Temporal succession and spatial heterogenicity in natural phytoplankton. In Buzzati-Traverso, A.A. (Ed.). *Perspective in marine biology* (pp. 323-347). Berkeley: University of California Press.

Maruthanayagam, V., Nagarajan, M. & Sundararaman, M. 2013. An insight into biological significance of marine cyanobacterial toxins in the recent decade. *Cah Biol Mar*, 54(2013):221-238.

McConnachie, A.J., de Wit, M.P., Hill, M.P. & Byrne, M.J. 2003. Economic evaluation of the successful biological control of Azolla filiculoides in South Africa. *Biological Control*, 28(1):25-32.

MELP (Ministry of Environment Lands and Parks). 1998. Guidelines for Interpreting Water Quality Data. British Columbia: Resources Inventory Committee. https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/interp/index.htm. Date of access: Oct 2016.

Mowe, M.A.D., Yeo, D.C.J., Mitrovic, S.M., Lim, R.P. & Furey, A. 2015. Tropical cyanobacterial blooms: a review of prevalence, problem taxa, toxins and influencing environmental factors. *Journal of Limnology*, 74(2):205-224.

Mucina, L. & Rutherford, M.C. 2006. The vegetation of South Africa, Lesotho and Swaziland. . Pretoria: South African National Biodiversity Institute.

Ndlela, L.L., Oberholster, P.J., Van Wyk, J.H. & Cheng, P.H. 2016. An overview of cyanobacterial bloom occurrences and research in Africa over the last decade. *Harmful Algae*, 60(2016):11-26.

Norman, N. & Whitfield, G. 2006. Geological journeys: A traveller's guide to South Africa's rocks and landforms. Cape Town: Struik Publishers.

Omar, W.M.W. 2010. Perspectives on the use of algae as biological indicators for monitoring and protecting aquatic environments, with special reference to Malaysian freshwater ecosystems. *Tropical life sciences research*, 21(2):51-67.

Oosthuizen, M. & Janse van Vuuren, S. 2014. Changes in density and composition of algal assemblages in certain unit processes of two South African water purification plants. *African journal of aquatic science*, 39(3):313-326.

Oyadomari, J. 2001. Keweenaw algae. www. keweenawalgae. mtu. edu Date of access: Jan 2016.

Palmer, C.M. 1980. Algae and water pollution: the identification, significance, and control of algae in water supplies and in polluted water. s.l.: Castle House Publications.

Peet, R.K. 1974. The measurement of species diversity. *Annual review of ecology and systematics*, 5(1):285-307.

Reynolds, C.S. 1992. *Eutrophication and the management of planktonic algae: What Vollenweider couldn't tell us.* In: Sutcliffe, David W. and Jones, J. Gwynfryn (eds.) Eutrophication: research and application to water supply. Ambleside, UK, Freshwater Biological Association, pp. 4-29. (FBA Special Publications, 3)

Pielou, E.C. 1966. The measurement of diversity in different types of biological collections. *Journal of theoretical biology*, 13(1966):131-144.

Pinedo, S., García, M., Satta, M.P., deTorres, M. & Ballesteros, E. 2007. Rocky-shore communities as indicators of water quality: A case study in the Northwestern Mediterranean. *Marine Pollution Bulletin*, 55(1-6):126-135.

Prescott, G.W. 1964. How to know the freshwater algae. US: Wm.C.Brown Company Publishers.

Pretorius, W. 2016. How the drought is affecting the Kruger National Park. https://www.news24.com/SouthAfrica/News/how-the-drought-is-affecting-the-kruger-national-park-20160908. Date of Access: June 2018.

Rand Water. 2017. Wastewater treatment plant in Thulamhashe [Correspondence]. 20 Sep. Potchefstroom

Reavie, E.D., Jicha, T.M., Angradi, T.R., Bolgrien, D.W. & Hill, B.H. 2010. Algal assemblages for large river monitoring: comparison among biovolume, absolute and relative abundance metrics. *Ecological Indicators*, 10(2):167-177.

Rountree, M.W., Rogers, K.H. & Heritage, G.L. 2000. Landscape state change in the semi-arid Sabie River, Kruger National Park, in response to flood and drought. *South African Geographical Journal*, 82(3):173-181.

Roux, F. & Selepe, M. 2011. Ecostatus of the Sabie Sand Catchments. http://inkomaticma.co.za/images/Ecostatus_of_the_Sabie__Sand_Catchments.pdf Date of access: May 2016.

Schneider, S.C. 2015. Greener rivers in a changing climate?—Effects of climate and hydrological regime on benthic algal assemblages in pristine streams. *Limnologica-Ecology and Management of Inland Waters*, 55(2015):21-32.

Shannon, C.E. & Wiener, W. 1949. The mathematical theory of communication. Champaign: University of Illinois Press.

Sharov, A.N. 2008. Phytoplankton as an indicator in estimating long-term changes in the water quality of large lakes. *Water Resources*, 35(6):668-673.

Sherwood, L., Woolverton, C.J., Willey, J.M. & Prescott, H. 2011. Prescott's microbiology. 8th ed. New York: McGraw-Hill.

South Africa. 2016. Classes of water resources and resource quality objectives for the catchments of the Inkomati. *Government Gazette*, 40531(616). 30 Dec.

Spaulding, S.A. s.a. Diatoms of the United States. https://westerndiatoms.colorado.edu/ Date of access: Aug 2017.

Spellerberg, I.F. 2008. Shannon–Wiener Index. Encyclopedia of Ecology. Amsterdam: Elsevier. p. 3249-3252.

Srinivasan, R. & Sorial, G.A. 2011. Treatment of taste and odor causing compounds 2-methyl isoborneol and geosmin in drinking water: A critical review. *Journal of Environmental Sciences*, 23(1):1-13.

Stevenson, J. 2014. Ecological assessments with algae: a review and synthesis. *Journal of Phycology*, 50(3):437-461.

Sun, L.L., Zhang, K.J., Zhang, T.Q. & Zhu, Z.W. 2014. Mechanism of Fishy Odor Compounds Metabolized by Algae. *Applied Mechanics and Materials*, 535:355-359.

Swanepoel, A., Du Preez, H., Schoeman, C., Janse van Vuuren, S. & Sundram, A. 2008. Condensed laboratory methods for monitoring phytoplankton, including cyanobacteria, in South African freshwaters. Pretoria: Water Research Commission.

Taş, B., Gönülol, A. & Taş, E. 2010. Seasonal dynamics and biomass of mixotrophic flagellate Dinobryon sertularia Ehrenberg (Chrysophyceae) in Derbent reservoir (Samsun, Turkey). *Turkish Journal of Fisheries and Aquatic Sciences*, 10(3).

Taylor, J.C., Harding, W. & Archibald, C. 2007a. A methods manual for the collection, preparation and analysis of diatom samples. Pretoria: Water Research Commission.

Taylor, J.C. & Cocquyt, C. 2016. Diatoms from the Congo and Zambezi Basins – Methodologies and identification of the genera. Vol. 16: Abc Taxa.

Taylor, J.C., Harding, W.R. & Archibald, C.G.M. 2007b. An illustrated guide to some common diatom species from South Africa. Gezina, South Africa: Water Research Commission.

Teta, R., Romano, V., Della Sala, G., Picchio, S., De Sterlich, C., Mangoni, A., Di Tullio, G., Costantino, V. & Lega, M. 2017. Cyanobacteria as indicators of water quality in Campania coasts, Italy: a monitoring strategy combining remote/proximal sensing and in situ data. *Environmental Research Letters*, 12(2):13.

Tsarenko, P.M. 1990. Short key of the Chlorococcalean algae of the Ukrainian SSR. Kiev: Naukova Dumka Publishing House.

Tyrrell, T. 2001. Redfield Ratio. Encyclopedia of Ocean Sciences 2nd ed. Oxford: Academic Press. p. 677-686.

US-EPA (Environmental Protection Agency), U.S. 2012. National recommended water quality criteria: Aquatic life. http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm. Date of access: Aug 2017.

Utermöhl, H. 1958. Zur Vervollkommung der quantitativen Phytoplankton Methodik. *Mitteilungen Internationale Vereinigung für Theoretische und Angewandte Limnologie*, 9(1):1-38.

Van Ginkel, C.E. 2011. Eutrophication: Present reality and future challenges for South Africa. *Water SA*, 37(5):693-701.

Van Ginkel, C.E. 2012. Algae, phytoplankton and eutrophication research and management in South Africa: past, present and future. *African Journal of Aquatic Science*, 37(1):17-25.

Van Niekerk, A.W. & Heritage, G.L. 1993. Geomorphology of the Sabie River: overview and classification. *South African Geographical Journal*, 77(1995):68-76.

Van Wyk, E., Van Wilgen, B.W. & Roux, D.J. 2001. How well has biophysical research served the needs of water resource management? Lessons from the Sabie-Sand catchment: commentary. *South African Journal of Science*, 97(9-10):349-356.

Vázquez, G., Aké-Castillo, J.A. & Favila, M.E. 2011. Algal assemblages and their relationship with water quality in tropical Mexican streams with different land uses. *Hydrobiologia*, 667(1):173-189.

Watson, S.B., Ridal, J. & Boyer, G.L. 2008. Taste and odour and cyanobacterial toxins: impairment, prediction, and management in the Great Lakes. *Canadian Journal of Fisheries and Aquatic Sciences*, 65(8):1779-1796.

Weeks, D.C., O'Keeffe, J.H., Fourie, A. & Davies, B.R. 1997. A pre-impoundment study of the Sabie-Sand River System, Mpumalanga with special reference to predicted impacts on the Kruger National Park: volume one: the ecological status of the Sabie-Sand River System. *SA Waterbulletin*, 23(2):325.

Wehr, J.D. & Sheath, R.G. 2003. Freshwater algae of North America: ecology and classification. London: Academic Press.

Wehr, J.D., Sheath, R.G. & Kociolek, J.P. 2015. Freshwater algae of North America: ecology and classification. 2nd ed. London: Elsevier Inc.

Weiner, E.R. 2008. Applications of environmental aquatic chemistry: a practical guide. 2nd ed. Boca Raton: CRC Press

Wetzel, R.G. 2001. Limnology: lake and river ecosystems. 3rd ed. California: Academic Press.

Williamson, S.D. & Balkwill, K. 2015. Plant census and floristic analysis of selected serpentine outcrops of the Barberton Greenstone Belt, Mpumalanga, South Africa. *South African Journal of Botany*, 97(2015):133-142.

Xing, W. & Liu, G. 2011. Iron biogeochemistry and its environmental impacts in freshwater lakes. *Fresenius Environmental Bulletin*, 20(6):1339-1345.

Yang, J., Hong Lv,., Liu, L., Yu, X. & Chen, H. 2016. Decline in water level boosts cyanobacteria dominance in subtropical reservoirs. *Science of the Total Environment*, 557(2016):445-452.

Ye, W., Liu, X., Tan, J., Li, D. & Yang, H. 2009. Diversity and dynamics of microcystin—Producing cyanobacteria in China's third largest lake, Lake Taihu. *Harmful Algae*, 8(5):637-644.

Zaitlin, B. & Watson, S.B. 2006. Actinomycetes in relation to taste and odour in drinking water: Myths, tenets and truths. *Water Research*, 40(9):1741-1753.

Zaitlin, B., Watson, S.B., Ridal, J., Satchwill, T. & Parkinson, D. 2003. Actinomycetes in Lake Ontario: habitats and geosmin and MIB production. *Journal American Water Works Association*, 95(2):113.

Zhao, Y., Yu, J., Su, M., An, W. & Yang, M. 2013. A fishy odor episode in a north China reservoir: Occurrence, origin, and possible odor causing compounds. *Journal of Environmental Sciences*, 25(12):2361-2366.

CHAPTER 8 APPENDICES

Appendix 1-A: List of all the genera found during the first year of sampling (2016).

Bacillariophyta	**Chlorophyta**	**Cyanophyta**
Achnanthes	*Actinastrum*	*Anabaena*
Achnanthidium	*Acutodesmus*	*Aphanocapsa*
Aulacoseira	*Ankistrodesmus*	*Arthrospira*
Caloneis	*Chlamydomonas*	*Chroococcus*
Capartogramma	*Chlorella*	*Geitlerinema*
Cocconeis	*Chlorococcum*	*Johannesbaptistia*
Craticula	*Closterium*	*Komvophoron*
Cyclotella	*Coelastrum*	*Leptolyngbya*
Cymatopleura	*Cosmarium*	*Merismopedia*
Cymbella	*Crucigenia*	*Oscillatoria*
Diatoma	*Crucigeniella*	*Phormidium*
Diploneis	*Desmodesmus*	*Pseudanabaena*
Encyonopsis	*Elakatothrix*	*Snowella*
Eunotia	*Euastrum*	*Spirulina*
Fragilaria	*Eudorina*	
Frustulia	*Microspora*	**Dinophyta**
Geissleria	*Monoraphidium*	*Ceratium*
Gomphonema	*Mougeotia*	*Peridiniopsis*
Gyrosigma	*Nephrocytium*	*Peridinium*
Hippodonta	*Oedogonium*	
Luticola	*Oocystis*	**Euglenophyta**
Mayamaea	*Pandorina*	*Euglena*
Melosira	*Pediastrum*	*Phacus*
Navicula	*Scenedesmus*	*Trachelomonas*
Nitzschia	*Schroederia*	
Pinnularia	*Selenastrum*	**Chrysophyta**
Plagiotropis	*Spirogyra*	*Dinobryon*
Rhoicosphenia	*Staurastrum*	
Rhopalodia	*Stigeoclonium*	
Sellaphora	*Tetraedron*	
Staurosira	*Tetrastrum*	
Surirella	*Treubaria*	
Synedra		

Appendix 1-B: List of all the genera found during the second year of sampling (2017).

