Water Quality and Algal Assemblages of the Sabie River and Tributaries, Including the Inyaka Dam, in Relation to Land Use Practices

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by

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EXECUTIVE SUMMARY

BACKGROUND

Aquatic ecosystems across the world are under pressure due to the increasing demand for water. This increase in demand is linked to a growth in urbanization, and industrial and agricultural development. These trends are also visible in South Africa where the river systems are furthermore stressed by the dry climatic conditions. The deterioration of river water quality due to unsustainable anthropogenic activities is currently an important environmental concern worldwide. Deforestation, agricultural activities and urbanization modify land surfaces which can alter runoff volume, generate pollution and can increase algal production.

The Sabie River catchment forms part of the bigger Inkomati-Usuthu Water Management Area (IUWMA) under the management of the Inkomati Usuthu Catchment Management Agency (IUCMA) in Mpumalanga Province. It 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 changing topography, through the Kruger National Park (KNP) into Mozambique where it becomes part of the Incomati Basin. During the past few years the demographic population in the Bushbuckridge area have greatly increased due to rural migration and immigrants from neighbouring countries. It is therefore anticipated that not only will the water requirement for this area increase but also the impact on the water quality of the Sand and Marite Rivers and subsequently the Sabie River. If the Sabie River's quality decreases due to the developments it can impact negatively on the Kruger National Park's ecosystem and tourism. Both decreased flow and an increase in rural development will lead to deterioration of water quality, which may be exacerbated during low flows as a result of the impact of climate change. Since the water of the Sabie River has been classified as good it is essential that the water quality is preserved.

Land use types are directly related to human activities and have an impact on water quality. Understanding the relationship between land use and water quality is necessary for effective water management. Currently the water quality of the Sabie River is rated as good within the confines of the Park. The Sand River converges with the Sabie River in the KNP. The ecostatus of the Sand River is rated as moderately impaired, mostly due to the rural transformation of the upper reaches and the conservation land uses in the lower reaches (Roux and Selepe, 2011). With expected increases in population in the area the Sand River has the potential to also impact negatively on the Sabie River's water quality.

A water resource is an aquatic ecosystem that comprises the physical aquatic habitat with its biota, as well as physical, chemical and ecological processes. Although cyanobacterial blooms have previously been studied within the confines of the KNP, very little research has been published on phytoplankton assemblages in the rest of the Sabie River and its tributaries. With an increase in the population and in light of the current drought situation in South Africa, possible harmful algal blooms pose a real 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 (WTPs). Treatment costs will escalate and could potentially impact water quality if WTPs are not able to deal increased algal biomass. This will affect the health of the communities served by these plants.

Although aquatic ecosystems are frequently subjected to extreme events such as floods or droughts, it can recover, which suggests that rivers can be used without causing permanent damage or change to its physical and chemical properties. However, droughts have become more frequent and severe in many regions of the world due to climate change. Large parts of South Africa have suffered a climatological drought from 2013 to 2016. Variations in precipitation may result in more extreme drought-flooding hydrological patterns in future.

RATIONALE

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. Forestry, commercial plantations, cultivated commercial lands and urban land uses are suspected of having increasing water demand on the water resources of the catchment. The densely populated rural or semi-urban developments within the catchment have raised increasing concerns over the past two decades due to the substantial increase in population. Initially it was pressures from the increasing water demand (lifted by the Integrated Water Supply Scheme from the Inyaka Dam) that impaired the livelihoods of the still expanding Bushbuckridge community. Now, water quality has raised increasing concerns.

The year 2016 was a dry rainfall year followed by a high rainfall year during 2017. By conducting water quality assessments in terms of physical, chemical microbial and hydro-biological factors, as well as land utilization, water quality can be determined in such circumstances, therefore contributing to this field of study in terms of river health and usage as well as management of the catchment.

Anthropogenic activities influence water quality. It has become important to assess water issues with regards to land use, as indicator of human activities. Understanding the relationship between land use and water quality is helpful in identifying primary threats to water quality. This study was initiated to contribute to the knowledge on the influence of land use on water quality and to assess the effectiveness of conservation practices in the KNP, the compliance to the international agreement of the SADC countries (South Africa, Swaziland and Mozambique), and the extent of the protection of the water resources in the catchment.

Aim:

The aim of the study was to investigate the influence of land use on the current spatial and temporal changes in algal assemblages and water quality of the Sabie River, including its major tributaries, the Sand and Marite Rivers, as well as the Inyaka Dam.

Objectives:

- Investigate the current phytoplankton assemblages and water quality of the Sabie River catchment in terms of physical, chemical and biological factors.
- Asses the land cover and land uses practices of the Sabie River catchment.
- Relate the present phytoplankton assemblages and water quality of the Sabie River catchment to land cover and land use practices.

METHODOLOGY

Study area

Sampling was coordinated with that of the IUCMA, as it assisted in the sharing of data, thereby benefitting both the IUCMA and the North-West University. The sampling sites chosen were:

Site 1: Sabie headwaters in the Sabie River, upstream from the town of Sabie;
Site 2: In the Sabie River downstream from the Sabie wastewater treatment works;
Site 3: Upstream from Hazyview, at the confluence of the Sabie, Mac-Mac and Sabaan Rivers;
Site 4: Downstream of Hoxane in the Sabie River;
Site 5: Sabie River at Kruger Gate outside the KNP;
Site 6: Sabie River Bridge at Skukuza in the KNP;
Site 7: Sand River Bridge near Skukuza in the KNP;
Site 8: Lower Sabie River, downstream from the confluence of the Sand and Sabie Rivers in the KNP;
Site 9: Sabie River ±5 km from the Mozambique border in the KNP;
Site 10: Marite River downstream from the Inyaka water treatment plant;
Site 11: Inyaka Dam at the dam wall;
Site 12: Sand River downstream from the Tulamahashe wastewater treatment plant. This site is upstream of site 7 in the Sand River, near Skukuza.

Land use analysis

Spatial analyses were conducted through ArcGIS, using the 3D analyst, spatial analyst and network analyst extensions in ArcGIS for land use interpretation. The main spatial datasets used for interpretation were the 2013/2014, 72 Class South African National Land Cover Dataset (DEA/CARDNO) and the SRTM90 Digital Elevation Model (DEM)

(Global Mapper). To assess spatial land use influences on water quality, a multivariate redundancy analysis (RDA) was conducted in order to compare both datasets.

Sampling and analyses

Four sampling occasions were undertaken during 2016 and 2017, namely in January, April, July and October of each year. A surface grab sample of 9 litres of water was taken at each sampling site. Physical-chemical parameters were measured *in-situ* with an YSI multimeter (pH, temperature (°C), dissolved oxygen (%), dissolved oxygen (mg/l) and specific conductivity (mS/m). All other chemical and biological analyses were carried out according to SANAS (South African National Accreditation System – affiliated at ILAC), standard methods (APHA, 2013) by Rand Water's Analytical Services. Concurrently with the water quality parameter determinations, planktonic algal cell identification and concentrations were determined at the North West University using the sedimentation technique.

Statistical analyses

All statistical analyses were carried out using Statistica version 13, Dell Inc. (2016). Initially, the Kolomogorov-Smirnov and Lilliefors tests for normality were conducted to determine if the data were distributed parametrically. The data did not meet the assumptions of normality in the distribution of all variables and thus non-parametric statistics were applied. The Kruskal-Wallis analysis (comparison of multiple groups) was used to compare multiple independent groups. An agglomerative hierarchical cluster analysis was conducted on the total dataset for 2016 and 2017.

Multivariate analyses

All multivariate analyses were determined with Canoco 4.5 (Ter Braak, and Šmilauer, 2002). All data was Log transformed, i.e. log(y+1). Principal Component Analysis (PCA) was firstly determined. A canonical correspondence analysis (CCA) was used to elucidate the relationships between biological assemblages of species and their environment. Then a redundancy analysis (RDA), was performed to determine environmental quality and landscape relationships. A Monte Carlo permutation test (499 permutations) was used to determine the statistical validity of the CCA and RDAs.

RESULTS AND DICUSSION

During this study it was clear that forestry, commercial plantations and cultivated commercial land showed less adverse impacts on the water quality. The major negative influences were urban in nature. The urban village of Thulamahashe (site 12) had the most negative impact on the water quality of the Sand River, tributary of the Sabie River. This was a direct consequence of the effluent from the wastewater treatment plant on the Sand River and other water quality parameters that are indicative of organic pollution originating from anthropogenic activities. These parameters were either high or in exceedance of the target water quality range (TWQR). Sites in the Sabie River Sand River occurring within conservation areas showed an improvement in the various parameters which suggests a positive influence on water quality from this land use/ tenure class. This was especially evident from the decrease in water quality parameters of concern from site 12 to site 7 which indicated that there was an improvement in water quality due to conservational practices within the Sand River.

Most of the water quality variables measured during this study complied with the TWQR as prescribed by the South African Water Quality Guidelines (DWAF, 1996a&b). There were however variables that did not comply to the TWQR regardless the climatic and hydrological conditions that governed. Total coliforms, *E. coli*, ammonia, aluminium and chloride concentrations did not comply during 2016 and 2017. The water quality variables in the Sand River complied with the set RQOs for that segment but the phosphate levels in the Sabie River did not comply with the RQOs set for that segment.

This study also showed adverse effects of both the drought and the immediate post drought conditions. Low flow conditions during the drought period were associated with higher values for EC, which can be linked to higher salinity. During 2016 higher temperatures, nutrient (total phosphates) concentrations and chlorophyll-*a* concentrations (observed at most sites) supported higher algal cell numbers, which resulted in an increase in the trophic level of the water resource during the drought period. An increase in concentrations of total coliforms and *E. coli*, metals such as aluminium and iron, nutrient (nitrate-nitrite) concentrations and an increase in turbidity was observed during the immediate post drought conditions. Mixed effects were observed for dissolved oxygen, total dissolved solids and chlorophyll-a during the extreme drought. However, many of these effects were directly related to the characteristics of the waterbody and its catchment.

The most abundant group of algae in the Sabie, Sand and Marite Rivers, with the exception of the Inyaka Dam and site 12 in the Sand River, was the Bacillariophyceae. The genera in this group are cosmopolitan, and grow well in the low flowing, alkaline waters of moderate salinity and low to moderate organic pollution. These were typical conditions observed in most of the rivers investigated.

The Inyaka Dam phytoplankton population was dominated by only one genus, *Dinobryon*, of the Chrysophyceae during the dry conditions while the Cyanophyceae such as *Anabaena* and *Aphanocapsa* dominated during the post drought conditions due to an increase in nutrients. During the low flow conditions of 2016 the Cyanophyceae dominated at site 12, probably due to higher nutrient concentrations, higher temperatures and a more stagnant environment as a result of the drought. These environmental conditions changed during 2017 and the algal dominance changed to Chlorophyceae. There was also a decrease in the abundance of harmful bloom-forming genera such as *Anabaena* and *Oscillatoria* at site 12 in 2017. The genus *Cylindrospermopsis* was only observed during 2016.

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 presence of various genera (from various groups of phytoplankton) indicative of organic pollution confirmed the deteriorating water quality observed at many sites but especially site 12 in the Sand River during the dry year. Multivariate statistical analyses confirmed that the water quality had a significant influence on the genera that occurred in the catchment during both 2016 and 2017.

CONCLUSION

In this study the effect of both low and high flows on water quality during the immediate post drought conditions were investigated. The compliance of most of the water quality parameters to the TWQR indicates the resilience and assimilative capacity of the Sabie-Sand catchment. However, the long-term effects of successive droughts, longer durations over multiple years or decades, which can occur as a result of climate change, might require further research and modelling.

The findings of this study are consistent with many other studies on the effect of droughts and the immediate post drought conditions experienced during high rainfall. This study showed adverse effects of the immediate post drought conditions by the increase in total coliforms and *E. coli* concentrations, metals such as aluminium and iron concentrations, as well as nutrient concentrations. Variable effects were observed for dissolved oxygen, total dissolved solids and chlorophyll-a. However, many of these effects are a result of the characteristics of the waterbody and its catchment.

Although the cell concentrations of phytoplankton assemblages decreased significantly during the immediate post drought conditions, the compilation of these assemblages increased in diversity and the genera observed were indicative of high water quality with low nutrient concentrations. However, it did confirm the impact of organic pollution evident form the bacterial counts.

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2-MIB	2-Methylisoborneol
CCA	canonical correspondence analysis
Chl-*a*	chlorophyll-*a*
COD	chemical oxygen demand
DEM	digital elevation model
DIN	dissolved inorganic nitrogen
DO	dissolved oxygen
DOC	dissolved organic carbon
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
E. coli	*Escherichia coli*
EC	electrical conductivity
GIS	geographic information system
ILAC	International Laboratory Accreditation Cooperation
IUCMA	Inkomati-Usuthu Catchment Management Agency
IUWMA	Inkomati-Usuthu Water Management Area
KNP	Kruger National Park
M alkalinity	total alkalinity
NLC	national land cover
NMDS	non-metric multidimensional scaling
NTU	nephelometric turbidity unit
PCA	principal component analysis
PSP	point source pollution
RDA	redundancy analysis
RQO	resource quality objective
SANAS	South African National Accreditation System
SRTM	Shuttle Radar Topography Mission
TDS	total dissolved solids
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
TWQR	target water quality range
WWTP	wastewater treatment plan

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1 INTRODUCTION

The Sabie-Sand River catchment lies to the north of the greater Inkomati-Usuthu Water Management Area (IUWMA) in the north-eastern region of South Africa. This drainage basin is classified by the Department of Water and Sanitation (DWS) as the X3 secondary drainage region. The primary Sabie River flows from its headwaters that originate east of the Great Escarpment and runs through various towns such as Sabie, Hazyview and Skukuza, which is situated in the Kruger National Park (KNP); to its cross-boundary end in the Corumana Dam in Mozambique. Two of the tributaries of the Sabie River, namely the Sand and Marite rivers, in addition to the Inyaka Dam (also called the Injaka Dam) that is situated within the Marite River were considered important for this study. The surrounding communities are dependent on these water bodies for drinking water, agriculture and the development of industries. Drink water is treated by a treatment plant, but the system is either ineffective or broken. The substantial growth of these communities during the past two to three decades raises increasing concerns regarding the demand on the water resources (Tlou, 2011). Forestry, commercial plantations, cultivated commercial lands and urban land uses are also increasingly impacting on the water quantity and quality of the catchment.

A healthy river ecosystem is of great importance to the surrounding communities, and the monitoring of water quality and the anthropogenic disturbances on a water resource is essential to indicate the quantity and quality of the water source for domestic-, agricultural- and industrial-uses and to ensure the sustainable ecological flow of the river. This is particularly relevant during times of extreme climatic conditions such as the drought experienced during 2016 and the immediate post-drought periods of intense precipitation in 2017. According to Wilbanks *et al.* (2007), the effect of climate change will be felt particularly as increases in weather extremes such as floods and droughts. The availability of and demand for water resources are predicted to be affected the most as a result of climate change (Matondo *et al.*, 2005; Wetherald & Manabe, 2002). Floods occurring as flash floods, river floods, sewer floods and urban floods are dependent on the volume, intensity and timing of precipitation in addition to the preceding conditions of the rivers and drainage basins (Kundzewicz *et al.*, 2007). Different types of droughts can also be experienced. An extended, below-average precipitation is known as a meteorological drought. If soil moisture is depleted due to insignificant or erratic rainfall, it is known as an agricultural drought. A drought that starts to affect the surface and groundwater levels is known as a hydrological drought (Kundzewicz *et al.*, 2007). A combination of all of these is an ecological environmental drought.