Bacillariophyta	**Chlorophyta**	**Cyanophyta**
Achnanthes	*Actinastrum*	*Anabaena*
Achnanthidium	*Acutodesmus*	*Aphanocapsa*
Capartogramma	*Ankistrodesmus*	*Aphanothece*
Cocconeis	*Chlamydomonas*	*Arthrospira*
Craticula	*Chlorella*	*Chroococcus*
Cyclotella	*Chlorococcum*	*Cylindrospermopsis*
Cymatopleura	*Closterium*	*Gloeocapsa*
Cymbella	*Coelastrum*	*Johannesbaptistia*
Diatoma	*Cosmarium*	*Komvophoron*
Diploneis	*Crucigenia*	*Leptolyngbya*
Encyonopsis	*Crucigeniella*	*Merismopedia*
Eunotia	*Desmodesmus*	*Oscillatoria*
Fallacia	*Dictyosphaerium*	*Phormidium*
Fragilaria	*Elakatothrix*	*Radiocystis*
Frustulia	*Euastrum*	*Synechocystis*
Geissleria	*Eudorina*	
Gomphonema	*Kirchneriella*	**Euglenophyta**
Gyrosigma	*Monoraphidium*	*Euglena*
Hantzschia	*Oedogonium*	*Phacus*
Hippodonta	*Oocystis*	*Strombomonas*
Melosira	*Pandorina*	*Trachelomonas*
Navicula	*Pediastrum*	
Neidium	*Scenedesmus*	**Dinophyta**
Nitzschia	*Schroederia*	*Ceratium*
Pinnularia	*Staurastrum*	*Peridiniopsis*
Placoneis	*Stigeoclonium*	*Peridinium*
Plagiotropis	*Tetraedron*	
Planothidium	*Tetrastrum*	**Chrysophyta**
Rhoicosphenia	*Treubaria*	*Dinobryon*
Rhopalodia	*Ulotrix*	
Sellaphora		
Surirella		
Synedra		
Tryblionella		
Urosolenia		

Appendix 2-A: Data 2016, Mean, Maximum and Minimum of each site

Sabie River 2016	Site 1			Site 2			Site 3		
Variable	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Chlorophyll-a	2.35	1	4.4	2.925	1	5.4	3.15	1	6.2
Phaeophytin-a (µg/l)	1	1	1	1	1	1	1.275	1	2.1
T Pigment (µg/l)	1.25	1	2	1.5	1	3	2.75	2.4	3
Coliforms (MPN/100	507	31	1145	2065	1789	2420	2099.6	727	3790
E. coli (MPN/100 ml)	9.75	0	17	225.25	4	548	35	3	67
Turbidity (NTU)	0.705	0.45	1.1	1.028	0.6	1.6	1.045	0.72	1.6
TDS (mg/l)	33	16	67	90	63	150	51	17	71
Suspended Solids	11.37	7.5	23	7.5	7.5	7.5	11.375	7.5	23
M Alkalinity (mg/l	14.5	14	15	59.5	54	64	56.5	51	61
Hardness (mg/l	10.05	8.2	11	58.5	51	63	54.75	51	59
pH	6.18	5.9	6.55	7.375	6.53	8.16	7.233	6.6	8.2
Air Pressure	654.6	652.9	659	681.8	679	685.7	711.35	709.1	714.9
Dissolved Oxygen	82.22	76.2	93.4	83.65	74.1	94.2	88.15	72.3	102.2
DO (mg/l)	8.1025	7.1	9.83	7.75	6.62	9.5	8.38	7.23	10.76
SPC (mS/m)	46.77	41.4	49.4	143.37	122	157.5	130.6	115	142
COD (mg/l)	5	5	5	6.75	5	12	5	5	5
Aluminium (µg/l)	12.5	12.5	12.5	17.375	12.5	32	15.875	12.5	26
Calcium (mg/l)	1.975	1.2	2.5	12.75	11	14	12.25	11	13
Iron (µg/l)	20.125	2.5	34	77.25	65	89	125	105	140
Potassium (mg/l)	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Magnesium (mg/l)	0.9375	0.75	1.5	22.7	7.7	67	7	6.2	7.6
Manganese (µg/l)	5	5	5	10.5	5	20	6.5	5	11
Sodium (mg/l)	1	1	1	2.775	2.4	3.7	3.875	3.1	5.6
Phosphorus (mg/l)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Zinc (mg/l)	0.0075	0.0075	0.008	0.008	0.008	0.008	0.198	0.0075	0.77
Silica (mg/l)	4.25	2.9	4.8	4.775	3.4	5.4	4.525	3.4	5.1
T Silica (mg/l)	9	6.2	10	10.325	7.3	12	9.575	7.3	11
Chloride (mg/l)	0.805	0.69	0.91	1.85	1.8	1.9	1.975	1.8	2.2
Nitrate- Nitrite (mg/l)	0.065	0.065	0.06	0.325	0.06	0.465	0.368	0.225	0.525
Ammonia (mg/l as N)	0.0625	0.025	0.1	0.063	0.02	0.1	0.063	0.025	0.1
Total Kjeldahl N	1.7	0.5	4.6	1.65	0.5	4.1	1.65	0.5	3.9
Total Nitrogen (mg/l)	1.8275	0.59	4.69	2.038	0.59	4.59	2.08	0.925	4.32
Ortho-Phosphate	0.0875	0.05	0.1	0.088	0.05	0.1	0.088	0.05	0.1
Total Phosphate	0.3375	0.3	0.35	0.338	0.3	0.35	0.338	0.3	0.35
TN:TP	5.3839	1.6857	13.4	6.053	1.686	13.114	6.184	2.6429	12.343
DOC (mg/l)	0.96	0.5	1.6	0.903	0.52	1.6	1.22	0.72	2.4
Sulphate (mg/l)	0.5	0.5	0.5	5.475	4.6	6.8	4.25	3.3	5.5
2-MIB (ng/l)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Geosmin (ng/l)	0.7675	0.25	1.5	1.453	0.91	2.4	2.8	2	3.8
TOC (mg/l)	0.815	0.56	1.3	0.93	0.65	1.4	1.093	0.8	1.7

	Site 4			Site 5			Site 6			Site 8			Site 9		
Variable	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Chlorophyll-a	1.97	1	3.6	1.8	0.5	4.7	3.45	1	5.3	2.875	1	6.9	1.775	1	2.8
Phaeophytin-a (µg/l)	1	1	1	1	1	1	1	1	1	2.375	1	6.5	1.375	1	2.5
T Pigment (µg/l)	1.3	1	2.2	1.6	1	3.4	3.55	1	5.5	5.15	2.2	13	2.625	1	4.9
Coliforms	1230	727	1664	1719.6	1187	1986	2360	866	3990	4670	1203	6867	4962.3	1450	6867
E. coli (MPN/100	69.75	9	93	356	63	866	207.7	32	365	387.2	241	613	273.7	185	461
Turbidity (NTU)	2.6	1.4	4.5	2.8	1.8	3.5	2.788	0.85	6.2	2.25	1.6	3.9	7.15	2.6	15
TDS (mg/l)	48	40	63	64.5	49	82	96.25	52	170	110.25	33	245	86.5	53	170
SS (mg/l)	9.875	7.5	17	9.875	7.5	17	10.625	7.5	20	14.75	7.5	26	11.625	7.5	24
M Alkalinity (mg/l	45.25	39	50	55	45	66	61.75	45	81	56	44	66	60.5	49	72
Hardness (mg/l)	39	31	48	33.375	7.5	47	49	36	59	47	35	59	50.25	37	63
pH	6.93	6.6	7.37	6.968	6.58	7.25	6.815	6.55	7.1	7.113	6.59	7.7	6.743	6.57	6.9
Air Pressure	720.25	717.9	724.2	720.67	693.5	734.5	733.875	730.3	737.7	738.87	735.7	741.8	745.125	743.1	746.8
DO (%)	85.4	66	105.3	82.925	77.8	85	85.4	63.8	98.1	91.9	87.4	98.8	76.325	62.8	83.3
DO (mg/l)	7.695	5.38	10.45	7.158	5.88	8.53	6.998	4.27	9.12	7.783	6.7	9.53	6.578	4.71	8.4
SPC(mS/m)	124.62	119.2	132.6	126.9	71.1	159	155.92	148.1	170.1	148.62	130.7	158.3	161.87	133.9	177.2
COD (mg/l)	5	5	5	8.5	5	19	7.25	5	14	5	5	5	5	5	5
Aluminium (µg/l)	83	66	110	41.375	12.5	83	61.375	12.5	105	54.875	12.5	100	118.25	45	190
Calcium (mg/l)	8.6	6.8	11	6.088	0.45	9.4	9.725	6.4	12	8.95	5.8	12	9.575	5.5	13
Iron (µg/l)	338.75	220	395	153.625	2.5	285	172.5	135	245	142.5	115	195	318.75	270	400
Potassium (mg/l)	0.75	0.75	0.75	0.75	0.75	0.75	1.013	0.75	1.8	0.75	0.75	0.75	1.775	1.5	2
Magnesium (mg/l)	5.075	4.1	6	4.988	0.75	6.9	7.125	5.8	8.5	7.125	6	8.4	7.575	6.7	8.7
Manganese (µg/l)	19.5	5	35	6.75	5	12	13	5	32	5	5	5	9.5	5	15
Sodium (mg/l)	5.65	5.2	6.4	6.075	1	8.5	15.15	7.9	35	9.25	8.9	10	10.45	9.8	11
Phosphorus (mg/l)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Zinc (mg/l)	0.008	0.0075	0.008	0.331	0.008	1.3	0.008	0.0075	0.008	0.008	0.008	0.008	0.008	0.008	0.008
Silica (mg/l)	4.925	3.7	5.8	3.875	0.5	5.9	5.8	4.1	8.4	4.65	3.2	6.7	5.025	3.4	8.2
T Silica (mg/l)	10.475	7.9	12	8.6	2.1	13	12.35	8.8	18	9.725	6.8	14	10.8	7.3	18

Chloride (mg/l)	3.425	3.3	3.7	12.4	5.3	33	13.9	5.1	38	6.775	6	7.9	8.275	7.4	10
Nitrate-Nitrite (mg/l)	0.178	0.065	0.295	0.133	0.06	0.205	0.143	0.065	0.235	0.12	0.06	0.285	0.216	0.06	0.65
Ammonia (mg/l as	0.06	0.025	0.1	0.063	0.025	0.1	0.063	0.025	0.1	0.063	0.025	0.1	0.063	0.025	0.1
Total Kjeldahl N	1.9	0.5	4.5	2.25	1.6	3.7	4.125	1.6	10	2.575	1.8	3.8	4.5	1.8	8.2
Total Nitrogen	2.14	0.665	4.82	2.445	1.865	3.93	4.33	1.935	10.23	2.758	1.89	3.89	4.779	1.89	8.955
Ortho-Phosphate	0.088	0.05	0.1	0.088	0.05	0.1	0.088	0.05	0.1	0.088	0.05	0.1	0.088	0.05	0.1
Total Phosphate	0.338	0.3	0.35	0.338	0.3	0.35	0.338	0.3	0.35	0.338	0.3	0.35	0.338	0.3	0.35
TN:TP	6.384	1.9	13.771	7.211	5.329	11.229	12.602	5.6857	29.229	8.222	5.4	11.114	14.72	5.4	29.85
DOC (mg/l)	1.525	1.3	1.9	1.85	1.4	2.5	1.62	0.88	2.8	1.85	1.3	2.3	2.45	1.9	2.8
Sulphate (mg/l)	3.15	2	3.7	4.275	3.6	5.5	3.925	2.5	5.7	3.65	2.3	4.4	4.1	2.5	5.7
2-MIB (ng/l)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Geosmin (ng/l)	4.1	2.9	5.3	4.888	0.25	15	2.688	0.52	8.8	3.323	0.99	7.1	7.85	1.7	17
TOC (mg/l)	1.7	1.4	2.1	2	1.5	2.4	1.9	1.3	2.9	1.95	1.4	2.3	2.65	2	3.2

Marite River & Inyaka Dam	**Site10**			**Site11**		
Variable	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Chlorophyll-*a* (µg/l)	1.825	1	2.8	3.875	2.5	7.5
Phaeophytin-a (µg/l)	1	1	1	1.275	1	2.1
T Pigment (µg/l)	1.95	1	3.1	4.25	2.1	7.4
Coliforms (MPN/100 ml)	2779	2430	2987	326.3333	99	554
E. coli (MPN/100 ml)	125.25	68	231	1.5	0	2
Turbidity (NTU)	7.475	1.5	21	9.95	1.7	34
Total Dissolved Solids (mg/l)	67.75	32	165	98.75	43	220
Suspended Solids (mg/l)	10.625	7.5	20	24	7.5	56
M Alkalinity (mg/l CaCO3)	24	21	28	21.5	20	24
Hardness (mg/l CaCO3)	13.75	10	18	11.5	11	13
pH	6.525	5.9	7.47	6.4925	5.96	7.25
Air Pressure (MMHg)	705.325	701.1	707.5	691.225	686.1	694
Dissolved Oxygen (%)	79.425	70.2	95.6	75.425	62.4	89.4
Dissolved Oxygen (mg/l)	7.048	5.81	9.66	6.4475	5.31	8.2
Specific conductance (mS/m)	76.925	58.6	100.4	62.05	57.3	71.1
Chemical Oxygen Demand (mg/l)	5	5	5	5	5	5
Aluminium (µg/l)	132.75	56	185	34.125	12.5	61
Calcium (mg/l)	3.225	2.1	4.4	2.6	2.3	3.3
Iron (µg/l)	545	280	640	540	200	1440
Potassium (mg/l)	0.75	0.75	0.75	0.75	0.75	0.75
Magnesium (mg/l)	1.35	0.75	2.1	0.625	0.25	0.75
Manganese (µg/l)	10	5	14	117.75	5	435
Sodium (mg/l)	7.4	6.2	8.4	5.8	5.5	6.3
Phosphorus (mg/l)	0.25	0.25	0.25	0.25	0.25	0.25
Zinc (mg/l)	0.01	0.008	0.019	0.7828	0.0075	3.1
Silica (mg/l)	6.5	4.1	8.8	5.05	2.9	5.9
T Silica (mg/l)	13.95	8.8	19	10.8	6.2	13
Chloride (mg/l)	3.313	0.25	4.7	2.6375	0.25	3.8
Nitrate- Nitrite (mg/l as N)	0.169	0.065	0.37	0.065	0.065	0.065
Ammonia (mg/l as N)	0.063	0.025	0.1	0.1975	0.1	0.37
Total Kjeldahl Nitrogen (mg/l as N)	3.675	1.6	5	3.65	1.3	6.8
Total Nitrogen (mg/l as N)	3.906	1.69	5.395	3.9125	1.465	7.235
Ortho-Phosphate (mg/l)	0.088	0.05	0.1	0.0875	0.05	0.1
Total Phosphate (mg/l)	0.338	0.3	0.35	0.3375	0.3	0.35
TN:TP	11.789	4.829	17.583	11.7696	4.1857	20.671
Dissolved Organic Carbon (mg/l)	2.05	1.5	2.7	2.2	1.6	2.9
Sulphate (mg/l)	0.563	0.05	1.2	0.5	0.5	0.5
2-Methylisoborneol (ng/l)	0.25	0.25	0.25	0.25	0.25	0.25
Geosmin (ng/l)	3.85	1.8	7.3	2.125	1.5	3.4
Total Organic Carbon (mg/l)	2	1.6	2.2	2.2	1.9	2.5

Sand River	Site=7			Site=12		
Variable	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Chlorophyll-*a* (µg/l)	3.75	1	7.2	62.2	6.7	170
Phaeophytin-a (µg/l)	2.3	1	3.6	51.5	20	120
T Pigment (µg/l)	4.575	1	11	113.8	27	290
Coliforms (MPN/100 ml)	1195.5	435	1956	143593.7	15531	241960
E. coli (MPN/100 ml)	83.667	4	236	26425.3	1986	98040
Turbidity (NTU)	3.35	2	5.9	3.7	1.5	6.9
Total Dissolved Solids	159.25	82	225	161	69	285
Suspended Solids (mg/l)	11.125	7.5	22	10.4	7.5	19
M Alkalinity (mg/l CaCO3)	66.25	55	83	105.3	68	150
Hardness (mg/l CaCO3)	48.5	44	58	62	46	86
pH	7.243	6.59	7.58	6.9	6.56	7.1
Air Pressure (MMHg)	733.4	731.2	737.5	720.1	717.5	723.4
Dissolved Oxygen (%)	86	76	95.6	40.2	21.1	69
Dissolved Oxygen (mg/l)	6.75	6.25	7.62	3.7	1.54	7.2
Specific conductance	292.625	243.5	329.4	389.2	276.2	602
Chemical Oxygen Demand	5	5	5	19	12	30
Aluminium (µg/l)	158.75	12.5	460	31.3	12.5	60
Calcium (mg/l)	9.9	7.9	13	14.8	10	21
Iron (µg/l)	288.75	105	680	161	24	300
Potassium (mg/l)	1.988	0.75	3.4	3.7	1.6	6.7
Magnesium (mg/l)	6.8	5.9	7.3	7.2	5.7	9.6
Manganese (µg/l)	16.5	5	51	11	5	29
Sodium (mg/l)	27.65	8.6	38	44	31	67
Phosphorus (mg/l)	0.25	0.25	0.25	0.7	0.25	1.3
Zinc (mg/l)	0.008	0.0075	0.008	1.9	0.01	7.6
Silica (mg/l)	7.325	4.5	12	7.4	5.1	10
T Silica (mg/l)	15.65	9.6	26	15.8	11	21
Chloride (mg/l)	24.1	6.4	35	24.2	1.6	40
Nitrate- Nitrite (mg/l as N)	0.065	0.065	0.065	0.6	0.07	1.6
Ammonia (mg/l as N)	0.063	0.025	0.1	5	0.1	11
Total Kjeldahl Nitrogen	2.175	1.2	3.3	13.1	1.5	31
Total Nitrogen (mg/l as N)	2.303	1.29	3.39	18.7	3.15	38.4
Ortho-Phosphate (mg/l)	0.088	0.05	0.1	0.5	0.05	1.1
Total Phosphate (mg/l)	0.338	0.3	0.35	1.1	0.3	2.4
TN/TP	6.884	3.6857	9.686	16	10.5	26.5
Dissolved Organic Carbon	2.575	1.7	4.2	6.2	4.2	9.6
Sulphate (mg/l)	5.925	3.5	9.2	7.3	2.1	13
2-Methylisoborneol (ng/l)	0.25	0.25	0.25	5.7	0.25	22
Geosmin (ng/l)	1.255	0.25	3.5	6.8	4.1	8.2
Total Organic Carbon (mg/l)	2.8	1.9	4.6	8.2	4	16

Appendix 2-B: Data 2017, Mean, Maximum and Min of each site.

Sabie River	Site=1			Site=2			Site 3		
Variable	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Chlorophyll-a	1	1	1	1,633	1	2,9	1	1	1
Phaeophytin-a (µg/l)	1	1	1	1	1	1	1	1	1
T Pigment (µg/l)	1	1	1	1	1	1	1	1	1
Coliforms (MPN/100	797,66	172	1300	8576,6	5730	10120	8006,3	579	1439
E. coli (MPN/100 ml)	26,666	2	58	1218,3	548	2420	586,66	27	1046
Turbidity (NTU)	0,5733	0,4	0,92	1,633	1	2,5	5,367	1,3	12
Total Dissolved Solids	38,666	27	48	46,333	27	61	73	53	88
Suspended Solids (mg/l)	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5	7,5
M Alkalinity (mg/l	15	10	21	45,333	31	61	39,333	28	51
Hardness (mg/l CaCO3)	9,4	7,5	13	40	26	51	36,667	24	47
pH	6,6433	6,17	6,92	7,223	6,48	7,62	6,91	6,37	7,23
Air Pressure MHg)	649,43	645,3	653,4	676,56	670,6	681,4	706,33	699,1	711,
Dissolved O (%)	84,6	80	88,2	84,733	78	94,2	87,967	82,5	95,2
Dissolved O (mg/l)	8,45	8,01	8,78	8,04	7,42	8,7	8,15	7,64	9
SPC (mS/m)	31,1	23,6	40,6	99,467	78	120	97,933	82,1	115
COD (mg/l)	5	5	5	5	5	5	5	5	5
Aluminium (µg/l)	12,5	12,5	12,5	60	28	92	103,66	36	165
Calcium (mg/l)	1,3833	0,45	2,7	8,7	5,6	11	7,867	5,1	10
Iron (µg/l)	17,666	11	23	140	110	175	235	130	305
Potassium (mg/l)	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75	0,75
Magnesium (mg/l)	1,0667	0,75	1,7	5,333	3,6	6,9	4,9	3,2	6,4
Manganese (µg/l)	5	5	5	25,333	21	31	7	5	11
Sodium (mg/l)	1	1	1	1,8	1	2,2	2,733	2,2	3
Phosphorus (mg/l)	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25	0,25
Zinc (mg/l)	0,0075	0,007	0,008	0,008	0,008	0,01	0,008	0,007	0,01
Silica (mg/l)	3,9667	3,9	4,1	4,6	4,4	4,9	5,1	4,7	5,5
T Silica (mg/l)	8,4667	8,3	8,8	9,667	9,4	10	11	10	12
Chloride (mg/l)	6,92	0,66	16	6,733	1,4	14	8	1,8	17
Nitrate- Nitrite (mg/l as	0,1817	0,065	0,275	0,375	0,285	0,56	0,325	0,185	0,5
Ammonia (mg/l)	0,025	0,025	0,025	0,025	0,025	0,03	0,025	0,025	0,03
Total Kjeldahl Nitrogen	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Total Nitrogen (mg/l as	0,5567	0,28	0,8	0,75	0,36	1,08	0,7	0,37	1,02
Ortho-Phosphate (mg/l)	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
Total Phosphate (mg/l)	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35
TN/TP	1,5905	0,8	2,286	2,143	1,029	3,09	2	1,057	2,91
Dissolved Organic	0,3367	0,1	0,57	0,41	0,1	0,64	0,463	0,1	0,71
Sulphate (mg/l)	2,9	0,5	4,3	4,5	3,2	7,1	4,667	3,4	7,2
2- isoborneol (ng/l)	16,33	0,25	48	0,8	0,25	1,9	0,8	0,25	1,9
Geosmin (ng/l)	2,3	0,25	6,4	0,69	0,25	1	0,89	0,71	1,1
Total Organic Carbon	0,3767	0,1	0,56	0,54	0,3	0,76	0,83	0,59	1,2

Marite River & Inyaka Dam	Site 10			Site 11		
Variable	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Chlorophyll-a	2,467	1	3,4	1,7667	1	2,2
Phaeophytin-a (µg/l)	1	1	1	1	1	1
T Pigment (µg/l)	1,333	1	2	1,9	1	2,7
Coliforms (MPN/100 ml)	6565,667	2420	12997	904,6667	173	1725
E. coli (MPN/100 ml)	234	107	464	71	1	189
Turbidity (NTU)	13,633	4,7	30	24,6	1,8	70
Total Dissolved Solids (mg/l)	74,333	63	81	29,1667	7,5	64
Suspended Solids (mg/l)	7,5	7,5	7,5	7,5	7,5	7,5
M Alkalinity (mg/l CaCO3)	24,667	24	26	16	15	17
Hardness (mg/l CaCO3)	14,667	11	19	10,0333	8,2	13
pH	6,787	6,59	7,09	6,6133	6,37	6,81
Air Pressure (MMHg)	701,667	699,9	704,1	686,2333	684,9	688
Dissolved Oxygen (%)	87,433	85,6	88,5	67,1	61,4	74,4
Dissolved Oxygen (mg/l)	7,717	6,8	8,6	5,6533	5,1	5,96
Specific conductance (mS/m)	73,9	67,2	81,2	50,3333	48,8	52,4
Chemical Oxygen Demand (mg/l)	7	5	11	5	5	5
Aluminium (µg/l)	4866,667	115	14300	206,6667	32	500
Calcium (mg/l)	3,333	2,3	4,5	1,9	1,2	3
Iron (µg/l)	6240	890	16920	451,6667	285	640
Potassium (mg/l)	1,1	0,75	1,8	0,75	0,75	0,75
Magnesium (mg/l)	1,867	1,6	2,2	1	0,75	1,5
Manganese (µg/l)	9	5	11	17,3333	5	42
Sodium (mg/l)	7,8	7,1	8,7	4,8	4,5	5,2
Phosphorus (mg/l)	0,25	0,25	0,25	0,25	0,25	0,25
Zinc (mg/l)	0,008	0,008	0,01	0,0075	0,0075	0,008
Silica (mg/l)	30,633	7,9	73	5,1	4,6	6
T Silica (mg/l)	19	16	24	10,9333	9,8	13
Chloride (mg/l)	18,767	5,2	44	12,6333	3	29
Nitrate- Nitrite (mg/l as N)	0,258	0,145	0,38	0,2283	0,065	0,355
Ammonia (mg/l as N)	0,025	0,025	0,03	0,0333	0,025	0,05
Total Kjeldahl Nitrogen (mg/l as N)	0,5	0,5	0,5	0,5	0,5	0,5
Total Nitrogen (mg/l as N)	0,633	0,33	0,9	0,6117	0,34	0,905
Ortho-Phosphate (mg/l)	0,1	0,1	0,1	0,1	0,1	0,1
Total Phosphate (mg/l)	0,35	0,35	0,35	0,35	0,35	0,35
TN/TP	1,81	0,943	2,57	1,7476	0,9714	2,586
Dissolved Organic Carbon (mg/l)	1,967	1	2,8	1,4333	1,1	1,9
Sulphate (mg/l)	2,467	0,5	4,6	2,1	0,5	4,5
2-Methylisoborneol (ng/l)	0,967	0,25	2,4	1,9667	0,25	5,4
Geosmin (ng/l)	4,467	1,6	6	0,5267	0,25	0,68
Total Organic Carbon (mg/l)	2,633	2	3,6	2,0667	2	2,2