Over the past decade, there has been an increasing number of studies done on the effects of drought on water quality. However, these were mostly conducted in North America, Europe and Australia. Yet the study of the impact of droughts in the southern African environment is also important. In general, droughts and the immediate post-drought periods are found to have significant effects on water quality. These effects are varied and depend on the characteristics of the waterbody and its catchment. However, droughts usually result in the deterioration of water quality in rivers and dams due to increased salinity (Yan *et al.*, 1996), acidification (Mosley *et al.*, 2014), temperature (Van Vliet & Zwolsman, 2008) and eutrophication (Mosley *et al.*, 2014). The impact of the drought in South Africa from 2013 until the 2015/2016 rainy season still needs to be determined (Savage, 2016 as cited by Africa Check, 2016).

The water quality of the Sabie River is vital to the economic health of the catchment, which serves the increasing number of rural communities in the area and agriculture, together with ecotourism, since the river flows through the KNP. Furthermore, the Sabie River System is an internationally shared watercourse with Mozambique and thus, South Africa has an obligation to meet international water requirements. The Sand and the Marite rivers are major tributaries of the Sabie River. Currently, the Inyaka Dam is the most significant impoundment in the Sabie-Sand Catchment, and it is at the heart of the Inyaka Regional Water Supply Scheme for the Bushbuckridge Local Municipality. During the past few years, rural communities in the Bushbuckridge area greatly increased in number due to rural migration and immigrants from neighbouring countries (Tlou, 2011). It is, therefore, anticipated that not only will the water requirement for this area increase but also the impact on the water quality of the Marite and Sand rivers and subsequently the Sabie River will magnify. In addition, the high ecological flow requirements of the KNP, together with the need to support rural development and improved service delivery to the rural sector, may lead to the system as a whole becoming water stressed. Improved operation of the system will be necessary if all the water requirements, including the Ecological Reserve, are to be met (Beumer & Mallory, 2014). Currently, the water quality of the Sabie River is rated as good within the confines of the park. The ecostatus of the Sand River is rated as moderately impaired, mainly due to the rural transformation of the upper reaches and the conservation land uses in the lower reaches (Roux & Selepe, 2011). Water quantities and qualities vary drastically when considering the inflow and abstraction of different natural and anthropogenic activities.

Yu *et al.* (2016) demonstrated that in the wet season, the correlation between land use and water quality had a high significance. In the dry season, land use vs water quality and water quantity had an even higher significant correlation across a broader range of land uses. It can be expected that river water quality will decline as land accessibility improves. River health is influenced by the fact that in low-lying areas, urban boundaries expand and land is more readily accessible for development through agriculture, plantation forestry and pastoral development (Larned *et al.*, 2004). Larned *et al*. (2004) also found that river health followed a deteriorating trend within developed catchments compared with undeveloped catchments.

Furthermore, it was observed that the algal assemblages of the river systems in the Sabie-Sand catchment have not been thoroughly investigated, especially in terms of land use and a drier rainfall year – low or no flow circumstances followed by high flow circumstances. An overview by Van Wyk *et al*., (2001) emphasises that both monitoring and studies of the phytoplankton occurring in the catchment are non-existent. Algae have a history of use in ecological assessments. Dominant genera in algal groupings change not only spatially but also seasonally as physical, chemical and biological conditions in the waterbody change (Wetzel, 2001). These organisms have a high rate of reproduction that allows them to respond rapidly to changing environmental conditions such as droughts (Sharov, 2008), and they are, therefore, valuable indicators of the health of waterbodies. The main factors that can affect the diversity of freshwater algae are climate, soil and hydrology of the area, together with anthropogenic factors such as land use. The species composition and biomass of algae are evaluated in assessments of aquatic ecosystems to determine threats to drinking water and the recreational uses of water resources (Stevenson, 2014).

As drier and hotter conditions occur, surface water temperatures rise. This, in time, promotes algal blooms (despite enhanced phosphorous removal in wastewater treatment plants [WWTPs]), increased fungal and bacterial content and enhanced transference of volatile and semi-volatile compounds such as pesticides, dioxins, ammonia and mercury into the atmosphere from surface water bodies (Chambers *et al.*, 2001; Harding & Paxton, 2001; Kumagai *et al.*, 2002; Schindler, 2001; Van Ginkel *et al.*, 2000; Wade *et al.*, 2002). Robarts *et al.* (2005) (as cited by Kundzewicz *et al.*, 2007). Moulton and Cuthbert (2000) mentioned that this increase in fungi and bacteria can possibly lead to bad tastes and odours and the resultant increase in the use of chemicals for purification of drinking water. In drought-prone areas, the deterioration in water quality will increase the frequency of water-related diseases, for example, diarrhoea (Harker *et al.*, 2004; Patz, 2001).

Although cyanobacterial blooms have previously received much attention within the confines of the KNP, very little research has been published on phytoplankton assemblages in the rest of the Sabie River and its tributaries. With the increase in the population and considering the impact of climate change, harmful algal blooms pose a real threat to the health of rural communities. Not only will algal blooms negatively affect both domestic and wild animals but they also have the potential to cause numerous problems within water treatment plants, which will affect the quality of the drinking water of the communities served by these treatment plants.

River health associated with water quality is assessed by measuring certain components or water parameters that include turbidity and suspended solids, toxic substances, temperature, heavy metals, dissolved oxygen, organic and inorganic chemicals, conductivity, total dissolved solids, major ions, pH, alkalinity and salinity (Dallas & Day, 2004; Karr & Chu, 1997). Ensuring that these parameters remain within appropriate limits can safeguard ecosystem protection. By conducting water-quality assessments in terms of land utilisation and the presence of algal, physical-chemical and microbial contaminants, the quality and quantity of source water can be determined within extreme circumstances and thus greatly contribute to catchment management, water purification and community development.

1.1 Rationale

Initially, it was the pressures of a shortage in water supply from the Inyaka Dam that impaired the livelihoods of the continually expanding Bushbuckridge community. The water restrictions imposed by the Integrated Water Supply Scheme have now been lifted. However, now, the quality of the water to both the Bushbuckridge community and the KNP has raised increasing concerns. As a compliance effort towards the conservation practices of the KNP, the international water agreement between South Africa, Swaziland and Mozambique and the protection of catchment water resources, this study was initiated to investigate the influence of land use on water quality during extreme climatic conditions. The water quality of the river system in this area has not yet been thoroughly investigated, especially in terms of land use and during both high and low rainfall years. The year 2016 was a dry rainfall year while 2017 demonstrated high rainfall. By conducting water-quality assessments in terms of physical, chemical, microbial and hydro-biological factors in association with land utilisation, water quality can be determined, thus greatly contributing to knowledge of river health, river usage and management of the catchment. It became increasingly important to assess water issues in regard to land use as an indicator of human activities.

1.2 Aim

The overall objective of the study is to investigate the influence of land use on the current spatial and temporal changes in phytoplankton community composition and water quality of the Sabie River, and its major tributaries, the Sand and Marite rivers, including the Inyaka Dam.

1.3 Objectives

The aims of the study are as follows:

- Investigate the current phytoplankton community composition changes and water quality of the Sabie River catchment in terms of physical, chemical and biological factors
- Assess the land-cover and land-use practices of the Sabie River catchment
- Relate the present phytoplankton community composition and the water quality of the Sabie River catchment to land-cover and land-use practices

2 STUDY AREA

2.1 Boundaries

The Sabie-Sand Catchment is one of three sub-catchments that fall under the Inkomati-Usuthu Water Management Area (IUWMA). As seen in Figure 2-1, the Sabie-Sand Catchment lies in the north of the IUWMA partly within the Kruger National Park (KNP) where the Sand River joins the Sabie River as one of its main tributaries, (Pollard & Du Toit, 2011). The Marite River, another tributary of the Sabie River, flows downstream from the Inyaka Dam and forms part of the Inyaka Dam Water Supply Scheme (Tlou, 2011). The main urban and semi-urban areas in the Sabie-Sand sub-catchments (hereon referred to as the catchment) include the towns of Sabie, Hazyview and Skukuza. Situated between the Marite and Sand rivers, Bushbuckridge is a densely populated, rural or semi-urban development within the catchment. The mountains along the Great Escarpment form the western boundary of the catchment and include Mauchsberg (2 209 m), the Formosa Mountains (2 232 m) and Mount Anderson (2 284 m). The headwaters of the Sabie River start below Mauchsberg near the Long Tom Pass and run eastwards through Sabiepoort in the Lebombo Mountains at the border between South Africa and Mozambique.

The Sabie River flows through three distinct land-use zones. Firstly, the river flows through a forestry-dominated mountainous area. Secondly, the river flows through a hilly and undulating landscape dominated by dense settlements and smallholder farming and thirdly, through a large conservation area represented by the KNP and the Sabie Sands Game Reserve. The Sabie River in Mozambique decants into Corumana Dam and the Incomati River near the town of Moamba in Southern Mozambique (Pollard & Du Toit, 2011). These rivers form part of the IUWMA and contribute to an international water course, the Incomati Basin. This is a shared basin with a transboundary nature reserve straddling South Africa, Swaziland and Mozambique (Tlou, 2011). Water management within the catchment requires that certain international obligations be fulfilled by South Africa in terms of cross-border flow, especially in regard to planners, managers and everyday decision-makers (Ashton *et al.*, 2006). Not only is the Tripartite Interim Agreement applicable to this study area but also, according to Pollard and Du Toit (2011), a large portion of this area falls within the Great Limpopo Transfrontier Conservation Area, which was promulgated in 2002. It is, therefore, very important for South Africa to adhere to the freshwater agreements and responsibilities pertaining to water quality and quantity. Table 2-1 and Figure 2-2 provide brief information regarding the habitat and locality of the 12 sites that were sampled during this study. Appendix A presents photographs of each site taken during the fieldwork conducted in 2016/2017.

Table 2-1: Description of the water-quality assessment sites of the Sabie, Sand and Marite Rivers.

Site name and abbreviation		Coordinates	Description
1. Sabie River Headwaters	Sabie HW	-25.14747, 30.66872	Site 1 is situated in the mountainous Sabie River headwaters above the town of Sabie. Site 1 serves as a convenient reference point to compare land use impacts further down the Sabie River. Since the only major influence is forestation, most water-quality parameters indicate a stream of pristine conditions.
2. Sabie River Wastewater Treatment	Sabie WWT	-25.07386, 30.85080	Site 2 is situated at a high relief along the Sabie River between forestry plantations. At the time of sampling, Site 2 was mostly surrounded by deforested plantations. Site 2 lies ~6.7 km below the Sabie WWTP, which is situated at 25.0912441S; 30.7942149E.S.
3. Sabie River Hazyview	Sabie BH	-25.03008, 31.02530	Site 3 is situated before the town of Hazyview and at the confluence of the Sabie River with the Mac-Mac River. The main adjacent land-use influences are forestry and plantation practices.
4. Sabie River Hoxane Water Treatment Works	Sabie Hoxane	-25.01933, 31.21733	Site 4, which is within the Sabie River, is situated in a lower moderate relief (flatter region) ~1.2 km below the Hoxane Water Treatment Works, which are located at 25.015117S; 31.208857E.
5. Sabie River Kruger Gate	Sabie KNP Gate	-24.97972, 31.48275	Site 5 designates the section of the Sabie River at the Kruger Gate of the KNP where sampling was conducted from a high bridge above the river. Site 5 has a prevailing low relief with sparse riparian vegetation and progressive sediment accumulation.
6. Sabie River Skukuza	Sabie Skukuza	-24.99088, 31.60175	Site 6 is a Sabie River site at Skukuza in the KNP just after the confluence with the intermittent Nwaswitshaka stream (a tributary of the Sabie River that was dry throughout the sampling time frame).

Site name and abbreviation		Coordinates	Description
7. Sand River Kruger National Park	Sand KNP	-24.96777, 31.62561	Site 7 pinpoints the Sand River near Skukuza within the KNP before its confluence with the Sabie River. This site clearly distinguishes the origin of the river's name, with the river flowing/transecting through thick sandy beds.
8. Lower Sabie River after Sabie-Sand confluence	Sabie Lower	-24.97527, 31.76805	Site 8 is located opposite the exclosure sites in the KNP next to the Nkuhlu picnic spot. This point within the Sabie River has a very broad, dendritic channel and is situated below the confluence of the Sabie and Sand rivers at Lower Sabie in the KNP.
9. Sabie River bordering Mozambique	Sabie Moz	-25.16041, 31.99875	Site 9 is situated at the lowest relief of all sampling points in the Sabie River, 5 km before the border with Mozambique in the KNP.
10. Marite River	Marite	-24.96081, 31.10850	Site 10 lies above Hazyview within the Marite River ~ approximately 18.2 km from where the Marite River flows from the Inyaka Dam. In this reach, the river traverses through natural bushy vegetation and over several bare rocky outcrops.
11. Inyaka Dam at the dam wall	Inyaka Dam Wall	-24.88538, 31.08469	Site 11 is situated in the Inyaka Dam along the dam wall at the dam sluice/outlet.
12. Sand River Thulamahashe Wastewater Treatment Plant	Sand Thulamahashe	-24.72186, 31.23716	Site 12 is situated underneath a high-water train bridge within the Sand River. The site is ~0.5 km below the Thulamahashe WWTP, which is located at 24.720727S, 31.231072E.

Sites sampled from February 2016 to October 2017

2.2 Topography and climate of the study area

The Sabie Catchment stretches west to east from the Drakensberg Escarpment to the Lebombo Mountains bordering Mozambique. The elevation along the Drakensberg Escarpment is approximately 2200 m and gradually decent to an altitude of 150 in the east in the catchment. Whereas, the western side of the catchment is mountainous and the topography towards the east flattens to a pediplain, commonly known as the Lowveld. A pediplain refers to an extensive flat terrain formed through the weathering, transportation and deposition of bedrock material below a mountain slope. The pediplain is therefore characterised by a coalescence of numerous pediments forming a gentle plain (Oberlander, 1989 as cited by White, 2004).

Elevation and topography have a major effect on the climate of the area. Whereas, the western side has a temperate to subtropical climate, the eastern side is semi-arid and hot (Smits et al., 2004). According to the Water Resources Study conducted in 2012 (WR, 2012) the average rainfall within the catchment decrease along the topographical gradient from between 1500-900 mm/a in the mountainous areas to between 600-348 mm/a through the foothills and towards the lower, flatter reaches of the Sabie River catchment. Figure 2-4 indicates the monthly rainfall for the years 2002-2008 represented by the Inyaka Dam Rainfall Station (western side) and the Skukuza Rainfall Station in the KNP (eastern side). This histogram provides an overall comparison of the differences between the western high and eastern low monthly rainfall figures. Summer temperatures are hot, winters are mild and frost free (DWAF, 2004; Rountree *et al.*, 2000; Venter *et al.*, 2003; Woodhouse, 1995). Summer temperatures are hot, winters are mild and frost free (DWAF, 2004; Rountree *et al.*, 2000; Venter *et al.*, 2003; Woodhouse, 1995). Evapotranspiration rates follow the same eastward trend (Department of Water Affairs and Forestry (DWAF) (2004). Evapotranspiration rates increase from 1400 mm/a to 1700 mm/a in an eastward direction (Jewitt *et al*., 1997 as cited by DWAF, 2004).