Sand River	Site 7			Site 12		
Variable	**Mean**	**Min**	**Max**	**Mean**	**Min**	**Max**
Chlorophyll-a	3	1	4,8	1,83	1	3,5
Phaeophytin-a (µg/l)	1	1	1	1,57	1	2,7
T Pigment (µg/l)	2,13	1	3,2	3,63	1	5,3
Coliforms (MPN/100 ml)	10526,33	5710	14670	73106,67	46110	111900
E. coli (MPN/100 ml)	137,33	86	169	6780,67	3282	11690
Turbidity (NTU)	22,9	2,7	36	19,2	3,6	28
Total Dissolved Solids (mg/l)	96,67	53	155	119,33	83	165
Suspended Solids (mg/l)	7,5	7,5	7,5	7,5	7,5	7,5
M Alkalinity (mg/l CaCO3)	57	56	58	57,67	46	76
Hardness (mg/l CaCO3)	37,33	37	38	38	32	46
pH	7,63	7,13	8,19	6,83	6,58	7,2
Air Pressure (MMHg)	728,5	724,7	730,5	714,9	708,5	718,3
Dissolved Oxygen (%)	83,67	76	88,3	68,63	65	73,3
Dissolved Oxygen (mg/l)	6,69	5,8	7,64	5,98	5,41	6,9
Specific conductance (mS/m)	187,47	174,9	202	191,83	167,6	234,9
Chemical Oxygen Demand	7,33	5	12	12	11	13
Aluminium (µg/l)	2657	91	5350	1164,33	53	2740
Calcium (mg/l)	8,47	8,2	8,8	9,1	7,7	11
Iron (µg/l)	636,67	110	930	2906,67	310	7390
Potassium (mg/l)	1,8	1,6	2	1	0,75	1,5
Magnesium (mg/l)	4,67	4,6	4,7	4,47	3,7	5,4
Manganese (µg/l)	5	5	5	5	5	5
Sodium (mg/l)	22	20	25	22,67	20	28
Phosphorus (mg/l)	0,25	0,25	0,25	0,25	0,25	0,3
Zinc (mg/l)	0,01	0,008	0,01	0,02	0,01	0
Silica (mg/l)	8,93	4,8	11	9,63	7,9	11
T Silica (mg/l)	19,33	10	24	20,67	17	24
Chloride (mg/l)	17,67	16	21	14,13	1,4	26
Nitrate- Nitrite (mg/l as N)	0,1	0,065	0,16	0,29	0,07	0,7
Ammonia (mg/l as N)	0,03	0,025	0,03	0,1	0,03	0,3
Total Kjeldahl Nitrogen (mg/l	0,5	0,5	0,5	0,5	0,5	0,5
Total Nitrogen (mg/l as N)	0,47	0,14	0,68	0,74	0,19	1,5
Ortho-Phosphate (mg/l)	0,1	0,1	0,1	0,1	0,1	0,1
Total Phosphate (mg/l)	0,35	0,35	0,35	0,35	0,35	0,4
TN/TP	1,34	0,4	1,94	2,12	0,53	4,1
DOC (mg/l)	2,13	1,6	2,9	2,83	2,2	3,4
Sulphate (mg/l)	5,57	3,9	7,2	5,67	3,6	7,9
2-Methylisoborneol (ng/l)	0,25	0,25	0,25	1,37	0,25	3,6
Geosmin (ng/l)	0,33	0,25	0,5	6,42	0,96	16
Total Organic Carbon (mg/l)	3	1,9	4,1	3,93	3,4	4,3

Appendix 3-A: Spearman Rank Correlations 2016 Data

Variable	Spearman Rank Order Correlations, Marked correlations are significant at p <,05								
	T Cya	T Bacil	T Chlor	T Chrys	T Dino	T Eugl	Chl-a	Phae	T pig
T Cya	1,0000	0,5708	0,3342	0,1473	0,1672	0,2466	-0,0129	-0,0773	-0,0962
T Bacil	0,5708	1,0000	0,4494	0,1419	0,0221	0,3016	0,2119	-0,0309	-0,0307
T Chlor	0,3342	0,4494	1,0000	-0,1131	-0,0508	0,2312	0,0587	0,0725	0,0274
T Chrys	0,1473	0,1419	-0,1131	1,0000	0,7618	-0,0294	0,0959	-0,0718	0,0717
T Dino	0,1672	0,0221	-0,0508	0,7618	1,0000	0,0249	0,0211	0,0158	0,2122
T Eugl	0,2466	0,3016	0,2312	-0,0294	0,0249	1,0000	0,1523	0,1478	0,1635
Chl-a	-0,0129	0,2119	0,0587	0,0959	0,0211	0,1523	1,0000	0,3827	0,5296
Phaeo	-0,0773	-0,0309	0,0725	-0,0718	0,0158	0,1478	0,3827	1,0000	0,6763
T pig	-0,0962	-0,0307	0,0274	0,0717	0,2122	0,1635	0,5296	0,6763	1,0000
Coli	0,0412	-0,1876	-0,1604	-0,2687	-0,0872	0,3374	0,2350	0,2841	0,3556
E.coli	0,1724	0,0547	0,2577	-0,3267	-0,1465	0,4835	-0,0126	0,3469	0,2160
Turb	0,1714	0,0607	0,1590	-0,0065	-0,0142	0,3489	0,0046	0,1602	0,1636
TDS	0,0242	0,2054	0,1714	-0,1060	-0,1287	0,1919	0,2330	0,1801	0,3459
SS	0,5015	0,5457	0,3095	0,0916	0,2037	0,3504	0,1525	-0,0921	-0,0427
EC	0,0584	0,2224	0,2917	-0,3540	-0,3047	0,4010	0,1664	0,4167	0,3446
M Alk	0,0403	0,1768	0,3247	-0,4056	-0,3791	0,3538	0,1141	0,4001	0,2973
Hard	-0,0287	0,1737	0,3050	-0,4141	-0,3761	0,2897	0,0662	0,1946	0,1651
pH	-0,2065	-0,2969	-0,2017	-0,0650	-0,0141	-0,0113	0,2881	0,0818	0,2261
Temp	-0,1641	-0,3391	-0,4081	0,1946	0,1785	-0,1124	0,2387	0,2367	0,3990
MMHg	0,0246	-0,0137	0,1202	-0,2562	-0,1175	0,3552	-0,0484	0,1917	0,1838
%DO	-0,0902	-0,1319	0,0586	-0,2567	-0,3000	-0,2356	-0,3072	-0,2217	-0,2865
DO	-0,0106	0,0745	0,2904	-0,3087	-0,3165	-0,0723	-0,3525	-0,3196	-0,4241
SPC	0,0384	0,1644	0,2491	-0,3803	-0,3466	0,3509	0,1394	0,4149	0,2805
COD	-0,1882	0,1166	0,1076	0,0293	-0,1693	0,2326	0,5558	0,4505	0,3274
Al	-0,0144	-0,2978	-0,4063	0,1130	0,1384	-0,0296	-0,1051	0,0077	0,1243
Ca	-0,0413	0,1777	0,2696	-0,4090	-0,4147	0,2486	0,0887	0,2315	0,1960
Fe	0,2187	-0,0555	-0,1110	0,1504	0,2693	0,1259	-0,1077	0,0928	0,2051
K	-0,0386	0,1360	0,1610	-0,2146	-0,1062	0,2376	0,3394	0,6079	0,5088
Mg	-0,1035	0,0857	0,2386	-0,4182	-0,3439	0,2475	0,0521	0,1497	0,0991
Mn	0,1230	0,1481	0,2645	0,0112	-0,0331	0,0085	-0,2499	0,0163	0,0311
Na	0,0809	0,0354	0,1556	-0,1073	-0,0253	0,3007	0,2881	0,5236	0,5401
P	0,0369	0,2725	0,2947	-0,0785	-0,0857	0,3383	0,3467	0,4774	0,3467
Zn	0,2439	0,3545	0,0339	0,0569	0,0328	0,4403	0,0823	0,1276	0,1074
Si	0,2577	0,0823	-0,0417	0,0487	0,1701	0,0939	0,1156	0,5304	0,3694
Tsi	0,2637	0,0866	-0,0352	0,0501	0,1660	0,0842	0,1264	0,5352	0,3764
Cl	-0,0849	-0,0992	0,0554	-0,2502	-0,1621	0,1560	0,1204	0,3172	0,4025
Nitra	-0,1471	-0,1146	-0,1829	-0,1973	-0,3075	-0,0801	-0,2135	-0,1744	-0,2443
Nitri	0,1578	-0,1052	0,0903	-0,1282	-0,1400	0,3202	0,1948	0,4140	0,2795
NO_3^+	-0,1028	-0,1164	-0,1086	-0,2367	-0,3440	0,0641	-0,0652	0,0668	-0,0533
NH_3	-0,2238	-0,2236	-0,3358	0,1775	0,1058	0,1202	0,4319	0,3574	0,4305
TKN	0,0925	0,0498	0,3284	-0,0799	-0,0527	0,1869	-0,0130	0,1983	0,1493
TN	0,0632	0,0473	0,2645	-0,0793	-0,0923	0,2133	0,0601	0,2732	0,2034
PO_4	0,2702	0,2121	0,1926	-0,0914	0,0590	0,3131	-0,1070	0,3093	0,0958
TP	0,2702	0,2121	0,1926	-0,0914	0,0590	0,3131	-0,1070	0,3093	0,0958
TN:TP	-0,0141	0,0008	0,2412	-0,0706	-0,1175	0,1651	0,0450	0,1926	0,1426
DOC	0,2511	0,2970	0,1319	0,2358	0,3244	0,3696	0,3711	0,4545	0,5035
SO_4	-0,2352	-0,0524	0,0343	-0,4207	-0,411496	0,07329	0,047669	0,246125	0,2173
MIB	0,00528	-0,078971	-0,057923	-0,054973	-0,060032	0,09133	0,242403	0,333753	0,2424
GM	0,45504	0,189200	0,355826	-0,135173	0,044534	0,52628	-0,007889	0,125409	0,0538
TOC	0,22261	0,179556	0,128240	0,158273	0,273062	0,34774	0,351869	0,496450	0,5849

Variables	Coli	E,coli	Turb	TDS	SS	EC	M Alk	Hard	pH
T Cya	0,0412	0,1724	0,1714	0,0242	0,5015	0,0584	0,0403	-0,0287	-0,2065
T Bacil	-0,1876	0,0547	0,0607	0,2054	0,5457	0,2224	0,1768	0,1737	-0,2969
T Chlor	-0,1604	0,2577	0,1590	0,1714	0,3095	0,2917	0,3247	0,3050	-0,2017
T Chrys	-0,2687	-0,3267	-0,0065	-0,1060	0,0916	-0,3540	-0,4056	-0,4141	-0,0650
T Dino	-0,0872	-0,1465	-0,0142	-0,1287	0,2037	-0,3047	-0,3791	-0,3761	-0,0141
T Eugl	0,3374	0,4835	0,3489	0,1919	0,3504	0,4010	0,3538	0,2897	-0,0113
Chl-a	0,2350	-0,0126	0,0046	0,2330	0,1525	0,1664	0,1141	0,0662	0,2881
Phaeo	0,2841	0,3469	0,1602	0,1801	-0,0921	0,4167	0,4001	0,1946	0,0818
T pig	0,3556	0,2160	0,1636	0,3459	-0,0427	0,3446	0,2973	0,1651	0,2261
Coli	1,0000	0,7145	0,2305	0,2163	-0,0578	0,3797	0,3656	0,2025	0,2658
E. coli	0,7145	1,0000	0,3288	0,2697	-0,0118	0,5887	0,5623	0,3612	0,1075
Turb	0,2305	0,3288	1,0000	0,3082	-0,0067	0,2805	0,2090	0,0166	-0,0379
TDS	0,2163	0,2697	0,3082	1,0000	-0,0515	0,6137	0,5813	0,4588	0,2140
SS	-0,0578	-0,0118	-0,0067	-0,0515	1,0000	0,0092	-0,0509	-0,0005	-0,1062
EC	0,3797	0,5887	0,2805	0,6137	0,0092	1,0000	0,9635	0,7717	0,2898
M Alk	0,3656	0,5623	0,2090	0,5813	-0,0509	0,9635	1,0000	0,8177	0,2599
Hard	0,2025	0,3612	0,0166	0,4588	-0,0005	0,7717	0,8177	1,0000	0,2938
pH	0,2658	0,1075	-0,0379	0,2140	-0,1062	0,2898	0,2599	0,2938	1,0000
Temp	0,3430	0,0725	0,2014	0,1960	-0,1975	0,0364	-0,0686	-0,2108	0,5413
MMHg	0,3426	0,4920	0,4756	0,3389	0,0573	0,6452	0,5594	0,3497	0,2050
%DO	-0,3309	-0,1514	0,0369	-0,0440	-0,0467	0,0600	0,1189	0,1980	-0,0921
DO	-0,4313	-0,1632	-0,1699	-0,2425	0,0579	-0,0041	0,0919	0,2469	-0,3466
SPC	0,4558	0,6203	0,3615	0,6281	-0,0236	0,9341	0,9104	0,7303	0,3058
COD	0,3267	0,2973	0,1682	0,3337	-0,1186	0,3580	0,3447	0,2527	0,1257
Al	0,4336	0,1705	0,5135	-0,0341	-0,2260	-0,0793	-0,1773	-0,2579	0,0636
Ca	0,1776	0,3155	-0,0108	0,4429	-0,0510	0,7483	0,8087	0,9815	0,2837
Fe	0,1818	0,0135	0,5376	-0,0092	0,0680	-0,0425	-0,1068	-0,1700	-0,0805
K	0,4127	0,3190	0,3632	0,4601	-0,0327	0,6471	0,5907	0,3592	0,1278
Mg	0,2348	0,4108	0,0156	0,4547	-0,0132	0,7550	0,7819	0,9337	0,3597
Mn	-0,2493	-0,0811	0,2606	0,0718	-0,0631	0,0674	0,1012	0,1804	-0,1973
Na	0,5079	0,4736	0,5800	0,5443	0,0279	0,6602	0,5591	0,3567	0,2213
P	0,2887	0,3416	0,2128	0,2690	0,0811	0,3471	0,3465	0,3466	0,0910
Zn	0,1035	0,0366	0,2977	0,1264	0,4310	0,0624	0,0471	0,1100	-0,1841
Si	0,2173	0,2280	0,1068	-0,0939	0,2433	0,1566	0,1360	0,0522	0,0679
Tsi	0,2129	0,2239	0,1056	-0,0966	0,2213	0,1439	0,1294	0,0473	0,0629
Cl	0,4980	0,4543	0,4861	0,4775	-0,1429	0,6264	0,5476	0,2614	0,2865
Nitra	0,1685	-0,0264	-0,0107	0,0391	-0,1816	0,0983	0,1759	0,3386	0,0364
Nitri	0,3157	0,3459	0,2926	0,1489	-0,0667	0,3150	0,3334	0,1853	-0,1296
NO_3 + NO_2	0,3479	0,1639	0,0678	0,1519	-0,2137	0,2743	0,3530	0,4027	-0,0105
NH_3	0,3784	-0,0365	0,1620	0,1716	-0,1806	-0,1110	-0,1502	-0,2177	0,2389
TKN	0,0302	0,2139	0,5040	0,2314	-0,1681	0,2124	0,2604	0,1682	-0,3224
TN	0,1105	0,2281	0,4940	0,2673	-0,2299	0,2536	0,3088	0,1860	-0,3345
PO_4	-0,0536	0,3232	-0,0607	-0,1825	0,3407	0,2288	0,2552	0,2285	-0,0204
TP	-0,0536	0,3232	-0,0607	-0,1825	0,3407	0,2288	0,2552	0,2285	-0,0204
TN:TP	0,0954	0,1765	0,4747	0,2606	-0,2947	0,2061	0,2667	0,1614	-0,3570
DOC	0,4457	0,2943	0,4056	0,4326	0,3801	0,3801	0,2729	0,0548	0,1042
SO_4	0,3651	0,4434	0,0776	0,4452	-0,2800	0,7488	0,7873	0,6927	0,3182
MIB	0,2718	0,2174	-0,1158	0,0263	-0,0874	0,1952	0,1844	0,0158	0,0579
GM	0,3021	0,3423	0,2096	-0,0531	0,3797	0,3059	0,3027	0,2577	0,0496
TOC	0,4579	0,3832	0,5015	0,4486	0,2398	0,4245	0,3035	0,0500	0,2355

Variables	Temp	MMHg	%DO	DO	SPC	COD	Al	Ca	Fe
T Cyan	-0,1641	0,0246	-0,0902	-0,0106	0,0384	-0,1882	-0,0144	-0,0413	0,2187
T Bacill	-0,3391	-0,0137	-0,1319	0,0745	0,1644	0,1166	-0,2978	0,1777	-0,0555
T Chloro	-0,4081	0,1202	0,0586	0,2904	0,2491	0,1076	-0,4063	0,2696	-0,1110
T Chryso	0,1946	-0,2562	-0,2567	-0,3087	-0,3803	0,0293	0,1130	-0,4090	0,1504
T Dino	0,1785	-0,1175	-0,3000	-0,3165	-0,3466	-0,1693	0,1384	-0,4147	0,2693
T Euglen	-0,1124	0,3552	-0,2356	-0,0723	0,3509	0,2326	-0,0296	0,2486	0,1259
Chl-a	0,2387	-0,0484	-0,3072	-0,3525	0,1394	0,5558	-0,1051	0,0887	-0,1077
Phaeo	0,2367	0,1917	-0,2217	-0,3196	0,4149	0,4505	0,0077	0,2315	0,0928
T pigm	0,3990	0,1838	-0,2865	-0,4241	0,2805	0,3274	0,1243	0,1960	0,2051
Coli	0,3430	0,3426	-0,3309	-0,4313	0,4558	0,3267	0,4336	0,1776	0,1818
E. coli	0,0725	0,4920	-0,1514	-0,1632	0,6203	0,2973	0,1705	0,3155	0,0135
Turb	0,2014	0,4756	0,0369	-0,1699	0,3615	0,1682	0,5135	-0,0108	0,5376
TDS	0,1960	0,3389	-0,0440	-0,2425	0,6281	0,3337	-0,0341	0,4429	-0,0092
SS	-0,1975	0,0573	-0,0467	0,0579	-0,0236	-0,1186	-0,2260	-0,0510	0,0680
EC	0,0364	0,6452	0,0600	-0,0041	0,9341	0,3580	-0,0793	0,7483	-0,0425
M Alk	-0,0686	0,5594	0,1189	0,0919	0,9104	0,3447	-0,1773	0,8087	-0,1068
Hard	-0,2108	0,3497	0,1980	0,2469	0,7303	0,2527	-0,2579	0,9815	-0,1700
pH	0,5413	0,2050	-0,0921	-0,3466	0,3058	0,1257	0,0636	0,2837	-0,0805
Temp	1,0000	0,2550	-0,3084	-0,7712	0,1381	0,1394	0,5651	-0,1919	0,3075
MMHg	0,2550	1,0000	0,1620	-0,0477	0,6683	-0,0030	0,3470	0,2920	0,2810
%DO	-0,3084	0,1620	1,0000	0,7802	0,0552	-0,3164	-0,0344	0,1626	-0,0667
DO	-0,7712	-0,0477	0,7802	1,0000	-0,0930	-0,3187	-0,4165	0,2208	-0,2496
SPC	0,1381	0,6683	0,0552	-0,0930	1,0000	0,3417	0,0498	0,7120	-0,0160
COD	0,1394	-0,0030	-0,3164	-0,3187	0,3417	1,0000	-0,1114	0,2833	-0,2080
Al	0,5651	0,3470	-0,0344	-0,4165	0,0498	-0,1114	1,0000	-0,2503	0,6839
Ca	-0,1919	0,2920	0,1626	0,2208	0,7120	0,2833	-0,2503	1,0000	-0,1535
Fe	0,3075	0,2810	-0,0667	-0,2496	-0,0160	-0,2080	0,6839	-0,1535	1,0000
K	0,2224	0,4662	-0,2542	-0,3506	0,6600	0,3582	0,1630	0,3731	0,2101
Mg	-0,1497	0,4207	0,2145	0,1942	0,7276	0,2423	-0,1864	0,8740	-0,2312
Mn	-0,3006	0,0279	0,1113	0,2635	0,0381	-0,1716	-0,0056	0,2195	0,4333
Na	0,4408	0,7175	-0,0938	-0,3688	0,7180	0,3489	0,3921	0,3324	0,3842
P	-0,1132	0,0065	-0,2867	-0,1540	0,3462	0,5580	-0,2319	0,3466	-0,1943
Zn	-0,2522	-0,1457	-0,0750	0,0671	0,0615	0,2022	-0,1041	0,1168	0,1233
Si	0,1932	0,0400	-0,0966	-0,2109	0,1796	0,0590	0,1681	0,0794	0,4298
Tsi	0,1852	0,0206	-0,0984	-0,2106	0,1657	0,0614	0,1571	0,0762	0,4269
Cl	0,3883	0,7523	0,0063	-0,2363	0,6459	0,1642	0,3566	0,2323	0,3563
Nitra	-0,1935	-0,0919	0,3106	0,2681	0,0557	0,1075	-0,0330	0,3580	-0,1825
Nitri	-0,0143	0,0613	-0,2554	-0,1794	0,3181	0,4653	0,1021	0,2279	0,1165
NO3,NO2	-0,1246	-0,0449	0,1118	0,0967	0,2300	0,3500	-0,0052	0,4525	-0,1240
NH3	0,5738	-0,1610	-0,4786	-0,6468	-0,0623	0,4645	0,2041	-0,1757	0,1033
TKN	-0,1996	0,2854	0,1723	0,1704	0,2705	0,0736	0,1376	0,1621	0,2140
TN	-0,1657	0,2492	0,0945	0,1082	0,3039	0,2055	0,1304	0,2070	0,2081
PO4	-0,3106	0,0492	0,0303	0,1836	0,1826	-0,0838	-0,2311	0,1954	0,0226
TP	-0,3106	0,0492	0,0303	0,1836	0,1826	-0,0838	-0,2311	0,1954	0,0226
TN:TP	-0,1746	0,2304	0,1338	0,1419	0,2553	0,2100	0,1409	0,1835	0,1973
DOC	0,3376	0,3764	-0,4579	-0,5717	0,4015	0,2948	0,3034	0,0503	0,4108
Sulp	0,0178	0,3487	0,2185	0,1009	0,7350	0,2794	-0,0087	0,7043	-0,1192
MIB	0,1948	0,0263	-0,2474	-0,2474	0,1947	0,3087	0,0595	0,0632	0,0052
Geos	-0,1899	0,2842	-0,1632	0,0488	0,2328	0,0500	-0,0244	0,2563	0,3277
TOC	0,4922	0,4637	-0,4369	-0,6405	0,4516	0,2716	0,3780	0,0387	0,4894

Variables	K	Mg	Mn	Na	P	Zn	Si	Tsi	Cl
T Cyan	-0,0386	-0,1035	0,1230	0,0809	0,0369	0,2439	0,2577	0,2637	-0,0849
T Bacill	0,1360	0,0857	0,1481	0,0354	0,2725	0,3545	0,0823	0,0866	-0,0992
T Chloro	0,1610	0,2386	0,2645	0,1556	0,2947	0,0339	-0,0417	-0,0352	0,0554
T Chryso	-0,2146	-0,4182	0,0112	-0,1073	-0,0785	0,0569	0,0487	0,0501	-0,2502
T Dino	-0,1062	-0,3439	-0,0331	-0,0253	-0,0857	0,0328	0,1701	0,1660	-0,1621
T Euglen	0,2376	0,2475	0,0085	0,3007	0,3383	0,4403	0,0939	0,0842	0,1560
Chl-a	0,3394	0,0521	-0,2499	0,2881	0,3467	0,0823	0,1156	0,1264	0,1204
Phaeo	0,6079	0,1497	0,0163	0,5236	0,4774	0,1276	0,5304	0,5352	0,3172
T pigm	0,5088	0,0991	0,0311	0,5401	0,3467	0,1074	0,3694	0,3764	0,4025
Coli	0,4127	0,2348	-0,2493	0,5079	0,2887	0,1035	0,2173	0,2129	0,4980
E. coli	0,3190	0,4108	-0,0811	0,4736	0,3416	0,0366	0,2280	0,2239	0,4543
Turb	0,3632	0,0156	0,2606	0,5800	0,2128	0,2977	0,1068	0,1056	0,4861
TDS	0,4601	0,4547	0,0718	0,5443	0,2690	0,1264	-0,0939	-0,0966	0,4775
SS	-0,0327	-0,0132	-0,0631	0,0279	0,0811	0,4310	0,2433	0,2213	-0,1429
EC	0,6471	0,7550	0,0674	0,6602	0,3471	0,0624	0,1566	0,1439	0,6264
M Alk	0,5907	0,7819	0,1012	0,5591	0,3465	0,0471	0,1360	0,1294	0,5476
Hard	0,3592	0,9337	0,1804	0,3567	0,3466	0,1100	0,0522	0,0473	0,2614
pH	0,1278	0,3597	-0,1973	0,2213	0,0910	-0,1841	0,0679	0,0629	0,2865
Temp	0,2224	-0,1497	-0,3006	0,4408	-0,1132	-0,2522	0,1932	0,1852	0,3883
MMHg	0,4662	0,4207	0,0279	0,7175	0,0065	-0,1457	0,0400	0,0206	0,7523
%DO	-0,2542	0,2145	0,1113	-0,0938	-0,2867	-0,0750	-0,0966	-0,0984	0,0063
DO	-0,3506	0,1942	0,2635	-0,3688	-0,1540	0,0671	-0,2109	-0,2106	-0,2363
SPC	0,6600	0,7276	0,0381	0,7180	0,3462	0,0615	0,1796	0,1657	0,6459
COD	0,3582	0,2423	-0,1716	0,3489	0,5580	0,2022	0,0590	0,0614	0,1642
Al	0,1630	-0,1864	-0,0056	0,3921	-0,2319	-0,1041	0,1681	0,1571	0,3566
Ca	0,3731	0,8740	0,2195	0,3324	0,3466	0,1168	0,0794	0,0762	0,2323
Fe	0,2101	-0,2312	0,4333	0,3842	-0,1943	0,1233	0,4298	0,4269	0,3563
K	1,0000	0,3347	0,0689	0,7513	0,4505	0,0940	0,3443	0,3455	0,5824
Mg	0,3347	1,0000	0,0321	0,3541	0,2769	0,0310	-0,0005	-0,0100	0,2906
Mn	0,0689	0,0321	1,0000	0,0588	0,0800	0,1601	0,2221	0,2327	0,1235
Na	0,7513	0,3541	0,0588	1,0000	0,3465	0,0804	0,3647	0,3522	0,8065
P	0,4505	0,2769	0,0800	0,3465	1,0000	0,5160	0,2382	0,2391	0,0387
Zn	0,0940	0,0310	0,1601	0,0804	0,5160	1,0000	0,3164	0,2974	-0,1561
Si	0,3443	-0,0005	0,2221	0,3647	0,2382	0,3164	1,0000	0,9967	0,1641
Tsi	0,3455	-0,0100	0,2327	0,3522	0,2391	0,2974	0,9967	1,0000	0,1549
Cl	0,5824	0,2906	0,1235	0,8065	0,0387	-0,1561	0,1641	0,1549	1,0000
Nitra	-0,1984	0,3160	0,0819	-0,2226	0,0297	0,0902	-0,2163	-0,2242	-0,2440
Nitri	0,4245	0,1120	-0,0086	0,3740	0,2912	0,2576	0,2298	0,2358	0,1456
NO3,NO2	0,0273	0,3307	0,0239	-0,0365	0,0968	0,0906	-0,1453	-0,1499	-0,1138
NH3	0,2586	-0,2464	-0,2097	0,2362	0,3828	0,2070	0,1141	0,1146	0,0356
TKN	0,3138	0,1230	0,3919	0,4150	0,3469	0,2284	0,0842	0,0865	0,2792
TN	0,3412	0,1116	0,3599	0,4208	0,3459	0,2500	0,0722	0,0732	0,2765
PO4	0,1620	0,2013	0,2146	0,0488	0,4365	0,3844	0,6436	0,6442	-0,0509
TP	0,1620	0,2013	0,2146	0,0488	0,4365	0,3844	0,6436	0,6442	-0,0509
TN/TP	0,2648	0,0895	0,3585	0,3653	0,2390	0,1531	-0,0471	-0,0447	0,2799
DOC	0,6629	0,0457	-0,0066	0,6801	0,3465	0,3380	0,3717	0,3525	0,4922
Sulp	0,4083	0,6747	0,0011	0,3342	0,0781	-0,1013	-0,0028	-0,0041	0,5168
MIB	0,2838	-0,0264	-0,1133	0,2054	-0,0304	-0,0600	0,2371	0,2379	0,1843
Geos	0,2338	0,1551	0,2059	0,2596	0,2640	0,3336	0,2383	0,2219	0,1353
TOC	0,6811	0,0412	0,0757	0,7757	0,3465	0,1978	0,4227	0,4141	0,6452