Rainfall variability is high within the Lowveld region therefore, droughts occur every three to four years (Cousins *et al*., n.d.). The Lowveld is both water insecure and a high risk water quality region due to the combination of the low and variable rainfall, and the expansion of rural settlements bordering the KNP (Pollard & Walker, 2000).

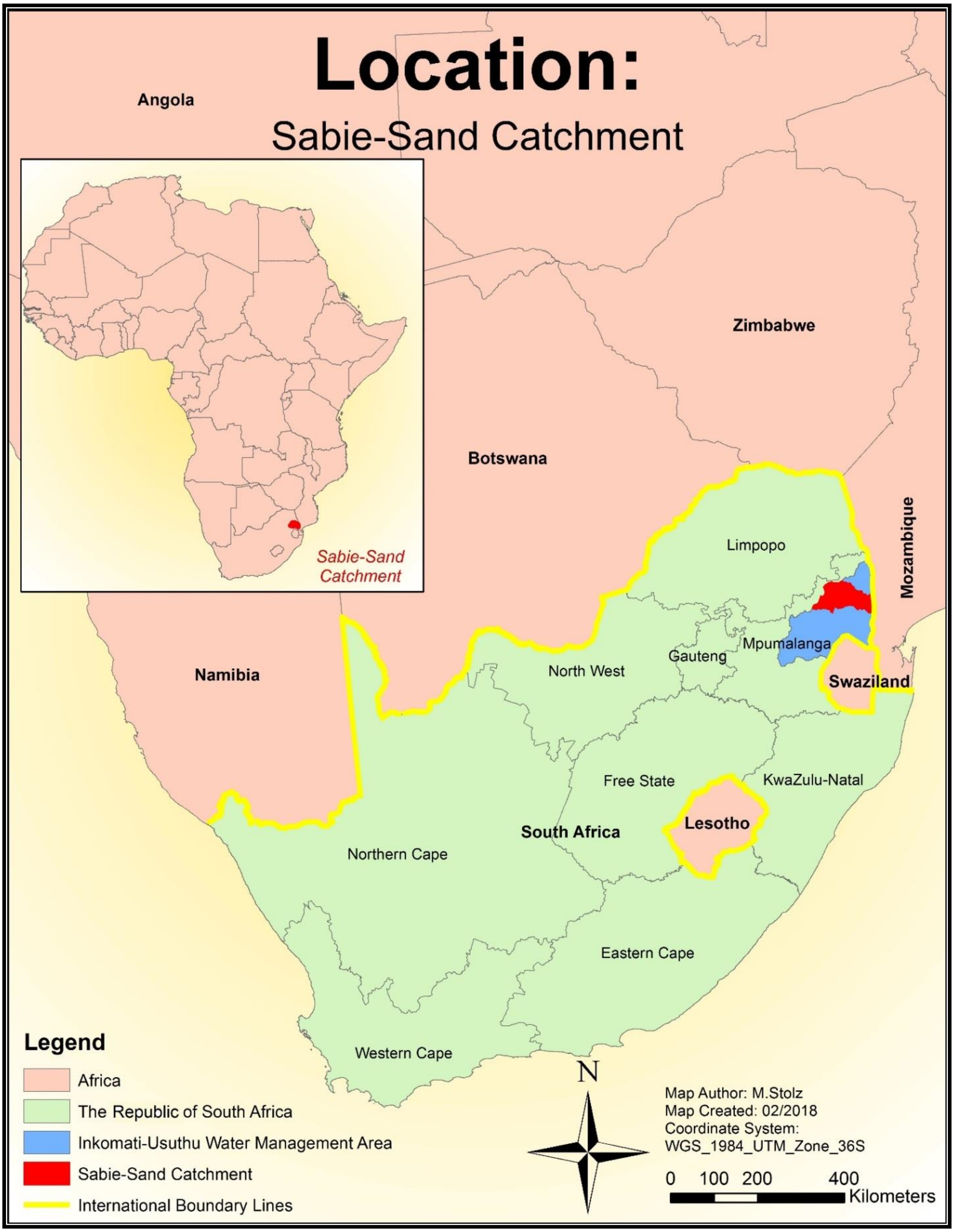


Figure 2-1: Sabie-Sand River catchment study area (DWS, 2017b) in Mpumalanga province in relation to the Inkomati-Usuthu Water Management Area (DWAF, 2012), the boundaries of South Africa and neighbouring countries (Maplibrary, 2007)

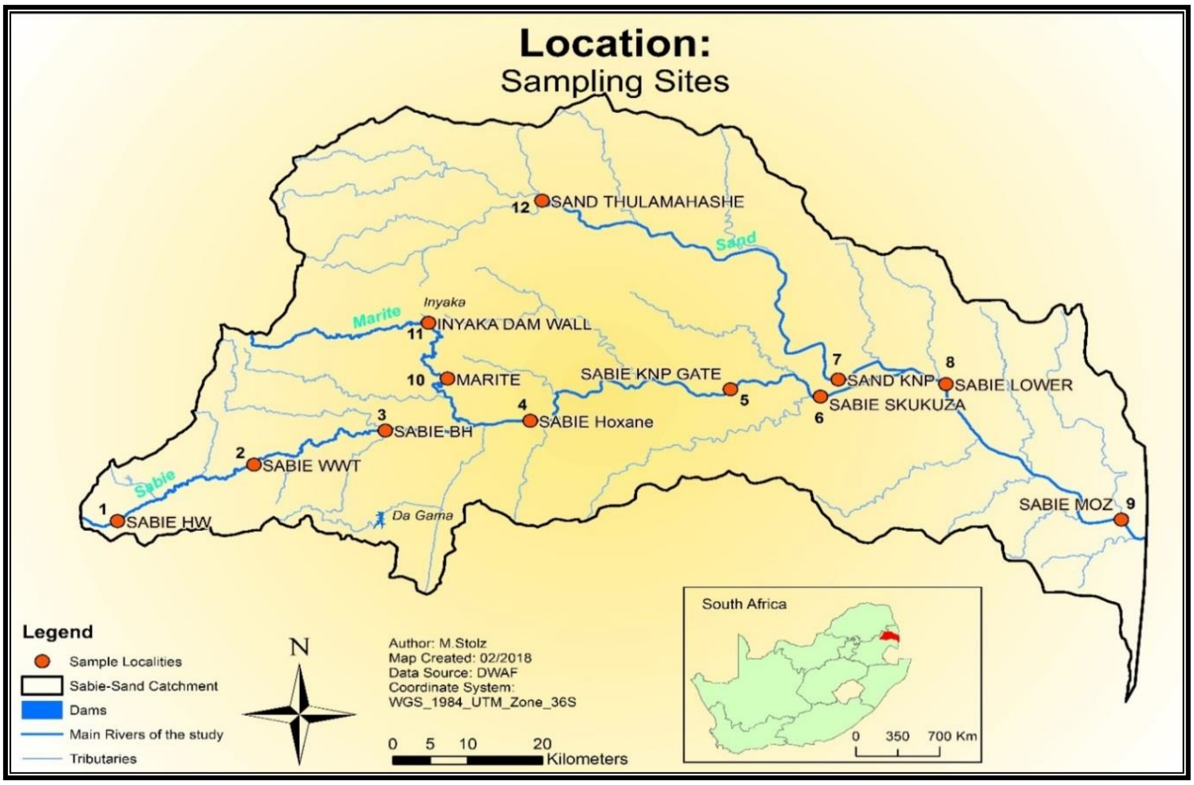


Figure 2-2: Locality map of sampling sites along the Sabie, Marite and Sand rivers.

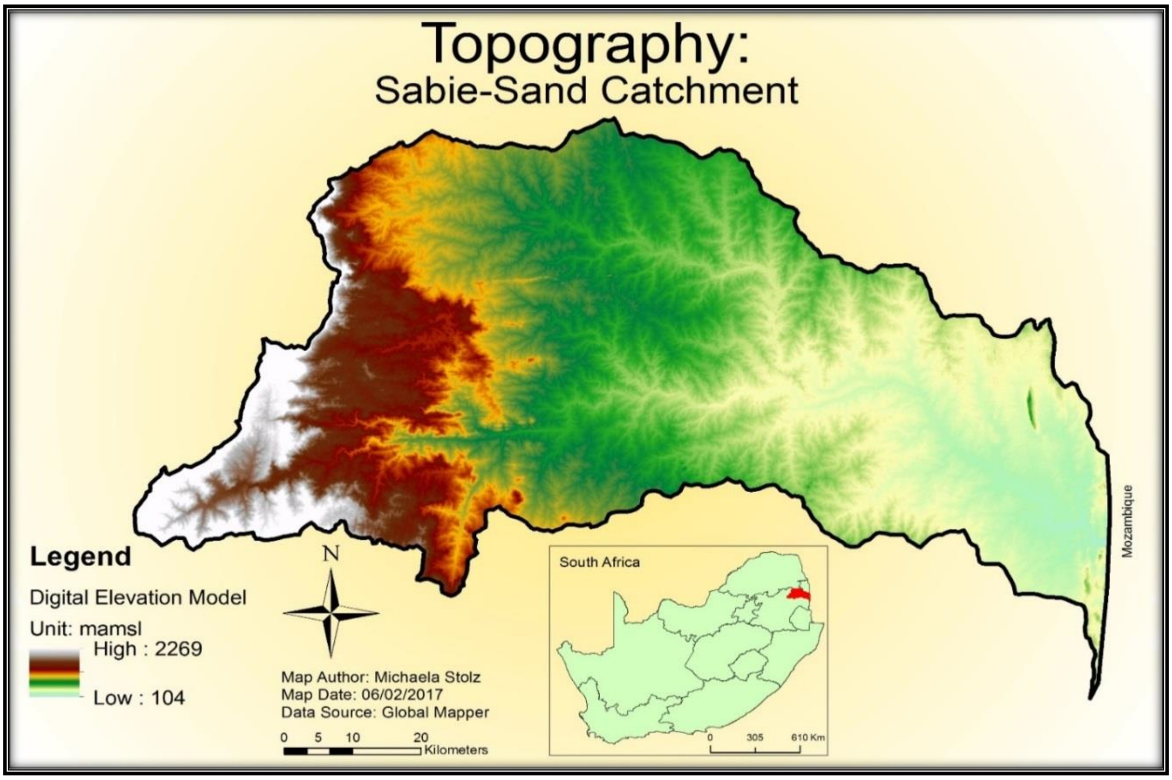


Figure 2-3: Topographic map of the Sabie catchment presented by Shuttle Radar Topography Mission DEM data (GlobalMapper, 2016)

The catchment receives varying amounts of rainfall that contribute to surface water (Middleton and Baily, 2005). The average annual rainfall that decreases along the topographical gradient from the mountainous areas through the foothills and towards the lower, flatter reaches of the Sabie River. It ranges between 1 500 mm/a and 900 mm/a to the west and 600 mm/a and 348 mm/a to the east of the catchment. These results in the catchment's surface mean annual runoff originating predominantly in the wetter, western parts of the catchment (Woodhouse, 1995). The average temperature at midday in summer is ~28°C and in winter, the average midday temperature is ~21.5°C (WR, 2012). During sampling times, the temperature of site-specific river water varied by 2°C on average depending on the ambient temperature and differences in topography.

Figure 2-4 below represents the average monthly rainfall of the Sabie-Sand Catchment from the west (operational rainfall station at Inyaka Dam) to the east (operational rainfall station at Skukuza in the KNP).

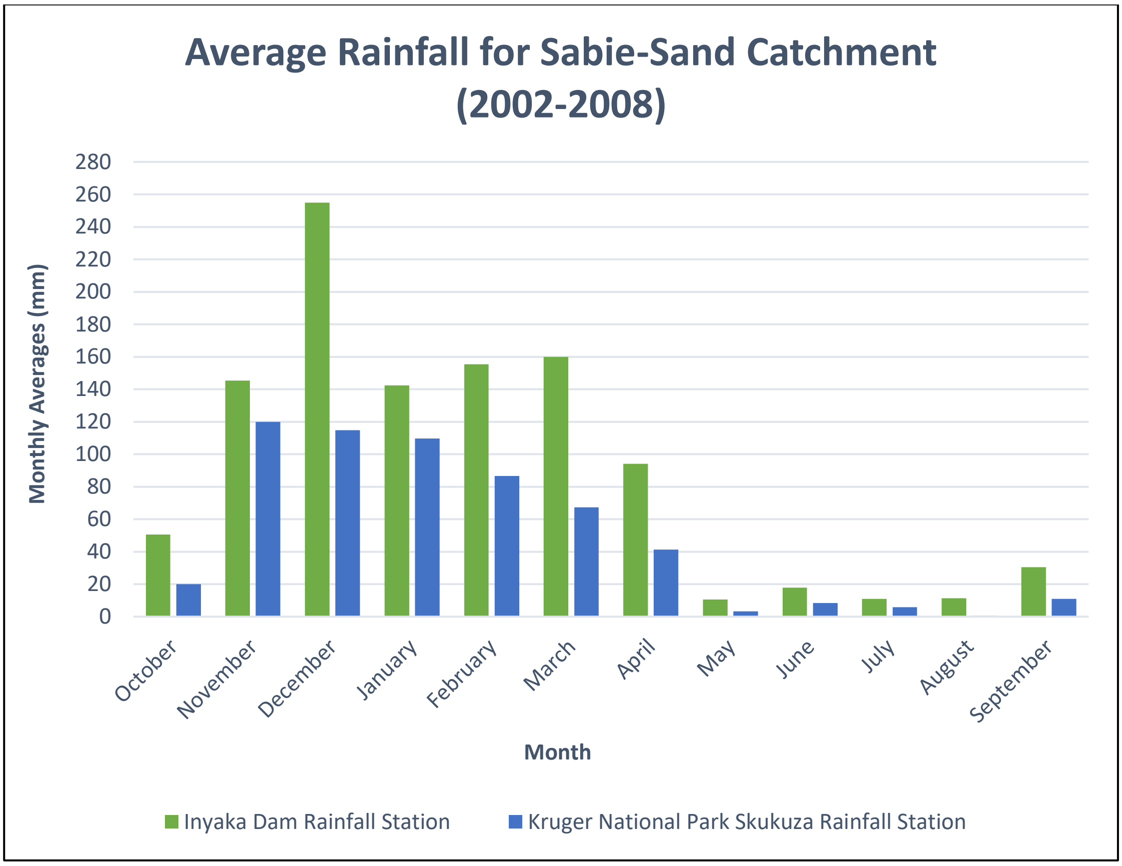


Figure 2-4: Rainfall column chart from January 2002 to December 2008

2.3 Vegetation

The vegetation of the Sabie-Sand Catchment is strongly related to topography and geological formations. Mucina and Rutherford (2006) classify the lowland pediplains and escarpment foothills as Savannah Biome with only the upper mountain plateau as Grassland Biome. Forests occur as zonal and intra-zonal patches along sheltered valleys and the steep slopes of the escarpment (Balance *et al.*, 2001; Coetzer *et al.*, 2010).

The Grassland Biomes are divided into the Lydenburg Montane Grassland, the Northern Escarpment Dolomite Grassland and the Northern Escarpment Quartzite Sourveld along the topographic catena (Mucina *et al.,* 2006). The vegetation of the Lydenburg Montane Grassland is described as forb-rich, short grassland with small forest and thicket patches along drainage lines. The Lydenburg Montane Grassland transcends into the Northern Escarpment Dolomite Grassland and is characterised as highly variable, shrub-rich grassland. Because of the dolomitic geology, the soils have a high pH and are rich in calcium and magnesium but low in phosphorous. The Northern Escarpment Quartzite Sourveld occurs on quartzites of the Black Reef Group at the base of the Transvaal Sequence. Due to the rocky relief and acidic soils, grass composition is characteristically sour. Northern Mistbelt Forest occurs as isolated patches within the Northern Escarpment Quartzite Sourveld extending along river valleys into the Savannah Biome below (Matthews *et al.*, 1991). Land use is mainly plantations with some limited cultivation. A detailed phytosociological analysis of the communities of the Escarpment Grassland was done by Matthews (1991) and parts of the vegetation of the Lydenburg Montane Grassland were described by Burgoyne (1995).

Further down from the escarpment, the catena climate becomes drier and warmer and grassland grades into the savannah of the Lowveld Bioregion. Rutherford *et al.* (2006) recognised seven savannah vegetation types on the lower plains of the Sabie catchment. Legogote Sour Bushveld occurs on the foothills of the Escarpment. The vegetation structure is characteristically open, sparse woodland. Dominant trees are *Pterocarpus angolensis*, *Sclerocarya birrea* subsp. *caffra*, *Vachellia sieberiana* var. *woodii* and *Vachellia davyi*. The central part of the Sabie catchment is described by Rutherford *et al.* (2006) as Granite Lowveld. Vegetation structure is tall shrubland/low woodland that is dominated by the trees *Senegalia nigrescens*, *Sclerocarya birrea* subsp. *caffra*, *Terminalia sericea*, *Combretum zeyheri* and *Combretum apiculatum*.

Within the Granite Lowveld sparse woodland, the herbaceous layer is dominated by *Themeda triandra*, which is present on vertic soils derived from the Timbavati Gabbro. Rutherford *et al.* (2006) refer to this as the Gabbro Grassy Bushveld. Related to the Legogote Sour Bushveld is the Pretoriuskop Sour Bushveld that is found on granite-derived soil relating to the upland topography. To the far east of the catchment, the Sabie River transects the Delagoa Lowveld, the Tshokwane-Hlane Basalt Lowveld and the Northern Lebombo Bushveld (Rutherford *et al.*, 2006). The Delagoa Lowveld is associated with sodium-rich duplex soils derived from the Karoo Supergroup shale (Gertenbach, 1983). The vegetation structure is open savannah dominated by *Senegalia senegal* var. *rostrata* and *Senegalia welwitschii* subsp. *delagoensis*. The Tshokwane-Hlane Basalt Lowveld occurs to the east of the Delagoa Lowveld on the Letaba Formation Basalts of the Karoo Supergroup. The vegetation is open, tree savannah dominated by the trees *Sclerocarya birrea* and *Senegalia nigrescens*. Northern Lebombo Bushveld occurs on the Lebombo Mountains. The savannah vegetation type is open, *Combretaceae* dominated woodland on clayey, shallow soils.

Siebert (2003) as cited by Ayres (2012) mentions four major riparian zones along the elevation gradient of the Sabie River. A dry riparian woodland occurs along higher altitudes dominated by *Acacia* spp., *Combretum imberbe*, *Gymnosporia senegalensis* and *Philenoptera violacea.* Along gradual topography the riverine zone forms a wet forest zone dominated by *Ficus* spp., *Diospyros mespiliformis* and *Trichilia emetic.* The riverine zone closer to the KNP and within the KNP forms a shrubby reed community dominated by *Flueggea virosa*, *Gymnosporia* spp., *Grewia* spp., *Phragmites mauritianus* and *Trema orientalis.* The Sabie river riparian zone on the eastern side of KNP is characterised as a reed scrub consisting of *Combretum* spp., *Phragmites mauritianus* and *Ficus* spp. (Siebert, 2003 as cited by Ayres, 2012).

2.4 Geology and soils

The area consistsconsist of ranges of bedrock lithologies, including metamorphic rocks such as quartzite, intrusive and extrusive igneous rocks such as granite and sedimentary rocks such as shale (Figure 2-5 and Figure 2-6). Other main geological rock types in the area include basalts, conglomerates, granites, andesites, irons and gneiss (Middleton & Bailey, 2005). These all form part of the three main lithostratigraphic units that underlie the catchment. To the west, the Transvaal Sequence (2 600-2 200 Ma old) overlies the older basement granite-gneiss complex (3 500-2 650 Ma old) and to the east is the youngest litho-stratigraphic unit of the area, the Karoo sequence (~250-183 Ma old).

Norman and Whitfield (2006) mentioned that to the topographically higher eastern section (the Transvaal highlands), the catchment's Transvaal Sequence consists of mainly sedimentary rock formations (Figure 2-6). According to the description of Norman and Whitfield (2006) and Chunnett *et al.* (1990), as cited by Wells (1992), for this catchment, the Transvaal Sequence is typically represented by quartzite of the Black Reef Formation and the Wolkberg Group, comparatively soft shale of the Wolkberg Group, dolomite of the Chuniespoort Group (Malmani Dolomite Subgroup), breccia, conglomerate, lava, tuff, diamictite, basalt and chert (Figure 2-6). Chunnett *et al.* (1990), as cited by Wells (1992), mention that the frequent gold deposits that occur within the Graskop and Sabie areas led to a small amount of mining activity in this part of the catchment.

According to Norman and Whitfield (2006), the catchment's largest lithological unit is the crystalline granite-gneiss Basement Complex of the Nelspruit Suite, which forms the Lowveld (Figure2-6). It contains granodiorite and massive, grey, coarse-grained, crystalline granite as well as intrusions of gabbro and diabase (also called dolerite) in the southwest, with a large tonalite intrusion in the centre of the Complex (Chunnett *et al.*, 1990 as cited by Wells, 1992). The quartzites within the Transvaal Supergroup are more resistant to weathering over time than the basement granite-gneiss, and this has resulted in a plateau (Lowveld) in the centre of the catchment (described above as pediplanation). The KNP is underlain by several varieties of basement granite-gneiss, several younger gabbroic and syenite intrusions and minor greenstone remnants (Norman & Whitfield, 2006). The underlying geology is an important factor in the catchment's topography and strongly controls the landscape (Figure 2-6).

According to Norman and Whitfield (2006), the eastern side of the catchment (especially the entire eastern strip of the KNP) mainly consists of sedimentary formations of the Karoo Supergroup such as river-channel sandstone/arenite (grey-green to reddish), dark coal seams from the Beaufort and Ecca Groups, yellow to pink fine-grained sandstone and siltstone of the Clarence Formation, igneous formations consisting of lower basaltic lavas and upper rhyolitic lavas from the Letaba and Jozini formations within the Lebombo Group and basalts from the Drakensberg Group (Figure 2-6). The geology also contains some granophyre and Karoo dolerite intrusions (Chunnett *et al.*, 1990 as cited by Wells, 1992).

Chunnett *et al.* 1990, as cited by Wells, 1992, state that compared to other areas in Southern Africa, the soils in this catchment have a low erosion risk and relatively high erosion resistance. The mountain grasslands and Afromontane forests of the upland areas and lower slopes respectively are underlain by shallow lithosols (beneath the grasslands) and well-developed, sometimes leached, mature soils (beneath the forest floor). According to O'Keeffe (1985), the lower catchment (outside the KNP) is represented by ferrallitic clays and arenosols, whereas the higher areas of the KNP are representative of shallow, sandy soils and the lower lying areas of sodic duplex soils. In the western region of the KNP, black and red clays overlie the gabbro that outlines the channel of the Sabie River (O'Keeffe, 1985).

The east of the catchment together with the lower topographies is represented by river channels typical to floodplains, for example, the anastomosing channels within streams of the lower Sabie catchment (Nanson & Gibling, 2004). In drought periods, this results in an accumulation and deposition of sediment with subsequent thicker vegetative establishment and stabilisation within the stream than the density found on the stream banks (Heritage & Van Niekerk, 1995; Rountree *et al.*, 2000). Rountree *et al.* (2000) mention that with low flow and sediment accumulation, terrestrial vegetation is established rather than water-dependent riparian vegetation. This observation was confirmed during the fieldwork for this study Also, in the far eastern side of the catchment, the Letaba Lava weathers to form a characteristic dark, clayey soil and the successive Jozini rhyolites yield lithosols (O'Keeffe, 1985; Norman and Whitfield 2006).

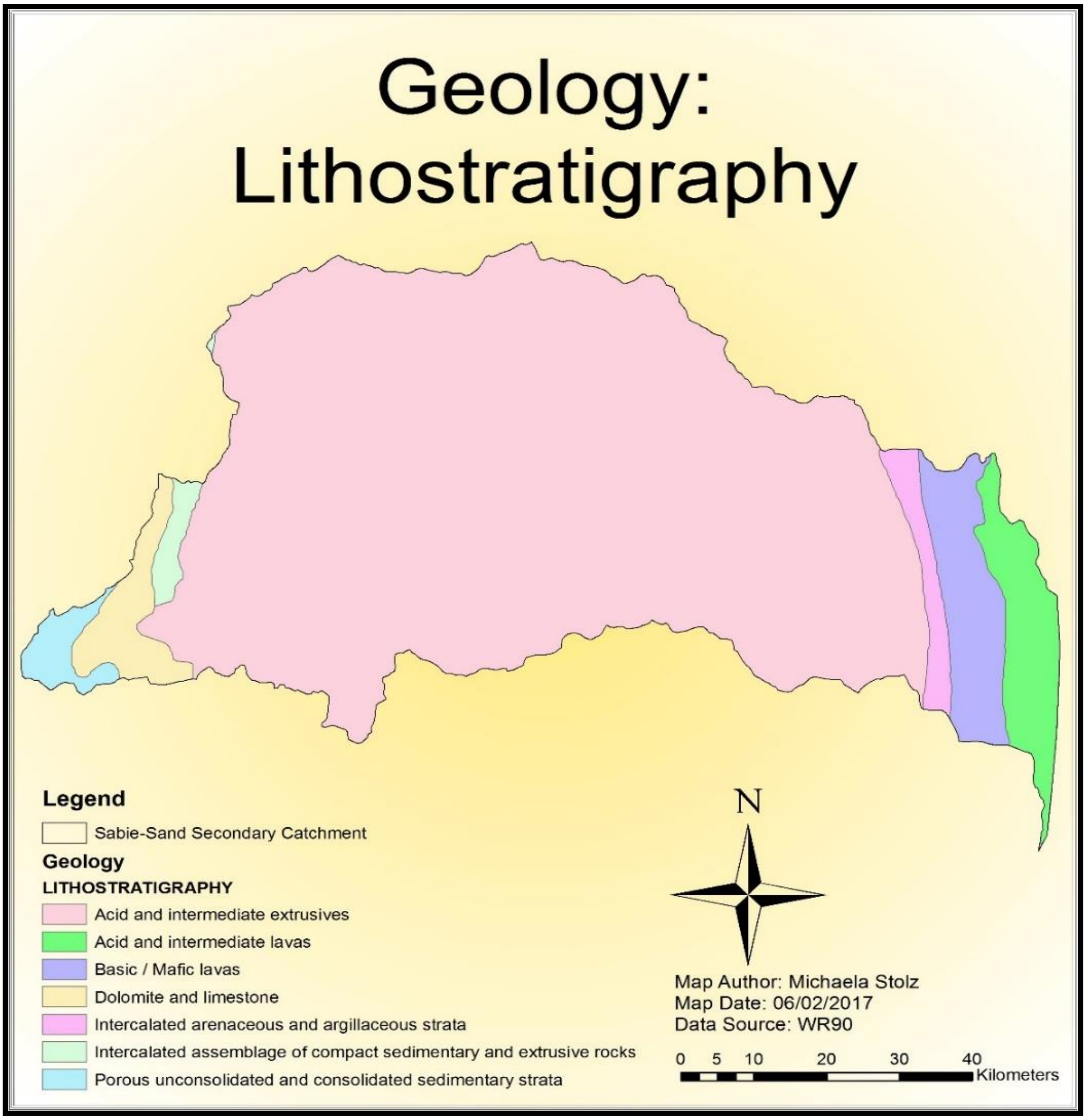


Figure 2-5: General lithology of the Sabie-Sand Catchment (WR, 1990).

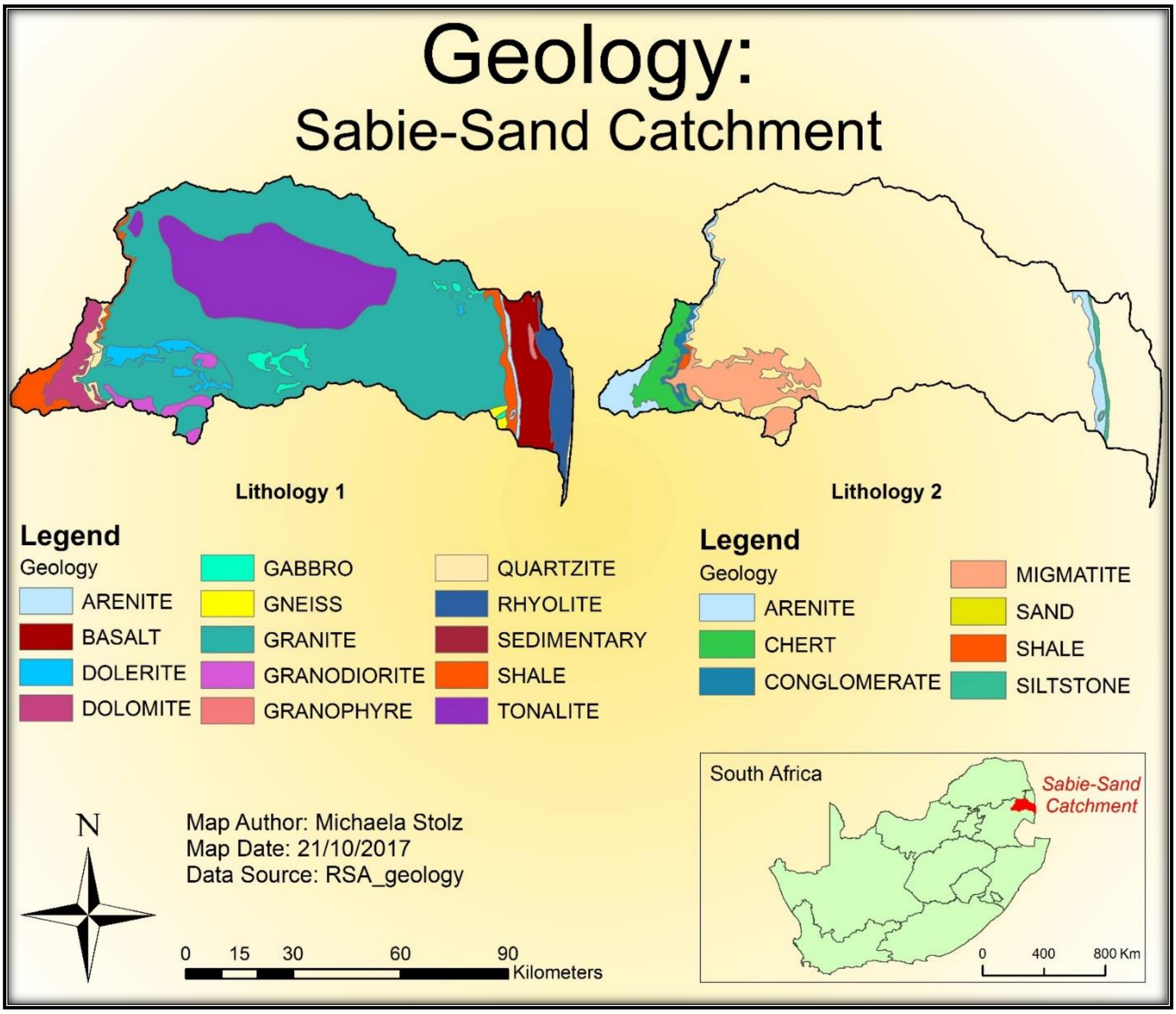


Figure 2-6: Lithological layers of the Sabie-Sand Catchment (Geoscience, 2003 and Land Type Survey Staff, 2002)

The first two lithological layers of the Sabie-Sand Catchment represent the various rock types found at the surface of the catchment. Most of these rocks will weather to form the catchment soils that contribute to surface water characteristics.