Variables	Nitra	Nitri	NO3/NO2	NH3	TKN	TN	PO4	TP	TN/TP
T Cyan	-0,1471	0,1578	-0,1028	-0,2238	0,0925	0,0632	0,2702	0,2702	-0,0141
T Bacill	-0,1146	-0,1052	-0,1164	-0,2236	0,0498	0,0473	0,2121	0,2121	0,0008
T Chloro	-0,1829	0,0903	-0,1086	-0,3358	0,3284	0,2645	0,1926	0,1926	0,2412
T Chryso	-0,1973	-0,1282	-0,2367	0,1775	-0,0799	-0,0793	-0,0914	-0,0914	-0,0706
T Dino	-0,3075	-0,1400	-0,3440	0,1058	-0,0527	-0,0923	0,0590	0,0590	-0,1175
T Euglen	-0,0801	0,3202	0,0641	0,1202	0,1869	0,2133	0,3131	0,3131	0,1651
Chl-a	-0,2135	0,1948	-0,0652	0,4319	-0,0130	0,0601	-0,1070	-0,1070	0,0450
Phaeo	-0,1744	0,4140	0,0668	0,3574	0,1983	0,2732	0,3093	0,3093	0,1926
T pigm	-0,2443	0,2795	-0,0533	0,4305	0,1493	0,2034	0,0958	0,0958	0,1426
Coli	0,1685	0,3157	0,3479	0,3784	0,0302	0,1105	-0,0536	-0,0536	0,0954
E. coli	-0,0264	0,3459	0,1639	-0,0365	0,2139	0,2281	0,3232	0,3232	0,1765
Turb	-0,0107	0,2926	0,0678	0,1620	0,5040	0,4940	-0,0607	-0,0607	0,4747
TDS	0,0391	0,1489	0,1519	0,1716	0,2314	0,2673	-0,1825	-0,1825	0,2606
SS	-0,1816	-0,0667	-0,2137	-0,1806	-0,1681	-0,2299	0,3407	0,3407	-0,2947
EC	0,0983	0,3150	0,2743	-0,1110	0,2124	0,2536	0,2288	0,2288	0,2061
M Alk	0,1759	0,3334	0,3530	-0,1502	0,2604	0,3088	0,2552	0,2552	0,2667
Hard	0,3386	0,1853	0,4027	-0,2177	0,1682	0,1860	0,2285	0,2285	0,1614
pH	0,0364	-0,1296	-0,0105	0,2389	-0,3224	-0,3345	-0,0204	-0,0204	-0,3570
Temp	-0,1935	-0,0143	-0,1246	0,5738	-0,1996	-0,1657	-0,3106	-0,3106	-0,1746
MMHg	-0,0919	0,0613	-0,0449	-0,1610	0,2854	0,2492	0,0492	0,0492	0,2304
%DO	0,3106	-0,2554	0,1118	-0,4786	0,1723	0,0945	0,0303	0,0303	0,1338
DO	0,2681	-0,1794	0,0967	-0,6468	0,1704	0,1082	0,1836	0,1836	0,1419
SPC	0,0557	0,3181	0,2300	-0,0623	0,2705	0,3039	0,1826	0,1826	0,2553
COD	0,1075	0,4653	0,3500	0,4645	0,0736	0,2055	-0,0838	-0,0838	0,2100
Al	-0,0330	0,1021	-0,0052	0,2041	0,1376	0,1304	-0,2311	-0,2311	0,1409
Ca	0,3580	0,2279	0,4525	-0,1757	0,1621	0,2070	0,1954	0,1954	0,1835
Fe	-0,1825	0,1165	-0,1240	0,1033	0,2140	0,2081	0,0226	0,0226	0,1973
K	-0,1984	0,4245	0,0273	0,2586	0,3138	0,3412	0,1620	0,1620	0,2648
Mg	0,3160	0,1120	0,3307	-0,2464	0,1230	0,1116	0,2013	0,2013	0,0895
Mn	0,0819	-0,0086	0,0239	-0,2097	0,3919	0,3599	0,2146	0,2146	0,3585
Na	-0,2226	0,3740	-0,0365	0,2362	0,4150	0,4208	0,0488	0,0488	0,3653
P	0,0297	0,2912	0,0968	0,3828	0,3469	0,3459	0,4365	0,4365	0,2390
Zn	0,0902	0,2576	0,0906	0,2070	0,2284	0,2500	0,3844	0,3844	0,1531
Si	-0,2163	0,2298	-0,1453	0,1141	0,0842	0,0722	0,6436	0,6436	-0,0471
Tsi	-0,2242	0,2358	-0,1499	0,1146	0,0865	0,0732	0,6442	0,6442	-0,0447
Cl	-0,2440	0,1456	-0,1138	0,0356	0,2792	0,2765	-0,0509	-0,0509	0,2799
Nitra	1,0000	0,0150	0,8761	-0,1044	0,0703	0,1244	-0,1581	-0,1581	0,1683
Nitri	0,0150	1,0000	0,4178	0,1513	0,2647	0,3863	0,1198	0,1198	0,3360
NO3, NO2	0,8761	0,4178	1,0000	0,0051	0,1070	0,2436	-0,1742	-0,1742	0,2797
NH3	-0,1044	0,1513	0,0051	1,0000	0,0603	0,1480	-0,1878	-0,1878	0,1247
TKN	0,0703	0,2647	0,1070	0,0603	1,0000	0,9672	0,1198	0,1198	0,9390
TN	0,1244	0,3863	0,2436	0,1480	0,9672	1,0000	0,0408	0,0408	0,9816
PO4	-0,1581	0,1198	-0,1742	-0,1878	0,1198	0,0408	1,0000	1,0000	-0,0950
TP	-0,1581	0,1198	-0,1742	-0,1878	0,1198	0,0408	1,0000	1,0000	-0,0950
TN:TP	0,1683	0,3360	0,2797	0,1247	0,9390	0,9816	-0,0950	-0,0950	1,0000
DOC	-0,3195	0,3142	-0,1234	0,2789	0,1545	0,1731	0,1166	0,1166	0,0970
Sulp	0,2097	0,1825	0,3504	-0,1178	0,0615	0,1233	0,0376	0,0376	0,1449
MIB	-0,1089	0,4269	0,1219	0,2503	0,1055	0,1842	0,0663	0,0663	0,1737
Geos	-0,0363	0,4317	0,1228	-0,0977	0,1690	0,1819	0,3368	0,3368	0,1129
TOC	-0,3706	0,3046	-0,1770	0,3285	0,2083	0,2048	0,1276	0,1276	0,1312

Variables	DOC	Sulp	MIB	Geos	TOC
T Cyan	0,251166	-0,235222	0,005282	0,455045	0,222610
T Bacill	0,297007	-0,052427	-0,078971	0,189200	0,179556
T Chloro	0,131904	0,034349	-0,057923	0,355826	0,128240
T Chryso	0,235842	-0,420777	-0,054973	-0,135173	0,158273
T Dino	0,324471	-0,411496	-0,060032	0,044534	0,273062
T Euglen	0,369665	0,073296	0,091339	0,526283	0,347747
Chl-a	0,371176	0,047669	0,242403	-0,007889	0,351869
Phaeo	0,454534	0,246125	0,333753	0,125409	0,496450
T pigm	0,503513	0,217364	0,242410	0,053891	0,584964
Coli	0,445777	0,365157	0,271808	0,302145	0,457951
E. coli	0,294385	0,443459	0,217454	0,342359	0,383293
Turb	0,405615	0,077696	-0,115881	0,209610	0,501508
TDS	0,432651	0,445295	0,026333	-0,053149	0,448669
SS	0,380109	-0,280087	-0,087463	0,379763	0,239805
EC	0,380148	0,748847	0,195294	0,305962	0,424522
M Alk	0,272920	0,787377	0,184436	0,302799	0,303570
Hard	0,054852	0,692706	0,015812	0,257719	0,050012
pH	0,104219	0,318250	0,057923	0,049665	0,235532
Temp	0,337635	0,017816	0,194838	-0,189974	0,492270
MMHg	0,376470	0,348722	0,026324	0,284283	0,463789
%DO	-0,457988	0,218509	-0,247463	-0,163259	-0,436947
DO	-0,571743	0,100931	-0,247456	0,048843	-0,640570
SPC	0,401559	0,735068	0,194795	0,232801	0,451661
COD	0,294890	0,279461	0,308757	0,050065	0,271665
Al	0,303455	-0,008716	0,059501	-0,024463	0,378094
Ca	0,050369	0,704315	0,063254	0,256300	0,038702
Fe	0,410810	-0,119226	0,005267	0,327774	0,489415
K	0,662918	0,408376	0,283874	0,233825	0,681119
Mg	0,045773	0,674771	-0,026419	0,155119	0,041276
Mn	-0,006617	0,001143	-0,113332	0,205964	0,075742
Na	0,680124	0,334237	0,205498	0,259653	0,775733
P	0,346573	0,078144	-0,030408	0,264062	0,346583
Zn	0,338030	-0,101389	-0,060027	0,333602	0,197868
Si	0,371714	-0,002894	0,237126	0,238336	0,422703
Tsi	0,352539	-0,004191	0,237910	0,221948	0,414171
Cl	0,492296	0,516814	0,184331	0,135358	0,645272
Nitra	-0,319586	0,209797	-0,108997	-0,036378	-0,370616
Nitri	0,314259	0,182585	0,426975	0,431757	0,304687
NO3 + NO2	-0,123488	0,350476	0,121935	0,122852	-0,177029
NH3	0,278924	-0,117863	0,250304	-0,097797	0,328549
TKN	0,154513	0,061522	0,105596	0,169077	0,208347
TN	0,173182	0,123385	0,184281	0,181993	0,204890
PO4	0,116631	0,037687	0,066368	0,336835	0,127661
TP	0,116631	0,037687	0,066368	0,336835	0,127661
TN:TP	0,097063	0,144991	0,173750	0,112921	0,131269
DOC	1,000000	0,096045	0,226580	0,356638	0,912591
Sulp	0,096045	1,000000	0,248694	0,006958	0,128728
MIB	0,226580	0,248694	1,000000	0,194859	0,226587
Geos	0,356638	0,006958	0,194859	1,000000	0,381729
TOC	0,912591	0,128728	0,226587	0,381729	1,000000