3 LAND USE

3.1 Introduction

The influences of a river are determined by establishing the demography of the region, the socio-economic structures and the physical, man-made landscapes created through the type, quality and flow rate of the river. Alternatively, influences are determined by establishing where the river is being affected by the various anthropogenic activities once the niche of the area is established (Kusangaya *et al.*, 2013).

The Sabie-Sand Catchment may soon be a water-stressed catchment because of conflicting demands for potable water and the requirements of the Ecological Reserve (DWA, 2013 as cited by Mallory *et al.*, 2013). A water requirement and availability study by Beumer and Mallory (2014), which analysed the volume of water from the Sabie River that was already allocated for use, concluded that the water from the river was fully allocated. Therefore, even though a surplus of water supply exists after implementing the Ecological Reserve, in the event that additional allocations are required, the risk exists that the Ecological Management Class of the Sabie River will have to degrade (Beumer & Mallory, 2014).

Regarding water quality, this degradation will negatively influence the status of the Sabie River. Degrading of its present ecological state will take place when lowering the desired Ecological Reserve from the existing Class A/B (Beumer & Mallory, 2014). The Ecological Management Class is closely related totoo, or is a representative value of the health and water quality of the Sabie River. As briefly described above with the implementation of the Integrated Water Supply Scheme, water quantities and qualities vary greatly when considering the inflow and the abstraction of different natural and anthropogenic activities. This corresponds to the importance of land use as a driver of river ecosystem health (Vrebos *et al.*, 2017). Typical land use activities that could alter the physical, biological and chemical characteristics of the Sabie River catchment identified by Mallory et al. (2013) include:

- economic drivers such as commercial forestry, irrigated agriculture and industries causing surface alterations as well as major water abstractions from the source;
- conservational practices, which cause not only remediating effects, but also influence water resources though natural wildlife intervention and possible overgrazing in riparian zones, that can result in erosion and sedimentation;
- social and demographic drivers, where, (1) urban infrastructure, semi-urban and rural township expansion contribute through being point sources (e.g. non-compliant Wastewater Treatment Plant [WWTP]) and non-point source (e.g. storm water runoff) polluters; and (2) an increase in water users; and
- impoundments used to bulk water supply for irrigation and ever increasing domestic purposes, in addition to other larger reservoirs, affectingdams, which affect temperature and oxygen levels and that can act asare sediment traps.

As mentioned above, previous studies such as those of O'Keeffe *et al.* (1996) and Mallory *et al.* (2013) assessed water demand upstream of the Kruger National Park (KNP) and the ecological river flow requirements of the Sabie River catchment (Pollard *et al.*, 2011). These studies provided information on water-supply schemes and cater for future developmentsdevelopment in land-use activities and increasing population. The positive and negative outcomes that the construction of the Inyaka Dam had for the Marite River, a tributary of the Sabie River, are also mentioned. Unfortunately, a full scale water-quality assessment in terms of land use after construction of the dam was not conducted. The foreseen increases in urbanisation and especially rural settlement development (i.e. in the Bushbuckridge area) have started to raise concerns in terms of the water quality of this South African river and its tributaries (Mallory *et al.*, 2013; Tlou, 2011). A study by Tlou (2011) focuses on the demographics of the Sabie-Sand River catchment and the Inyaka Dam Water Supply Scheme. It indicated that although the water quality is relatively good, supply problems and quality deterioration may be experienced in the future, especially if water sanitation facilities are not properly managed. These problems relate to increases in population and rural land use and may even be enhanced during drought periods by the shifting climate. Recent climatic situations in this study area demonstrated that 2015 was a very dry year with minimal precipitation. Minor flash floods were only experienced in March 2016 with higher rainfall figures in October 2016. A nationwide drought was experienced from 2013 to 2016 during which effective or significant rainfall was only experienced in the summer of 2016/2017. It is suspected that land use and rural urbanisation within the area of the Sabie River have an increasingly negative effect on the water quality of the Sabie River. The main aims of the current study were to conduct an in-depth investigation into the different land uses surrounding the Sabie River and to evaluate the influence thereof on the water quality of the Sabie River and two of its main tributaries.

Although land use and land cover are two different concepts, the interconnected nature of the two aspects often compels researchers to use the terms interchangeably. The Food and Agriculture Organization (2002: 7) defines land cover as “the observed (bio) physical cover on the earth's surface” whereas land use refers to “the arrangements, activities and inputs people undertake in a certain land cover type to produce, change or maintain it”. Since land use is such a dynamic entity and land-use data at various levels are non-existent, available land-cover data are used as a proxy.

3.2 Materials and methods

3.2.1 Land-use analysis

It is important to understand landscape dynamics for efficient land management. According to Foley *et al.* (2005), land management refers to the methods used for the managing of land development and land use while considering strategies for sustainable social, environmental and economic benefits. Land management forms the base upon which to conduct studies regarding the change and influence of land use on various other characteristics of the physical environment. Land cover change detection forms the basis of monitoring land uses, for example urban growth expansion. In short, land use refers to the type of use assigned to the land cover (Di Gregorio & Jansen, 2000). Geographic information system (GIS) techniques are at the forefront of detecting surface changes and the causes of these changes, whether natural or anthropogenic in nature. The Spatial Planning and Land Use Management Act (No. 16 of 2013) enables a framework for the assessment of land use, land-use influences and the management thereof in South Africa.

There is no detailed and complete land-use dataset available for the Sabie-Sand Catchment area. Such a dataset is very dynamic and difficult to map. Furthermore, land use is a reflection of multiple factors, including anthropogenic activities and geomorphic land characteristics (Yu *et al.*, 2016). This study used the land-cover data as a surrogate for land use at a very high level. The land-use dataset was the fundamental dataset used to answer the research question, using the ancillary datasets to support the possible spatial influences. To accommodate the land-use types that are likely to affect water quality, a point pollution dataset of mines, industries, wastewater treatment plants (WWTPs), etc. was created and evaluated, and the most important points were included in the analysis.

In order to answer the research question, it was necessary to group land-cover classes derived from the 2013/2014 national land cover (NLC) layer of the Sabie-Sand Catchment into broad classes of transformed and natural areas. Land-cover classes of transformed areas included urban areas, mines, agriculture and plantations. Natural areas included grassland, wetland, woodland, and indigenous forest (Table 3-1). Surface runoff is influenced by various factors, two of which are land-use type and land cover. As a result, the majority of land-use and land-cover influences within the catchment represent a non-point source pollution type. Therefore, the geographical information software, ArcGIS (Esri, 2015) was used to analyse the non-point sources and some possibly significant point-sources in the catchment.

Various digital elevation model (DEM) datasets are available for the study area. A DEM is a grid that presents elevation data of the Earth's surface in which each grid cell represents an elevation value. Digital elevation model data contain terrain morphological information that can be derived as secondary products, for example, slope, aspect (slope direction), sub-basins (sub-catchment), river networks and curvature (Lee & White, 1992). The spatial resolution of the DEM, that is, the size of each cell determines the level of topographical detail. The Shuttle Radar Topography Mission (SRTM) DEM is a freely available, internationally known reference dataset and was, therefore, used for this study (Table 3-2). The 90 m SRTM DEM for this study area was downloaded via Global Mapper from CGIAR-CSI (Jarvis *et al.*, 2008). Six quadrangles (S25E030; S25E031; S25E032; S26E030; S26E031; S26E032) were downloaded from Global Mapper on 04/06/2016, mosaicked and re-projected using nearest neighbour resampling (Jarvis *et al.*, 2008). The ArcGIS 3D Analyst extension was used to calculate slope, drainage patterns and sub-catchments corresponding to the 12 sampling point localities. The sub-catchment polygons were then used as zonal data to calculate statistics regarding the initial upstream land use, geology, elevation, slopes, etc. It was hypothesized that the water quality would vary according to the different land uses occurring upstream from the sampling localities (Kändler *et al.*, 2017).

The GIS layers used for the study included layers regarding land cover, elevation, terrain morphology derived from the DEM, conservation boundaries, geological lithologies, streams and river systems, built-up areas and village areas. The GIS data for the Sabie-Sand Catchment were sourced from existing databases. A GIS has the capability to relate spatial data of a certain location (defined within a coordinate system) stored in multiple layers that will eventually combine to form spatial information of that specific location on Earth (Lee & White, 1992).

Table 3-1: Symbol legend for the combined 18-class land-use interpretation extracted from 57 classes clipped from the South African National 2013/2014 Land Cover Dataset

Colour	Class Name	Class ID	Transformed/ Natural	Description
	Cultivated Commercial	CuCom	Transformed	Cultivated commercial fields (high, low and medium classes); cultivated commercial pivots (high and medium classes)
	Cultivated Orchards	CuOrc	Transformed	Cultivated orchards (high, low and medium classes)
	Cultivated Subsistence	CuSub	Transformed	Cultivated subsistence (high, low and medium classes)
	Erosion – Bare	EBare	Transformed	Erosion donga; bare, non-vegetated
	Grassland – Low Shrubland	GrasL	Natural	Grassland; low shrubland
	Indigenous Forest	IndFo	Natural	Indigenous forest
	Mines	Mines	Transformed	Mines 1 bare; mines 2 semi-bare; mines water permanent
	Plantations – Woodlots	PlanW	Transformed	Plantations/woodlots
	Urban Built-up	UrBuU	Transformed	Urban built-up (bare, dense trees / bush, low vegetation / grass, open trees / bush classes); Urban commercial Urban industrial
	Urban Informal	UrInf	Transformed	Urban informal (dense trees / bush, low vegetation / grass, open trees / bush classes)
	Urban Lawns	UrLaw	Transformed	Urban school and sports ground; urban sports and golf (bare, dense trees / bush, low vegetation / grass, open trees / bush classes)
	Urban Residential	UrRes	Transformed	Urban residential (bare, dense trees / bush, low vegetation / grass, open trees / bush classes)
	Urban Smallholding	UrSma	Transformed	Urban smallholding (bare, dense trees / bush, low vegetation / grass, open trees / bush classes)
	Urban Townships	UrTsh	Transformed	Urban townships (bare, dense trees / bush, low vegetation / grass, open trees / bush classes)
	Urban Village	UrVil	Transformed	Urban village (bare, dense trees / bush, low vegetation / grass, open trees / bush classes)
	Water	Water	Natural	Water permanent; water seasonal

Colour	Class Name	Class ID	Transformed/ Natural	Description
	Woodland	WdlnO	Natural	Woodland/open bush; thicket/dense bush
	Wetlands	Wetld	Natural	Wetlands

Table 3-2: Shuttle Radar Topography Mission data product specifications

SRTM DEM Product Specifications used within this study	
Projection	Geographic
Horizontal Datum	WGS84
Vertical Datum	EGM96 (Earth Gravitational Model 1996)
Vertical Units	Metres
Spatial Resolution	3 arc-seconds for global coverage (90 metres)
Raster Size	1 degree x 1 degree tiles terrain grid

Source: USGS, 2015

The 72 Class GTI South African National 2013/2014 Land Cover Dataset derived by Geoterra Image (Pty) Ltd. was used in this study as an alternative for land-use information because no detailed land-use data are available for the 2015/2016 season in the study area. This layer was sourced from the South African Department of Environmental Affairs (DEA, 2016). Derived from multi-seasonal Landsat 8 satellite imagery (April 2013-March 2014), the NLC2013/14 dataset is based on 30 x 30 m raster cells (30 m resolution) and can be used as an approximate scale of 1:60 000-1:250 000 for GIS-based mapping and modelling applications (Geoterra Image, 2015). Based on the standard map projection for distributing Landsat 8 data, the original land-cover dataset was processed in Universal Transverse Mercator (UTM) 35 North, WGS84 datum format as provided by the United States Geological Survey (USGS) (Geoterra Image, 2015). Geoterra Image developed repeatable and standardised semi-automated modelling procedures to generate this dataset. Desktop accuracy assessment was done visually against high resolution imagery and photography of equivalent dates in Google Earth. Industry standard error (confusion) matrices were used to report accuracies, namely Producer, User and Kappa values (Geoterra Image, 2015). The dataset was made available in both UTM35 (north) and (south), WGS84 map projections and WGS84 geographic coordinates. Associated characteristics stored in an attribute table included the count, class name, class type and class description.

The X primary drainage region (Inkomati catchment) and the X3 secondary drainage region (Sabie-Sand Catchment) were obtained from the Resource Quality Information Services of the Department of Water and Sanitation (DWS, 2017b). The original KMZ/KML files were converted to a shapefile using ArcGIS10.4 and used to define the boundary of the Sabie-Sand Catchment. The catchment boundary was then used to define the geographical extent for the study area. Quaternary catchment boundary data for the Sabie-Sand Catchment were not used since the specific catchment boundaries for each sampling point were generated for spatial analysis purposes.

Game reserves and nature reserves form one of the main land tenure classes within the study area. Forming one of the three main land tenure classes is the conservation aspect of this study area. The conservation boundaries of the various South African National Parks (SANParks) and game reserves were derived from the South African Protected Areas Database (DEA, 2016) layer obtained from the EGIS portal of the DEA with the following link: https://egis.environment.gov.za/ (see metadata). A communities shapefile sourced from Department of Agriculture, Forestry and Fisheries (Original data custodian and publication date for the community layer is unknown) was used to indicate urban and semi-urban boundaries.

There were three different datasets available that represented catchment geology. The 1:250 000 scale WR90 geological layer was used to obtain attribute data such as area and one field of descriptive lithology (LITHOS) describing the characteristics of the rocks found in the area (acidic, porous, etc.). The second set of geological data layer at a minimum scale of 1:10 000 000 was used to obtain attribute data such as old name (e.g. Timeball Hill and Rooihoogte), stratigraphic name (e.g. Timeball Hill), stratigraphic rank (e.g. formation), stratigraphic parent (e.g. Pretoria), chronological name (e.g. Vaalian), chronological rank (e.g. era), and five different lithologies (e.g. lithology 1: shale) (GeoScience, 2003). Ultimately, the lithology 1 attribute from GeoScience (2003) was used when conducting the multivariate analysis (Table 3-5).

The third layer was a 1:250 000 scale soil and geological rock combination derived from the Agricultural Research Council (ARC) land types of South Africa (Land Type Survey Staff, 2002). The soil data obtained from this layer (Table 3-6) were the main soil data used for the multivariate analysis.

Although this layer contained soil and geology information, a single lithology layer from GeoScience (2003) was eventually used to represent the catchment geology as seen in Figure 2-6. An example of the soil and geology information contained in the third layer is Ab10, which represents (1) the soil properties: red-yellow apedal, freely drained soils; red, dystrophic and/or mesotrophic; and (2) geology: biotite granite and migmatite (Nelspruit granite), granodiorite (Hebron granite), mafic and ultramafic gneisses (Bandelierkop Complex), Cunning Moor tonalite (all of the Archaeozoic) and diabase. Soil descriptions of the land types occurring in the catchment are listed in a descriptive table (Table 3-7).

3.2.2 Spatial analysis methods

ArcGIS10.4, together with the Spatial Analyst, Network Analyst and 3D Analyst Extensions, was used for analysis and the presentation of spatial datasets. All GIS data were clipped according to the sub-catchment boundaries presented by the Sabie-Sand Catchment and thereafter clipped to the sub-catchment boundaries delineated through the DEM.

The sites chosen were on the Sabie, Sand and Marite rivers and close to the outlet of the Inyaka Dam Wall. The Sabie River and its tributaries were sampled at 12 localities (Table 2-1; Figure 2-2). Site locations were initially based on existing survey points that corresponded with the sites monitored by the Inkomati-Usuthu Catchment Management Agency. Site accessibility was the second factor considered in the allocation of sampling localities. For analysis purposes, the river systems were divided into segments via the sampling localities, and each individual drainage basin was delineated accordingly. The assumption was that land-use activities, climate, soil and terrain characteristics (physical parameters) associated with each upstream river segment would determine the water quality at the sampling locality. The sampling locality was also used as a pour point to determine the associated sub-catchment (Figure 3-1). Therefore, it was decided to analyse the land-use influence on the rivers via 12 sub-catchments that covered the entire extent of the land uses affecting the river segment. These sub-catchments were used on the land-cover dataset to calculate the statistics per segment.

Twelve sub-catchments were delineated by considering the 12 sampling localities and using the DEM (Figure 3-1) and the 12 points as pour points or endpoints. These endpoints marked the lowest point of flow that a possible contaminant or river variable would pass before entering a new sub-catchment. The river segments between the sampling localities transect different land uses. River quality and water features together with land uses were examined between each sampling locality while considering the sampling results above that node within the river. The river segment together with its surrounding land uses formed its own sub-catchment (Figure 3-1).

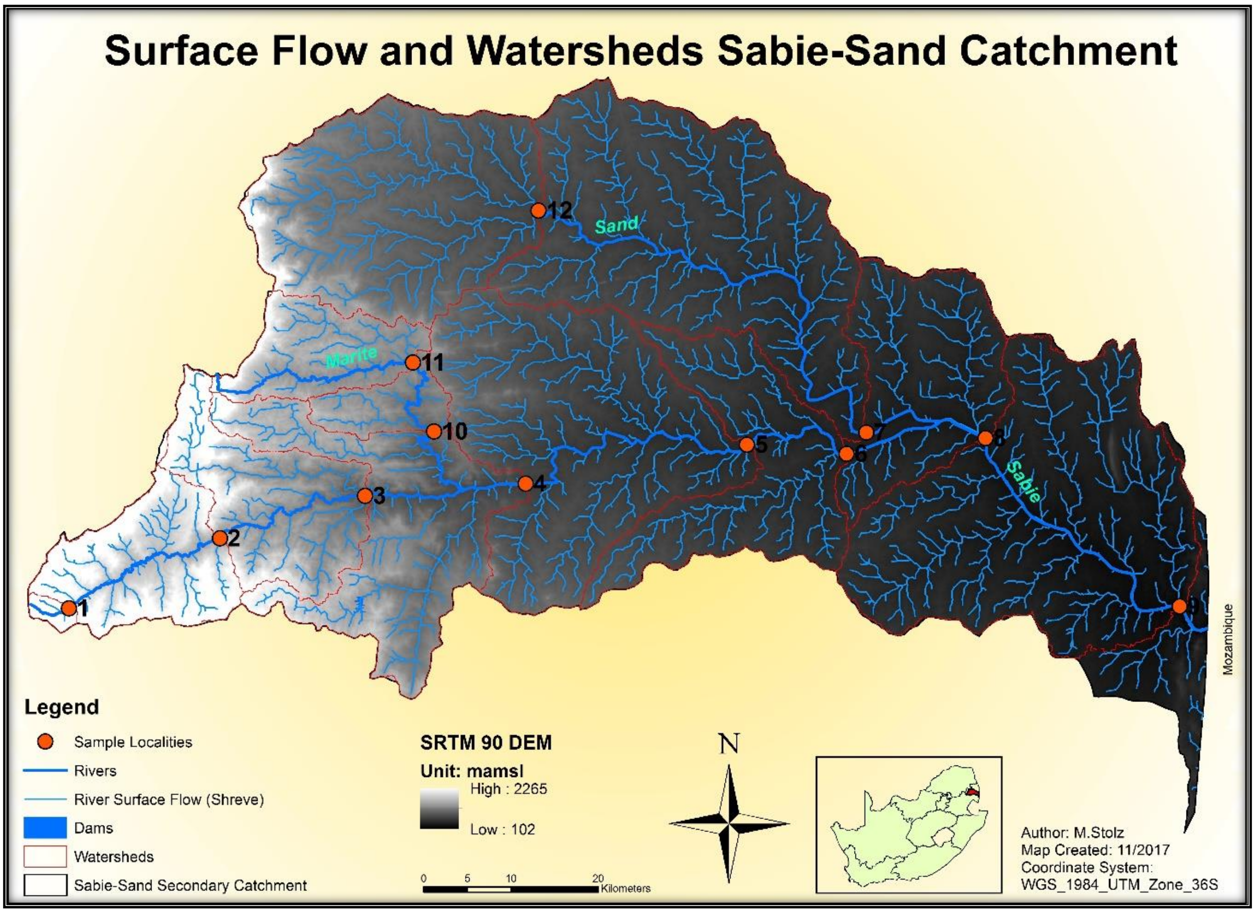


Figure 3-1: The Shreve – ordered river network (blue) and twelve delineated sub-catchments (red) generated from the SRTM digital elevation model (Jarvis et al., 2008), downloaded from GeoMapper (2012)

The STRM90 DEM grid represents a 90 m x 90 m land surface area (Figure 3-1). Using the geoprocessing tools in ArcGIS, the six individual DEM tiles were merged and clipped to the secondary catchment boundary. Figure 3-2 explains the workflow process to mosaic the individual DEM tiles and clip it to the extent of the Sabie River catchment. The 90 m DEM dataset was the input dataset for further hydrological and surface analyses.

The workflow followed to mosaic individual tiles and process the SRTM to a catchment wide DEM is presented in Figure 3-2. The 90 m DEM dataset was the basis for further hydrological and surface analyses.

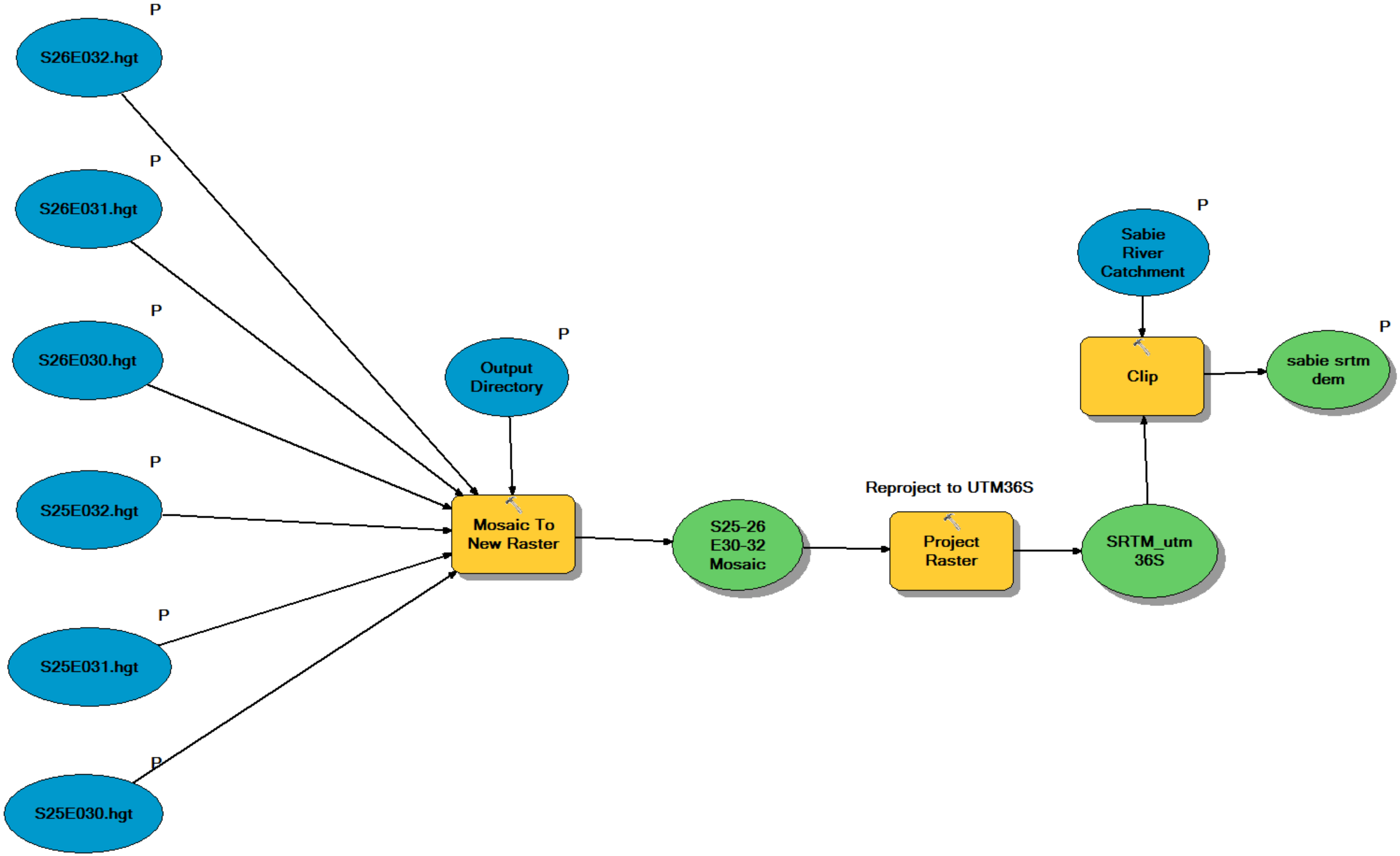


Figure 3-2: Processing SRTM tiles to conform to UTM36S projection and Sabie River catchment

ArcGIS Spatial Analyst provides the option to calculate the slope as a degree or percentage (Figure 3-3). In this study, the percentage slope was used. Slope steepness can further be accentuated using the Hillshade tool. Slope percentage ranges from 0 to infinity, meaning that the more vertical a slope becomes, the larger is the slope percentage. In regard to a slope with an angle of 45 degrees, the percentage rise or slope percentage is 100% (Esri, 2016a). Apart from calculating the overall slopes of the 12 sub-catchments, the specific slopes of the main channels of the Sabie, Sand and Mariti rivers were also obtained. This enabled a closer analysis of the correlation between water-quality parameters and slope (Figure 3-4).

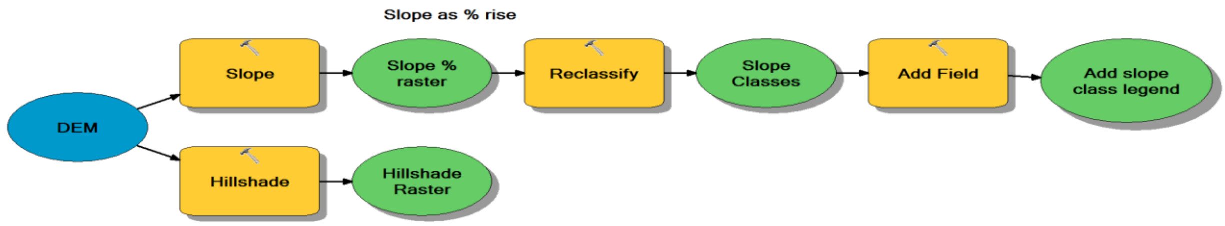


Figure 3-3: Processing SRTM DEM to percentage slope for Sabie catchment

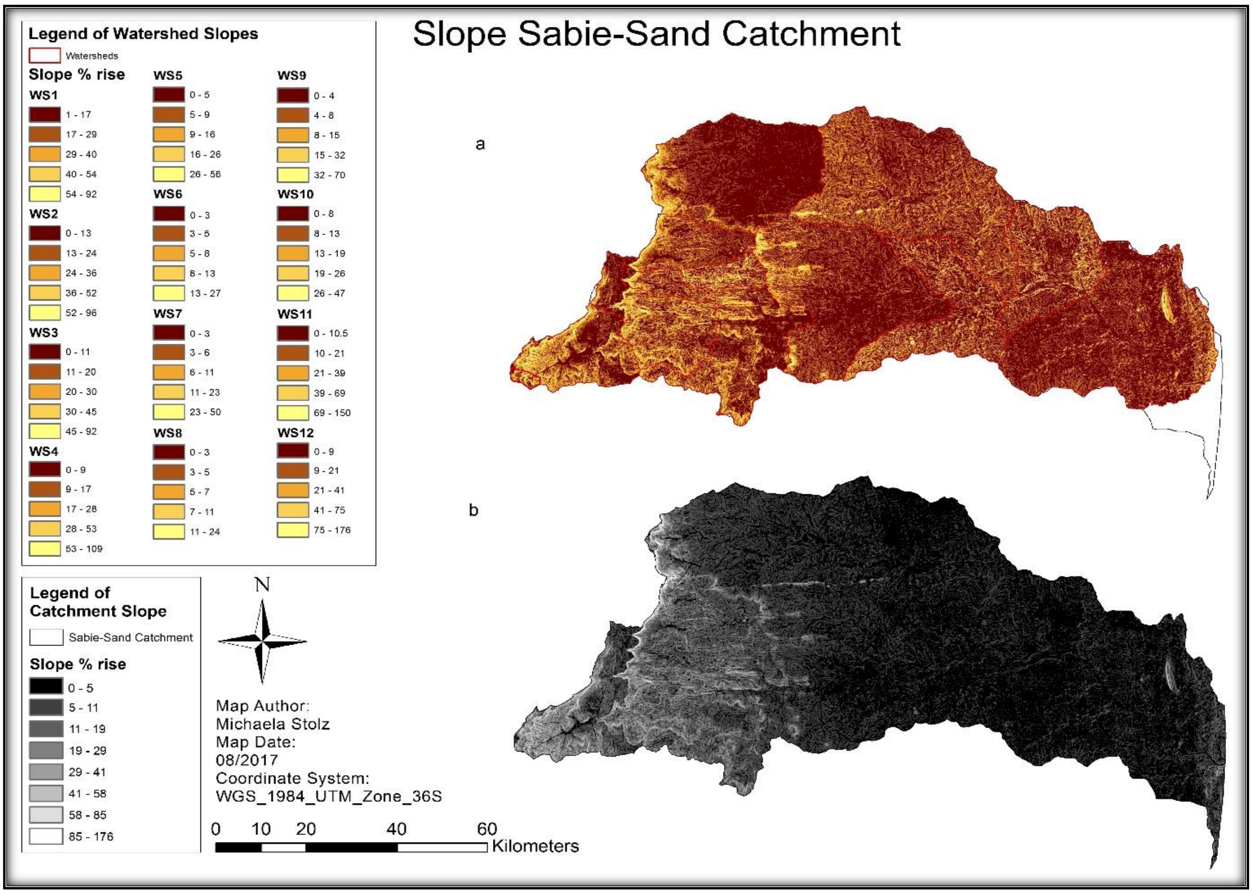


Figure 3-4: Slopes of Sabie-Sand Catchment (Stolz, 2018)

The 12 sub-catchments used to analyse data for this study were created with the hydrology tools of ArcMap10.4. Calculation of the sampling points' sub-catchments required setting the sampling points as pour points. The sampling point sub-catchment is derived from the SRTM DEM Flow Direction and Flow Accumulation rasters (Figure 3-5).