Appendix 3-B: Spearman Rank Correlations 2017 Data

Variable	Spearman Rank Order Correlations Marked correlations are significant at p <,05000								
	T Cyan	T Bacill	T Chloro	T Chryso	T Dino	T Euglen	Chl-a	P	T Pig
T Cyan	1,0000	0,1834	0,4999	0,5334	0,4320	0,0495	0,3000	-0,2400	0,3783
T Bacill	0,1834	1,0000	0,0182	-0,2949	-0,2847	0,0813	0,1060	-0,1024	0,0842
T Chloro	0,4999	0,0182	1,0000	0,4576	0,3639	0,5728	-0,0327	0,1695	0,2902
T Chryso	0,5334	-0,2949	0,4576	1,0000	0,5941	-0,0509	0,0740	-0,0970	0,1679
T Dino	0,4320	-0,2847	0,3639	0,5941	1,0000	0,1267	0,1644	-0,1382	0,1805
T Euglen	0,0495	0,0813	0,5728	-0,0509	0,1267	1,0000	0,1538	0,1469	0,2514
Chl-a	0,3000	0,1060	-0,0327	0,0740	0,1644	0,1538	1,0000	-0,1859	0,6188
P	-0,2400	-0,1024	0,1695	-0,0970	-0,1382	0,1469	-0,1859	1,0000	0,3374
T Pig	0,3783	0,0842	0,2902	0,1679	0,1805	0,2514	0,6188	0,3374	1,0000
Coli	-0,2269	0,0729	0,2011	-0,4264	-0,1536	0,3535	0,1696	0,2717	0,2771
E. coli	-0,3102	0,1880	0,1484	-0,3756	-0,1530	0,1755	0,0065	0,2836	0,0555
Turb	0,0358	0,0755	0,2800	-0,0667	0,0758	0,4331	0,2999	0,0992	0,3813
TDS	-0,1344	-0,0379	0,4893	-0,2175	-0,1344	0,6396	-0,2686	0,1840	-0,1318
EC	-0,0820	0,2082	-0,0789	-0,5236	-0,4755	0,2448	0,2712	0,2494	0,2880
M Alk	-0,0018	0,4954	0,1179	-0,4700	-0,4710	0,3575	0,1559	0,1702	0,2554
Hard	-0,0360	0,6000	-0,1233	-0,5031	-0,5340	0,1684	0,0589	0,1109	-0,0204
TEMP	0,1480	-0,0066	0,2982	-0,0235	0,2068	0,3445	0,2433	-0,0200	0,2859
MMHg	0,1470	0,2988	0,0214	-0,3026	-0,3012	0,2940	0,2664	0,0803	0,2917
%DO	0,0038	0,1612	-0,3934	-0,1905	-0,3298	-0,1566	0,1408	-0,2640	-0,1062
DO	-0,1881	0,1363	-0,5732	-0,2127	-0,4176	-0,3784	-0,0164	-0,1885	-0,2726
SPC	0,0360	0,3289	0,1908	-0,4451	-0,3547	0,3554	0,3312	0,2155	0,4162
pH	0,1517	0,2135	-0,2561	-0,3088	-0,2890	-0,1089	0,4107	-0,0427	0,3531
COD	-0,1578	-0,1619	0,2711	-0,1951	0,2125	0,5391	0,4384	0,2029	0,4922
Al	-0,0310	-0,0249	0,3746	0,0012	0,1442	0,5132	0,2139	0,0111	0,2139
Ca	-0,0401	0,5707	-0,0445	-0,4991	-0,5374	0,2109	0,0295	0,1409	-0,0107
Fe	0,0257	-0,2293	0,5017	0,2537	0,3087	0,6032	0,2143	0,0784	0,2009
K	-0,0220	0,0603	0,1774	-0,1951	-0,0963	0,4380	0,3244	0,1421	0,2529
Mg	-0,0449	0,6180	-0,2172	-0,5254	-0,5455	0,1172	0,0804	0,0439	-0,0693
Mn	-0,1103	0,0423	-0,0227	0,2261	0,0462	0,0126	-0,1615	0,0582	-0,1728
Na	0,2028	0,1147	0,4670	-0,1399	-0,0732	0,6484	0,3793	0,2612	0,5328
Si	-0,0774	-0,1693	0,5178	0,0582	0,0754	0,6815	0,1549	0,1939	0,2328
Zn	-0,1233	-0,0081	0,2685	-0,0676	-0,0963	0,2150	-0,1296	0,7171	0,3201
Tsi	-0,0900	-0,1457	0,5339	0,0335	0,1237	0,6941	0,1294	0,2297	0,2325
Cl	0,1536	0,2539	0,4140	0,0102	-0,1423	0,4449	-0,1940	0,0869	-0,0545
Fluor	0,2246	0,0604	-0,1047	-0,0307	-0,1257	-0,0326	0,4890	-0,0406	0,3078
Nitra	-0,2933	-0,0743	-0,4234	0,0142	-0,1578	-0,2661	0,1269	0,3595	0,1874
Nitri	0,0294	-0,0797	0,3964	-0,0970	0,1305	0,3545	0,1046	0,5000	0,4727
NO3/NO2	-0,2848	-0,0778	-0,4137	0,0101	-0,1398	-0,2523	0,1463	0,3588	0,2099
NH3	0,0868	-0,1137	0,2830	0,2425	0,1753	0,1757	-0,0309	0,5000	0,3374
TN:TP	0,0075	0,1621	-0,1090	0,0789	-0,3104	-0,0672	-0,0710	0,1250	-0,0746
DOC	0,1180	-0,2096	0,4165	0,1216	0,1554	0,4453	0,4573	0,3350	0,5741
Sulp	-0,0631	0,1875	-0,2796	-0,3500	-0,4679	-0,0720	0,4311	0,2895	0,4636
MIB	0,0177	-0,1182	0,0491	0,0526	0,4131	-0,1331	0,0858	-0,1182	0,0446
Geos	-0,0043	0,0003	0,0375	-0,0142	0,1384	0,1030	0,1457	0,1369	0,0634
TOC	0,1558	-0,2169	0,5543	0,1610	0,2418	0,5911	0,3651	0,2999	0,5138

Variables	Coli	E,coli	Turb	TDS	EC	M Alk	Hard
T Cyan	-0,2269	-0,3102	0,0358	-0,1344	-0,0820	-0,0018	-0,0360
T Bacill	0,0729	0,1880	0,0755	-0,0379	0,2082	0,4954	0,6000
T Chloro	0,2011	0,1484	0,2800	0,4893	-0,0789	0,1179	-0,1233
T Chryso	-0,4264	-0,3756	-0,0667	-0,2175	-0,5236	-0,4700	-0,5031
T Dino	-0,1536	-0,1530	0,0758	-0,1344	-0,4755	-0,4710	-0,5340
T Euglen	0,3535	0,1755	0,4331	0,6396	0,2448	0,3575	0,1684
Chl-a	0,1696	0,0065	0,2999	-0,2686	0,2712	0,1559	0,0589
P	0,2717	0,2836	0,0992	0,1840	0,2494	0,1702	0,1109
T Pig	0,2771	0,0555	0,3813	-0,1318	0,2880	0,2554	-0,0204
Coli	1,0000	0,8082	0,5690	0,5438	0,3224	0,2857	0,1227
E. coli	0,8082	1,0000	0,3501	0,3390	0,1687	0,2350	0,2316
Turb	0,5690	0,3501	1,0000	0,4890	0,2884	0,1803	0,0010
TDS	0,5438	0,3390	0,4890	1,0000	0,2611	0,2732	0,1359
EC	0,3224	0,1687	0,2884	0,2611	1,0000	0,6770	0,6320
M Alk	0,2857	0,2350	0,1803	0,2732	0,6770	1,0000	0,7909
Hard	0,1227	0,2316	0,0010	0,1359	0,6320	0,7909	1,0000
TEMP	0,5535	0,2304	0,8564	0,5028	0,1262	0,0278	-0,1688
MMHg	0,3055	0,0602	0,5217	0,2847	0,6099	0,5467	0,5271
%DO	-0,0694	-0,2122	-0,0842	-0,1289	0,0232	-0,0429	0,1113
DO	-0,4219	-0,2895	-0,6419	-0,4711	-0,0439	-0,0154	0,2100
SPC	0,5551	0,3538	0,4414	0,3552	0,7761	0,7670	0,6196
pH	0,2373	0,0184	0,2883	-0,1113	0,4754	0,3393	0,2293
COD	0,5987	0,3881	0,4921	0,3612	0,3362	0,2227	-0,0184
Al	0,6293	0,4030	0,9043	0,6318	0,1328	0,0858	-0,1319
Ca	0,1713	0,2674	0,0315	0,2021	0,6552	0,8237	0,9884
Fe	0,4019	0,2822	0,7000	0,4994	0,0119	-0,0117	-0,2328
K	0,3578	0,0385	0,3745	0,4026	0,3771	0,3680	0,1404
Mg	0,0716	0,1859	-0,0097	0,0779	0,5961	0,7363	0,9823
Mn	-0,0919	0,1423	-0,3375	-0,2382	-0,3565	-0,1657	-0,0748
Na	0,5111	0,1825	0,6609	0,5473	0,6293	0,5889	0,3433
Si	0,5875	0,3709	0,7320	0,7380	0,1515	0,1558	-0,0905
Zn	0,2685	0,2847	-0,0732	0,2034	0,2689	0,2849	0,2198
Tsi	0,6070	0,3857	0,7617	0,7592	0,1907	0,1857	-0,0617
Cl	0,0225	-0,0875	0,0645	0,4393	0,1707	0,3288	0,3638
Fluor	-0,2378	-0,2674	-0,3055	-0,3195	0,4063	0,2558	0,1779
Nitra	0,0099	0,1867	-0,1631	-0,4164	-0,0581	-0,0447	0,0389
Nitri	0,3965	0,3744	0,0651	0,2578	0,3119	0,2611	0,1279
NO3/NO2	0,0265	0,2041	-0,1563	-0,4146	-0,0514	-0,0431	0,0358
NH3	0,0107	0,0113	-0,1731	-0,0372	0,0334	0,0454	-0,0139
TN:TP	-0,4216	-0,1848	-0,5916	-0,2971	0,1789	0,2706	0,4759
DOC	0,4717	0,2218	0,6419	0,3341	0,3472	0,2412	-0,0796
Sulp	0,1134	0,0353	-0,0411	-0,2568	0,6593	0,5511	0,5331
MIB	0,0417	0,0453	0,0409	-0,1235	-0,4374	-0,4142	-0,4932
Geos	0,1227	0,2894	-0,0690	-0,0347	-0,0571	0,0771	0,0961
TOC	0,5046	0,2251	0,7427	0,5304	0,3158	0,2388	-0,0783

Variables	TEMP	MMHg	%DO	DO	SPC	pH	COD	Al	Ca
T Cyan	0,1480	0,1470	0,0038	-0,1881	0,0360	0,1517	-0,1578	-0,0310	-0,0401
T Bacill	-0,0066	0,2988	0,1612	0,1363	0,3289	0,2135	-0,1619	-0,0249	0,5707
T Chloro	0,2982	0,0214	-0,3934	-0,5732	0,1908	-0,2561	0,2711	0,3746	-0,0445
T Chryso	-0,0235	-0,3026	-0,1905	-0,2127	-0,4451	-0,3088	-0,1951	0,0012	-0,4991
T Dino	0,2068	-0,3012	-0,3298	-0,4176	-0,3547	-0,2890	0,2125	0,1442	-0,5374
T Euglen	0,3445	0,2940	-0,1566	-0,3784	0,3554	-0,1089	0,5391	0,5132	0,2109
Chl-a	0,2433	0,2664	0,1408	-0,0164	0,3312	0,4107	0,4384	0,2139	0,0295
P	-0,0200	0,0803	-0,2640	-0,1885	0,2155	-0,0427	0,2029	0,0111	0,1409
T Pig	0,2859	0,2917	-0,1062	-0,2726	0,4162	0,3531	0,4922	0,2139	-0,0107
Coli	0,5535	0,3055	-0,0694	-0,4219	0,5551	0,2373	0,5987	0,6293	0,1713
E. coli	0,2304	0,0602	-0,2122	-0,2895	0,3538	0,0184	0,3881	0,4030	0,2674
Turb	0,8564	0,5217	-0,0842	-0,6419	0,4414	0,2883	0,4921	0,9043	0,0315
TDS	0,5028	0,2847	-0,1289	-0,4711	0,3552	-0,1113	0,3612	0,6318	0,2021
EC	0,1262	0,6099	0,0232	-0,0439	0,7761	0,4754	0,3362	0,1328	0,6552
M Alk	0,0278	0,5467	-0,0429	-0,0154	0,7670	0,3393	0,2227	0,0858	0,8237
Hard	-0,1688	0,5271	0,1113	0,2100	0,6196	0,2293	-0,0184	-0,1319	0,9884
TEMP	1,0000	0,3871	-0,0606	-0,7248	0,3091	0,2880	0,3993	0,8584	-0,1397
MMHg	0,3871	1,0000	0,1827	-0,1952	0,6602	0,4080	0,1630	0,3241	0,5082
%DO	-0,0606	0,1827	1,0000	0,6743	-0,1091	0,4516	-0,1991	-0,1279	0,0454
DO	-0,7248	-0,1952	0,6743	1,0000	-0,2495	0,1530	-0,3922	-0,6694	0,1387
SPC	0,3091	0,6602	-0,1091	-0,2495	1,0000	0,4377	0,4626	0,3516	0,6676
pH	0,2880	0,4080	0,4516	0,1530	0,4377	1,0000	0,0478	0,1363	0,2051
COD	0,3993	0,1630	-0,1991	-0,3922	0,4626	0,0478	1,0000	0,4987	0,0340
Al	0,8584	0,3241	-0,1279	-0,6694	0,3516	0,1363	0,4987	1,0000	-0,0845
Ca	-0,1397	0,5082	0,0454	0,1387	0,6676	0,2051	0,0340	-0,0845	1,0000
Fe	0,5752	0,2089	-0,3007	-0,6261	0,2312	-0,0670	0,4744	0,7925	-0,1854
K	0,4107	0,3794	0,0768	-0,2059	0,5069	0,1193	0,4284	0,4283	0,1779
Mg	-0,1697	0,5412	0,1553	0,2548	0,5600	0,2649	-0,0901	-0,1612	0,9533
Mn	-0,3297	-0,3112	-0,0431	0,1684	-0,3250	-0,1019	-0,3169	-0,1912	-0,0984
Na	0,5331	0,7088	-0,1221	-0,4695	0,7975	0,2706	0,5561	0,5843	0,3902
Si	0,6447	0,2953	-0,1436	-0,5342	0,3655	0,0288	0,5860	0,8447	-0,0386
Zn	-0,2196	0,0244	-0,2197	-0,0325	0,2847	-0,2196	0,3533	-0,1465	0,2606
Tsi	0,6862	0,3091	-0,2013	-0,6047	0,4108	0,0035	0,6214	0,8688	-0,0046
Cl	0,0703	0,3996	-0,1658	-0,2282	0,2664	-0,3487	-0,0137	0,0755	0,3764
Fluor	-0,3350	0,0385	0,1237	0,3858	0,2507	0,3676	0,0812	-0,3511	0,1536
Nitra	-0,3429	-0,1600	0,0005	0,2994	-0,1004	0,1669	-0,0184	-0,2623	0,0042
Nitri	0,0252	-0,0103	-0,2924	-0,2112	0,3516	-0,0881	0,5396	0,0565	0,1693
NO3/NO2	-0,3324	-0,1658	-0,0078	0,2895	-0,0935	0,1748	0,0018	-0,2528	0,0008
NH3	-0,2242	-0,0897	-0,3264	-0,1544	0,0567	-0,2697	0,2029	-0,2612	0,0160
TN:TP	-0,7667	0,0000	-0,0816	0,4625	0,0282	-0,1723	-0,3357	-0,6594	0,4521
DOC	0,5149	0,4069	-0,2341	-0,5399	0,5153	0,2148	0,6407	0,5975	-0,0257
Sulp	-0,1999	0,4414	0,1534	0,3004	0,6039	0,5469	0,1883	-0,2386	0,5056
MIB	0,1624	-0,4787	0,1432	0,0197	-0,3498	-0,0199	0,1324	0,0875	-0,4859
Geos	-0,3199	-0,1431	-0,0453	0,2095	0,0491	-0,0854	0,1958	-0,0501	0,0989
TOC	0,6578	0,4413	-0,2893	-0,6865	0,5111	0,1229	0,6725	0,7362	-0,0176