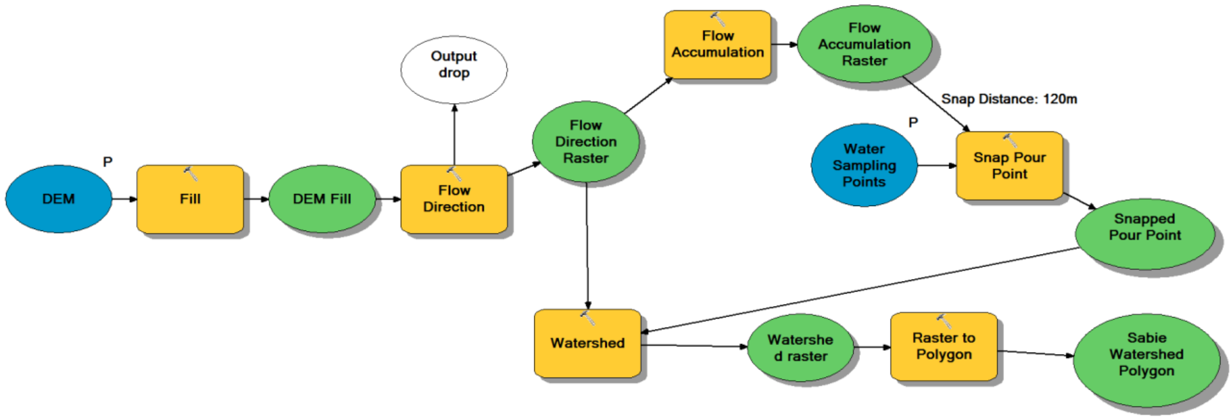


Figure 3-5: Analysis of SRTM DEM to determine sampling point sub-catchment area

A workflow to determine the change in elevation between the lowest and the highest point along a river segment is presented in Figure 3-6. To determine this river feature at 1:500 000, DWA500 was used. This only included the main river channels and the sub-catchment raster, thus indicating the extent of the sub-catchment of each sample point. Within a semi-automated process, the end points along the river line feature need to be identified. In this study, this was achieved using the Feature Vertices to Point tool (Figure 3-6).

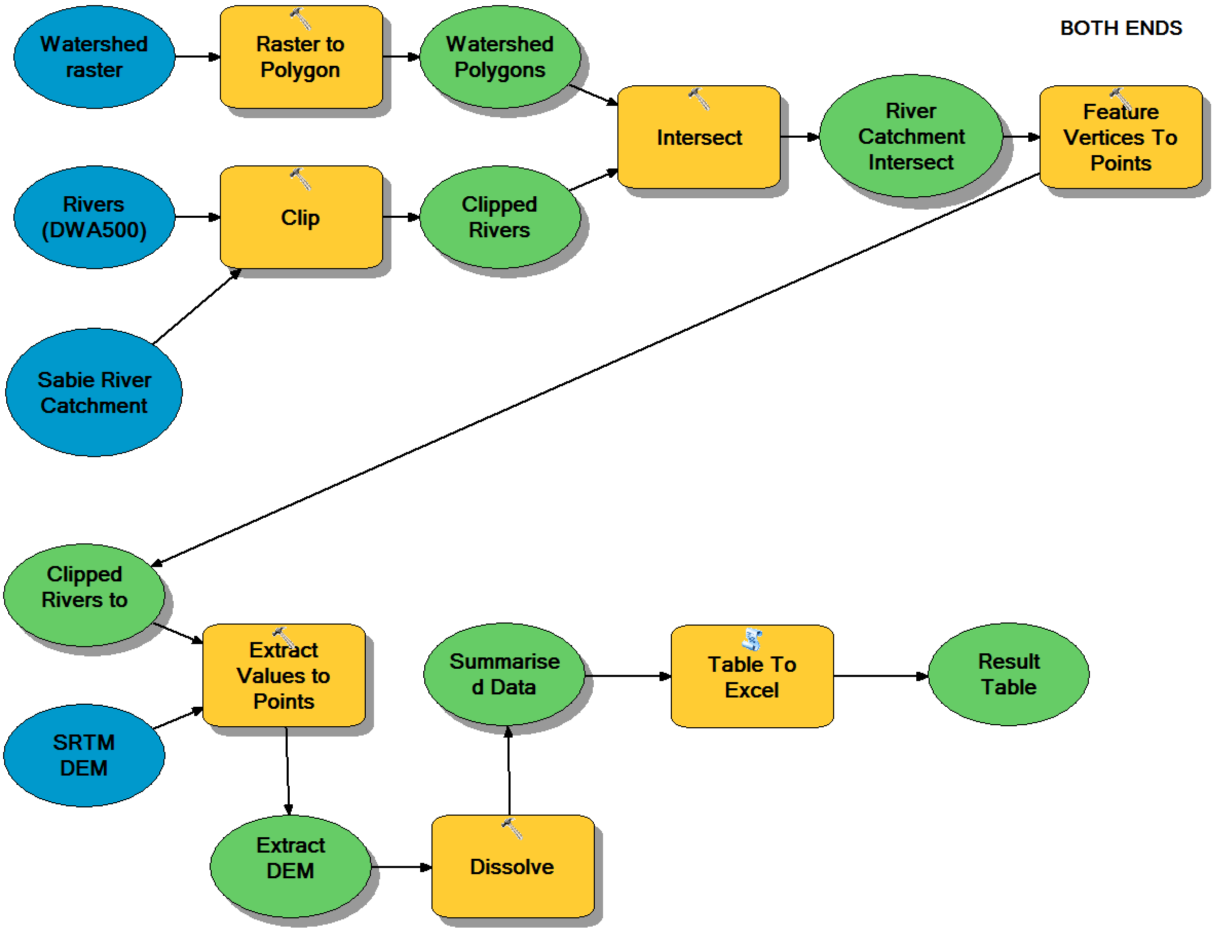


Figure 3-6: Defining river elevation using the sub-catchment polygons and Topo 1:250 000 river data

Figure 3.7 and 3.8 presents the workflow to extract a flow network from the SRTM DEM data. Sinks in the dem layer first needs to be filled to ensure proper connectivity of flow patterns within the DEM (Figure 3-7). Thereafter the flow direction (FlowDir) is calculated and the flow accumulation (FlowAcc) raster can then be derived from the flow direction raster. Using a conditional statement areas of significant flow accumulation, representing the flow network, can be determined. The flow network ultimately represents the river network. Based on how and where the flow lines connect will determine its stream order dataset. Figure 3-8 represents the final workflow to determine the stream order, using the Shreve order method, and to convert the flow network to a line vectorised stream network.

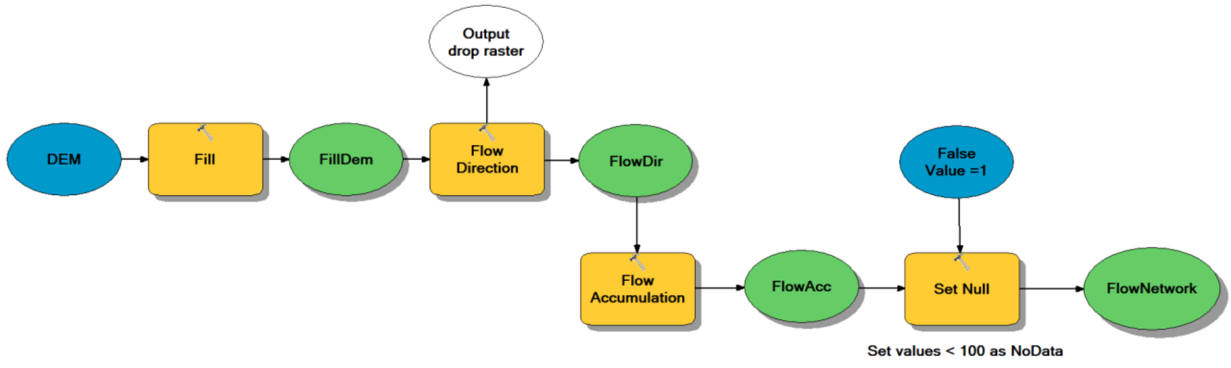


Figure 3-7: Model to calculate flow network from SRTM DEM for Sabie catchment

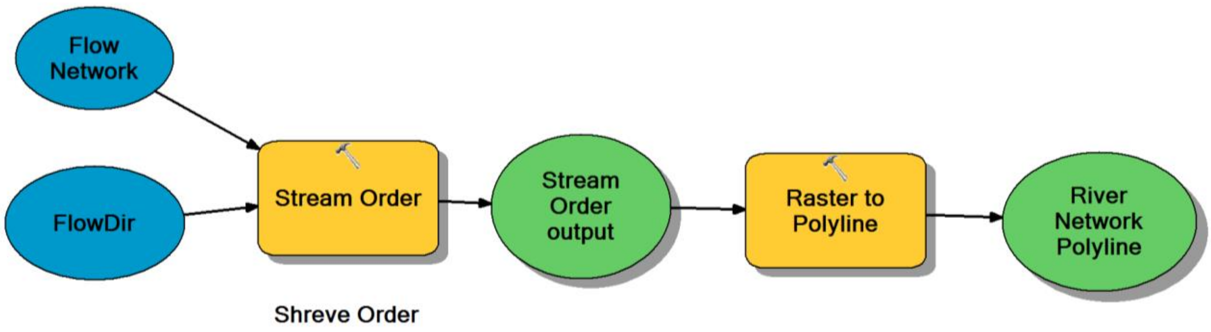


Figure 3-8: Defining the Flow Network stream order based on its Shreve order

3.2.3 Land use

A visual inspection was done by overlaying and comparing two datasets, the NLC data with 2015 SPOT 6/7 mosaic obtained from the South African National Space Agency (SANSA, 2015) and Google Earth Pro imagery (Google Earth, 2015). The 2015 SPOT/6/7 images were acquired on 24 March 2015 and 30 April 2015. Creating updated land-cover data for the study was deemed unnecessary since only minor land cover changes were observed. The NLC layer (Figure 3-9) was clipped according to the sub-catchment boundaries. This resulted in 12 sub-catchments, each with their own land cover layer. These raster datasets were representative of the non-point pollution sources of each catchment.

Initially, the 72-class NLC layer obtained from the EGIS website of the DEA was clipped to the Sabie-Sand Catchment (X3 secondary catchment boundary). Only 57 classes were applicable to this study area. The clipped dataset was then used to merge similar land-use types into broader categories. The broad, summarised 6-8 class classification used by several studies as seen in Table 3-1 was considered. Because the spatial scales of the 12 sub-catchments were relatively small compared with those in the literature, it was decided to aggregate the 57 class land-cover dataset into an 18-class land cover dataset (Figure 3-9). Clipping the 18-class land-cover dataset according to the 12 sub-catchments provided a cell count of the land-cover classes for each sub-catchment. These counts were used to obtain land cover percentages for the sub-catchments.

The data were divided into a binary class of transformed and natural. Transformed refers to all the anthropogenic land uses that have fully changed the landscape, and natural means that although the landscape is used, it has not been changed in its entirety. These are the transformed and natural land uses based on the 57-class land-cover layer. Transformed classes included cultivated commercial fields, barren land, plantations, mines and built-up areas. Natural vegetation classes included grassland, indigenous forest, thicket, woodland, low shrubland and permanent water. Three broad land-tenure classes were recognised, namely communal, commercial and conservation.

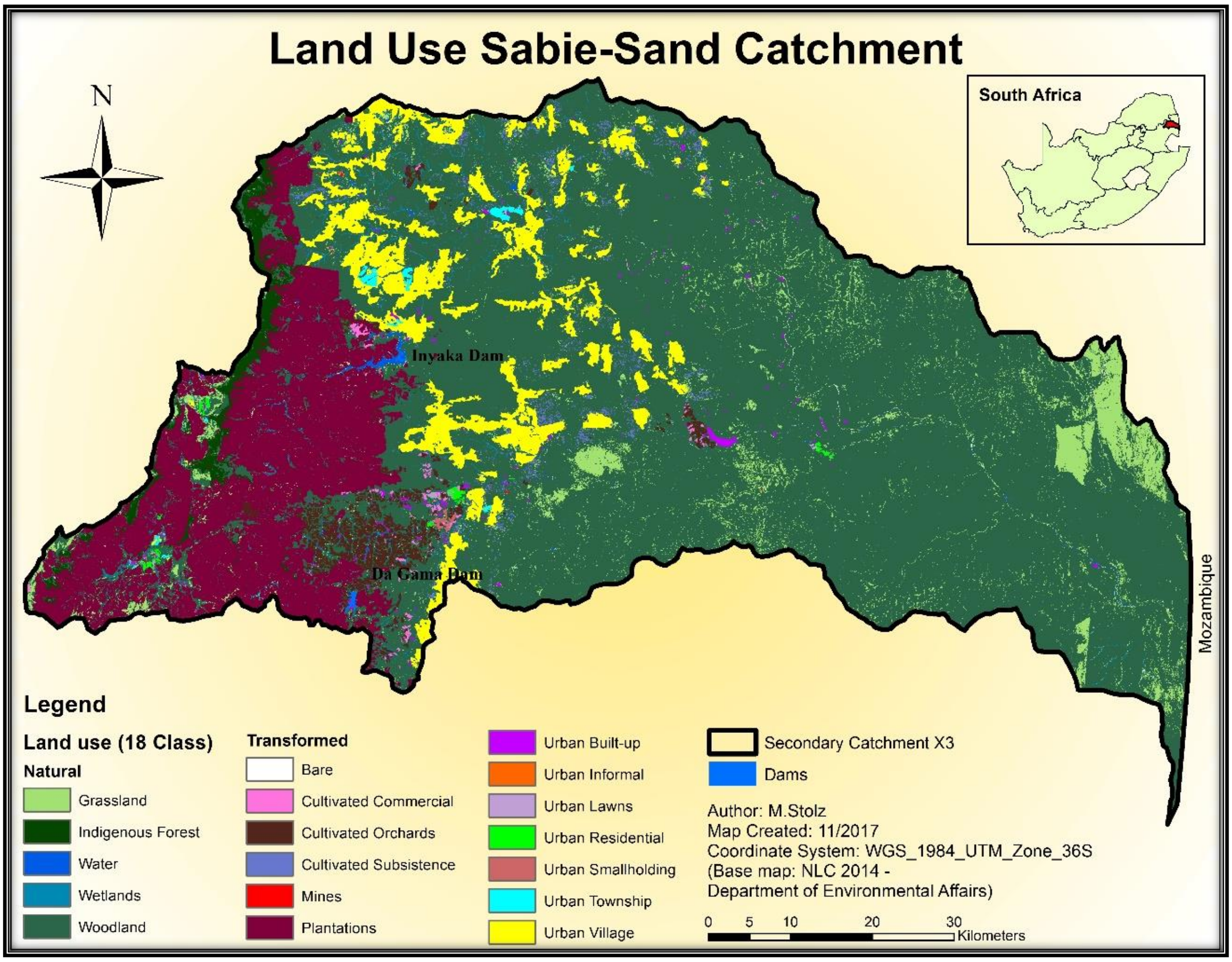


Figure 3-9: Sabie-Sands Catchment simplified, 18 class, land cover map derived from the 57 class 2013/2014 NLC layer (Geoterra Image, 2015)

3.2.4 Land use (point sources)

A major point source pollution (PSP) layer was created that consisted of identified pollution points near the rivers. It was foreseen that the intensity and range of influence of these pollution points could have an influence on river water quality. Therefore, the main use for this layer was to serve as an indicator of any outlier polluter that could not be explained through normal land-use activities. This was accomplished by digitising the point localities that may contribute to changing water quality and as far as possible, by verifying the data during field sampling trips and interrogating Street View photographs from Google Earth. This source layer (Figure 3-10) captures the localities of the most important WWTPs (green), large industries and factories such as saw mills and timber mills (blue) and bare ground/diggings from abandoned mines (red). Initially, active deforestation of timber plantation/woodlots during the sampling time was considered a PSP due to the increased probability of runoff. This was later revised since such plantations/woodlots were still regarded as non-point sources. This layer can be consulted when changes in water quality reflect other pollution possibilities not explained by non-point pollution sources.