Variables	Fe	K	Mg	Mn	Na	Si	Zn	Tsi	Cℓ
T Cyan	0,0257	-0,0220	-0,0449	-0,1103	0,2028	-0,0774	-0,1233	-0,0900	0,1536
T Bacill	-0,2293	0,0603	0,6180	0,0423	0,1147	-0,1693	-0,0081	-0,1457	0,2539
T Chloro	0,5017	0,1774	-0,2172	-0,0227	0,4670	0,5178	0,2685	0,5339	0,4140
T Chryso	0,2537	-0,1951	-0,5254	0,2261	-0,1399	0,0582	-0,0676	0,0335	0,0102
T Dino	0,3087	-0,0963	-0,5455	0,0462	-0,0732	0,0754	-0,0963	0,1237	-0,1423
T Euglen	0,6032	0,4380	0,1172	0,0126	0,6484	0,6815	0,2150	0,6941	0,4449
Chl-a	0,2143	0,3244	0,0804	-0,1615	0,3793	0,1549	-0,1296	0,1294	-0,1940
P	0,0784	0,1421	0,0439	0,0582	0,2612	0,1939	0,7171	0,2297	0,0869
T Pig	0,2009	0,2529	-0,0693	-0,1728	0,5328	0,2328	0,3201	0,2325	-0,0545
Coli	0,4019	0,3578	0,0716	-0,0919	0,5111	0,5875	0,2685	0,6070	0,0225
E. coli	0,2822	0,0385	0,1859	0,1423	0,1825	0,3709	0,2847	0,3857	-0,0875
Turb	0,7000	0,3745	-0,0097	-0,3375	0,6609	0,7320	-0,0732	0,7617	0,0645
TDS	0,4994	0,4026	0,0779	-0,2382	0,5473	0,7380	0,2034	0,7592	0,4393
EC	0,0119	0,3771	0,5961	-0,3565	0,6293	0,1515	0,2689	0,1907	0,1707
M Alk	-0,0117	0,3680	0,7363	-0,1657	0,5889	0,1558	0,2849	0,1857	0,3288
Hard	-0,2328	0,1404	0,9823	-0,0748	0,3433	-0,0905	0,2198	-0,0617	0,3638
TEMP	0,5752	0,4107	-0,1697	-0,3297	0,5331	0,6447	-0,2196	0,6862	0,0703
MMHg	0,2089	0,3794	0,5412	-0,3112	0,7088	0,2953	0,0244	0,3091	0,3996
%DO	-0,3007	0,0768	0,1553	-0,0431	-0,1221	-0,1436	-0,2197	-0,2013	-0,1658
DO	-0,6261	-0,2059	0,2548	0,1684	-0,4695	-0,5342	-0,0325	-0,6047	-0,2282
SPC	0,2312	0,5069	0,5600	-0,3250	0,7975	0,3655	0,2847	0,4108	0,2664
pH	-0,0670	0,1193	0,2649	-0,1019	0,2706	0,0288	-0,2196	0,0035	-0,3487
COD	0,4744	0,4284	-0,0901	-0,3169	0,5561	0,5860	0,3533	0,6214	-0,0137
Al	0,7925	0,4283	-0,1612	-0,1912	0,5843	0,8447	-0,1465	0,8688	0,0755
Ca	-0,1854	0,1779	0,9533	-0,0984	0,3902	-0,0386	0,2606	-0,0046	0,3764
Fe	1,0000	0,2843	-0,2661	0,0598	0,5284	0,8488	-0,0244	0,8427	0,0454
K	0,2843	1,0000	0,0618	-0,3168	0,5924	0,4790	0,2708	0,5148	0,2066
Mg	-0,2661	0,0618	1,0000	-0,0675	0,2887	-0,1434	0,1059	-0,1238	0,3600
Mn	0,0598	-0,3168	-0,0675	1,0000	-0,4183	-0,1091	-0,1098	-0,1610	-0,1172
Na	0,5284	0,5924	0,2887	-0,4183	1,0000	0,6522	0,2851	0,6812	0,4378
Si	0,8488	0,4790	-0,1434	-0,1091	0,6522	1,0000	0,1629	0,9842	0,1794
Zn	-0,0244	0,2708	0,1059	-0,1098	0,2851	0,1629	1,0000	0,1879	0,1872
Tsi	0,8427	0,5148	-0,1238	-0,1610	0,6812	0,9842	0,1879	1,0000	0,2044
Cl	0,0454	0,2066	0,3600	-0,1172	0,4378	0,1794	0,1872	0,2044	1,0000
Fluor	-0,1121	0,1154	0,1752	-0,0086	0,1090	-0,1431	0,0809	-0,1842	-0,2560
Nitra	-0,0959	-0,1627	0,0501	0,3641	-0,2825	-0,1238	0,2864	-0,1737	-0,4809
Nitri	0,1692	0,1421	0,0155	-0,1575	0,3635	0,2904	0,7171	0,3209	-0,0436
NO3/NO2	-0,0835	-0,1734	0,0457	0,3634	-0,2751	-0,1143	0,2859	-0,1639	-0,5025
NH3	0,1011	0,1421	-0,1036	0,1626	0,1136	0,0121	0,7171	0,0302	0,0642
TN:TP	-0,3456	-0,2053	0,4723	0,3248	-0,1336	-0,3855	0,2854	-0,4255	0,2520
DOC	0,7568	0,4629	-0,1389	-0,2381	0,7551	0,7078	0,2850	0,7032	-0,0130
Sulp	-0,1566	0,1776	0,5191	-0,0931	0,3350	-0,0847	0,2850	-0,0971	-0,1041
MIB	-0,0384	-0,0485	-0,5077	-0,1734	-0,2879	-0,0420	-0,0824	-0,0226	-0,5569
Geos	0,1610	-0,2062	0,0821	0,0613	0,0379	0,0657	0,2863	0,0351	-0,2309
TOC	0,8167	0,5294	-0,1490	-0,2779	0,8081	0,8309	0,2605	0,8493	0,1406

Variables	Fluor	Nitra	Nitri	NO3/NO2	NH3	TN/TP
T Cyan	0,2246	-0,2933	0,0294	-0,2848	0,0868	0,0075
T Bacill	0,0604	-0,0743	-0,0797	-0,0778	-0,1137	0,1621
T Chloro	-0,1047	-0,4234	0,3964	-0,4137	0,2830	-0,1090
T Chryso	-0,0307	0,0142	-0,0970	0,0101	0,2425	0,0789
T Dino	-0,1257	-0,1578	0,1305	-0,1398	0,1753	-0,3104
T Euglen	-0,0326	-0,2661	0,3545	-0,2523	0,1757	-0,0672
Chl-a	0,4890	0,1269	0,1046	0,1463	-0,0309	-0,0710
P	-0,0406	0,3595	0,5000	0,3588	0,5000	0,1250
T Pig	0,3078	0,1874	0,4727	0,2099	0,3374	-0,0746
Coli	-0,2378	0,0099	0,3965	0,0265	0,0107	-0,4216
E. coli	-0,2674	0,1867	0,3744	0,2041	0,0113	-0,1848
Turb	-0,3055	-0,1631	0,0651	-0,1563	-0,1731	-0,5916
TDS	-0,3195	-0,4164	0,2578	-0,4146	-0,0372	-0,2971
EC	0,4063	-0,0581	0,3119	-0,0514	0,0334	0,1789
M Alk	0,2558	-0,0447	0,2611	-0,0431	0,0454	0,2706
Hard	0,1779	0,0389	0,1279	0,0358	-0,0139	0,4759
TEMP	-0,3350	-0,3429	0,0252	-0,3324	-0,2242	-0,7667
MMHg	0,0385	-0,1600	-0,0103	-0,1658	-0,0897	0,0000
%DO	0,1237	0,0005	-0,2924	-0,0078	-0,3264	-0,0816
DO	0,3858	0,2994	-0,2112	0,2895	-0,1544	0,4625
SPC	0,2507	-0,1004	0,3516	-0,0935	0,0567	0,0282
pH	0,3676	0,1669	-0,0881	0,1748	-0,2697	-0,1723
COD	0,0812	-0,0184	0,5396	0,0018	0,2029	-0,3357
Al	-0,3511	-0,2623	0,0565	-0,2528	-0,2612	-0,6594
Ca	0,1536	0,0042	0,1693	0,0008	0,0160	0,4521
Fe	-0,1121	-0,0959	0,1692	-0,0835	0,1011	-0,3456
K	0,1154	-0,1627	0,1421	-0,1734	0,1421	-0,2053
Mg	0,1752	0,0501	0,0155	0,0457	-0,1036	0,4723
Mn	-0,0086	0,3641	-0,1575	0,3634	0,1626	0,3248
Na	0,1090	-0,2825	0,3635	-0,2751	0,1136	-0,1336
Si	-0,1431	-0,1238	0,2904	-0,1143	0,0121	-0,3855
Zn	0,0809	0,2864	0,7171	0,2859	0,7171	0,2854
Tsi	-0,1842	-0,1737	0,3209	-0,1639	0,0302	-0,4255
Cl	-0,2560	-0,4809	-0,0436	-0,5025	0,0642	0,2520
Fluor	1,0000	0,1804	0,2664	0,1992	0,1536	0,3892
Nitra	0,1804	1,0000	0,0513	0,9981	0,3423	0,3982
Nitri	0,2664	0,0513	1,0000	0,0911	0,5000	0,0227
NO3/NO2	0,1992	0,9981	0,0911	1,0000	0,3417	0,3871
NH3	0,1536	0,3423	0,5000	0,3417	1,0000	0,3752
TN:TP	0,3892	0,3982	0,0227	0,3871	0,3752	1,0000
DOC	0,1818	0,0455	0,3917	0,0572	0,3122	-0,2452
Sulp	0,6596	0,4274	0,2895	0,4359	0,2271	0,4452
MIB	-0,1152	-0,1368	0,1937	-0,1145	-0,1182	-0,5985
Geos	0,1980	0,2693	0,3536	0,2877	0,0513	0,1274
TOC	0,0037	-0,1116	0,3907	-0,1007	0,2601	-0,3422

Variables	DOC	Sulp	MIB	Geos	TOC
T Cyan	0,118055	-0,063158	0,017794	-0,004383	0,155802
T Bacill	-0,209611	0,187569	-0,118286	0,000388	-0,216927
T Chloro	0,416570	-0,279650	0,049184	0,037539	0,554303
T Chryso	0,121684	-0,350032	0,052658	-0,014204	0,161082
T Dino	0,155431	-0,467958	0,413179	0,138428	0,241806
T Euglen	0,445319	-0,072022	-0,133112	0,103078	0,591194
Chl-a	0,457354	0,431147	0,085881	0,145714	0,365132
P	0,335011	0,289567	-0,118224	0,136904	0,299930
T Pig	0,574123	0,463632	0,044649	0,063434	0,513833
Coli	0,471744	0,113467	0,041740	0,122736	0,504607
E. coli	0,221879	0,035367	0,045364	0,289435	0,225135
Turb	0,641946	-0,041170	0,040992	-0,069002	0,742752
TDS	0,334171	-0,256815	-0,123566	-0,034704	0,530416
EC	0,347296	0,659310	-0,437481	-0,057188	0,315824
M Alk	0,241217	0,551115	-0,414203	0,077193	0,238866
Hard	-0,079626	0,533170	-0,493242	0,096186	-0,078326
TEMP	0,514945	-0,199936	0,162434	-0,319943	0,657864
MMHg	0,406983	0,441482	-0,478734	-0,143146	0,441324
%DO	-0,234199	0,153460	0,143275	-0,045308	-0,289313
DO	-0,539978	0,300412	0,019749	0,209518	-0,686530
SPC	0,515331	0,603929	-0,349830	0,049182	0,511143
pH	0,214856	0,546995	-0,019934	-0,085433	0,122907
COD	0,640790	0,188373	0,132416	0,195812	0,672598
Al	0,597577	-0,238642	0,087502	-0,050114	0,736242
Ca	-0,025729	0,505642	-0,485941	0,098919	-0,017602
Fe	0,756896	-0,156602	-0,038486	0,161025	0,816793
K	0,462974	0,177625	-0,048537	-0,206278	0,529484
Mg	-0,138996	0,519187	-0,507795	0,082162	-0,149039
Mn	-0,238167	-0,093111	-0,173496	0,061385	-0,277970
Na	0,755128	0,335096	-0,287928	0,037911	0,808179
Si	0,707882	-0,084747	-0,042060	0,065704	0,830969
Zn	0,285041	0,285023	-0,082427	0,286355	0,260575
Tsi	0,703298	-0,097192	-0,022643	0,035106	0,849310
Cl	-0,013018	-0,104137	-0,556942	-0,230937	0,140666
Fluor	0,181858	0,659629	-0,115264	0,198070	0,003701
Nitra	0,045558	0,427429	-0,136898	0,269336	-0,111645
Nitri	0,391793	0,289567	0,193755	0,353668	0,390769
NO3/NO2	0,057248	0,435901	-0,114575	0,287757	-0,100706
NH3	0,312298	0,227111	-0,118224	0,051339	0,260188
TN:TP	-0,245254	0,445277	-0,598579	0,127409	-0,342265
DOC	1,000000	0,298149	-0,102185	0,161497	0,937460
Sulp	0,298149	1,000000	-0,391095	0,060436	0,121075
MIB	-0,102185	-0,391095	1,000000	0,165318	-0,090053
Geos	0,161497	0,060436	0,165318	1,000000	0,039316
TOC	0,937460	0,121075	-0,090053	0,039316	1,000000