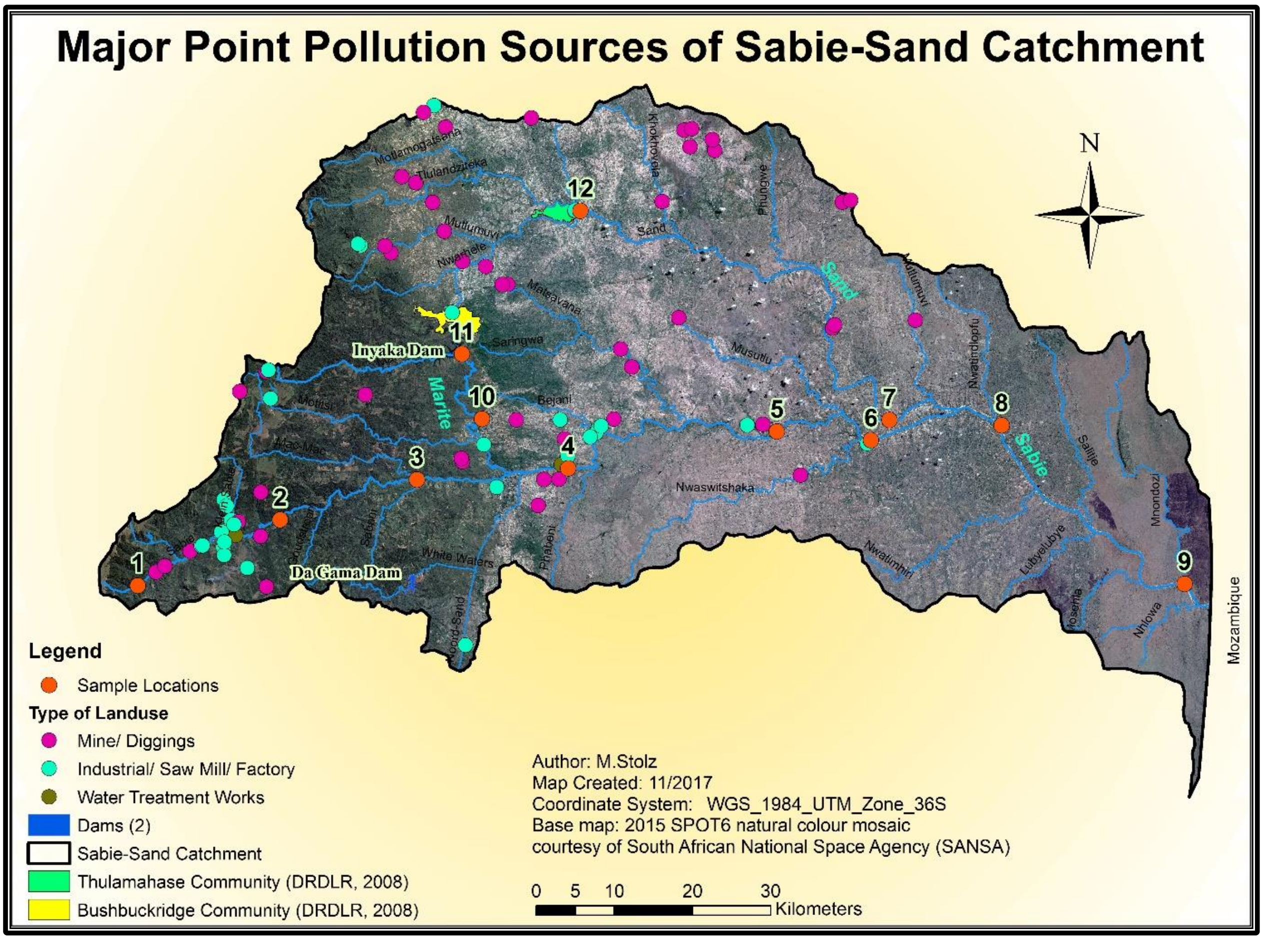


Figure 3-10: Possible major point source pollution layer for Sabie-Sand Catchment

The distances between PSPs and sampling localities were used to represent their possible influence on water quality. The distance of the PSP to the sampling locality was obtained using the Network Analyst extension on a Shreve river network. This meant that the route options of a PSP were determined by the river network (drainage line), allowing it to follow a path created by water even if it were only following a smaller tributary stream into the primary river network. Within the Network Analyst extension, the shortest downstream flow path was determined using the new route option. The shortest flow path was determined for each PSP to the nearest downstream sampling point.

3.2.5 Ancillary data

River flow data for gauging stations were obtained from DWS (2017a). These stations were representatives of the surface water flow through the sampling localities closest to the station. Unfortunately, the datasets for these gauging stations were not updated for the sampling periods, and only historical data were available for some of the stations. The lack of surface-flow data for certain stations was because the stations were non-operational due to floods or poor maintenance. In addition, not all of the sampling localities had stations close by. The river flow through each sampling locality could, therefore, not be analysed in terms of the most up-to-date data or working gauging station closest to the node. The river flows through the highest and lowest nodes were originally compared with surface flow station data to determine whether possible over abstraction of river water was taking place. On reflection, such an approach ignores in-catchment abstractions and discharge into the stream. To compensate for these types of inflows and outflows of the system, a model of catchment hydrology would be required, which is beyond the scope of this study.

3.3 Results

The tables and figures that follow summarise the physical and spatial parameters of the Sabie-Sand Catchment and serve as the results of the land-use analysis. The combined 18-class land-use data are represented in the pie charts for each sub-catchment (See Figure 3-11 to Figure 3.13 and Table 3-3 for detailed land-use results).

3.3.1 Land use and tenure

The highest percentage land use for sub-catchments 1, 2 and 3 as seen in Table 3-3 is the commercial practices of plantations and woodlots (PlanW) at 74%, 71% and 66% respectively, followed by grasslands (GrasL) at 11% for sub-catchment 1, and woodland-open bush (WdlnO) at 15.7% for sub-catchments 2 and 3. Plantation-woodlot represents 66% of the catchment within sub-catchment 3, 56.6% in catchment 10 and 64.9% in catchment 11 (Table 3-3).

This is supported by the effects of land-use noted in the State-of-the Rivers Report that covers sub-catchments 1 and 2 of the present study (Roux and Selepe, 2011). The possible threats from extensive forestry, which this previous study highlighted, included extensive siltation, erosion and abstraction. Roux and Selepe (2011) also mentioned alien riparian vegetation that may further reduce biodiversity and pose a threat to the natural vegetation system function. The study area of Roux and Selepe (2011) correlates with sub-catchments 3, 10 and 11 of the present study has the same forestry and alien vegetation impacts as mentioned, but includes banana plantations as a form of monoculture, which causes high erosion and sedimentation risks to the land surface. Plantation-woodlot percentages for sub-catchment 3 is 66%, for sub-catchment 10 is 56.6% and for sub-catchment 11 is 64.9%.

Dominant land use for sub-catchments 4 to 9 and sub-catchment 12 was woodland-open bush, which ranged from 39.40% to 95.40%. As confirmed by Roux and Selepe (2011), large parts of sub-catchments 4, 10 and 12 exist as communal occupancy or tenure (Table 3-3). Activities related to rural communities include small-scale and subsistence farming of fruit and livestock. This type of farming is prone to overgrazing of land, and as with banana monoculture, erosion and sedimentation pose a threat to the water quality. Livestock farming (cattle, goats, pigs and poultry) and crop farming (maize, vegetables, etc.) are the dominant types of subsistence farming in the rural area. Although sub-catchment 5 of the present study has a high woodland-open bush land-use percentage (Table 3-3), it is subjected to the rural community activities mentioned above (Observations during the present study; Roux and Selepe, 2011).

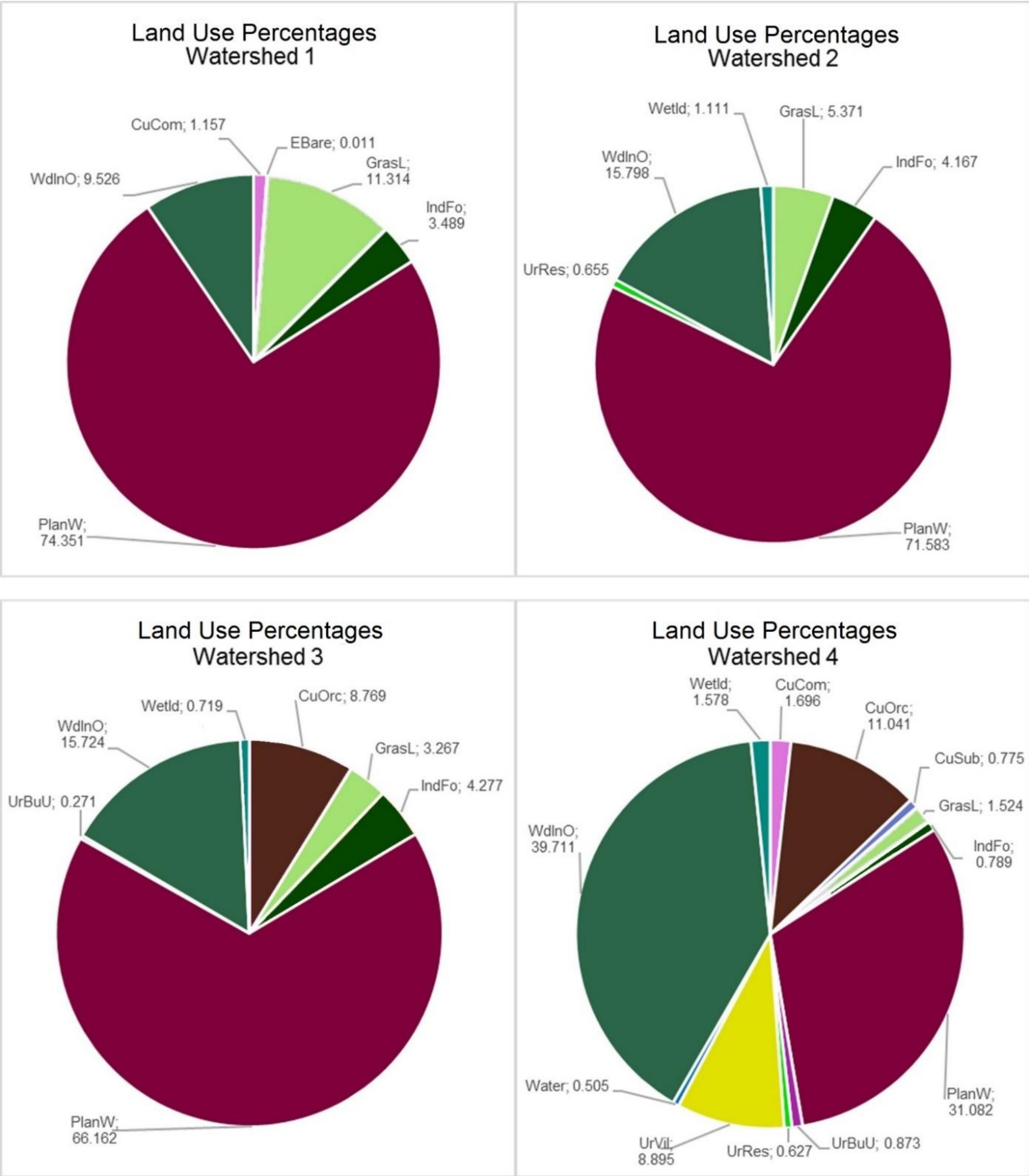
To the east of the commercial farming and forestry areas and to the west of the KNP are former ‘self-governing territories’, also known as homeland areas (referred to as a communal tenure class in the present study). It is evident from the study conducted by Woodhouse (1995) that farming in these areas is poorly developed. The reason is uncertain, but Woodhouse (1995) believes that this may be due to low and irregular rainfall in the area, as well as lower potential soils. The soils are stony or very sandy, which limits cultivation in these flatter areas

Table 3-3: Land-use results for sub-catchments 1-12 as the extracted 18-class land-use categories.

Sub-catchment	Land use as percentage of each sub-catchment																	
	CuCo	**CuOrc**	**CuSub**	**EBare**	**GrasL**	**IndFo**	**Mines**	**PlanW**	**UrBuU**	**UrInf**	**UrLaw**	**UrRes**	**UrSma**	**UrTsh**	**UrVil**	**Water**	**WdlnO**	**Wetld**
1	1.157	0.000	0.000	0.011	11.314	3.489	0.000	74.351	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	9.526	0.152
2	0.133	0.054	0.000	0.056	5.371	4.167	0.010	71.583	0.387	0.000	0.139	0.655	0.031	0.355	0.148	0.001	15.798	1.111
3	0.165	8.769	0.000	0.047	3.267	4.277	0.004	66.162	0.271	0.013	0.014	0.196	0.009	0.033	0.116	0.215	15.724	0.719
4	1.696	11.041	0.775	0.078	1.524	0.789	0.024	31.082	0.873	0.000	0.262	0.627	0.489	0.051	8.895	0.505	39.711	1.578
5	0.000	0.000	0.422	0.056	6.127	0.000	0.018	0.000	0.200	0.000	0.073	0.275	0.000	0.000	1.832	0.088	90.908	0.000
6	0.154	0.735	2.220	0.053	4.501	0.000	0.010	0.053	0.499	0.000	0.004	0.000	0.000	0.039	11.032	0.090	80.495	0.114
7	0.004	0.012	1.537	0.135	3.622	0.000	0.005	0.000	0.350	0.000	0.000	0.000	0.000	0.027	5.650	0.053	88.242	0.363
8	0.000	0.000	0.000	0.117	4.388	0.000	0.001	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.067	95.416	0.000
9	0.000	0.000	0.000	0.127	12.033	0.000	0.001	0.000	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.104	87.693	0.021
10	0.039	0.959	0.136	0.049	0.370	0.241	0.007	56.611	0.038	0.000	0.000	0.000	0.037	0.000	6.227	0.130	34.568	0.588
11	1.151	1.214	0.044	0.243	1.468	10.360	0.000	64.992	0.258	0.000	0.006	0.000	0.070	0.266	3.823	3.375	12.060	0.669
12	0.033	0.669	1.773	0.046	1.903	3.937	0.070	10.914	0.291	0.000	0.030	0.000	0.000	1.239	22.172	0.184	54.173	2.564

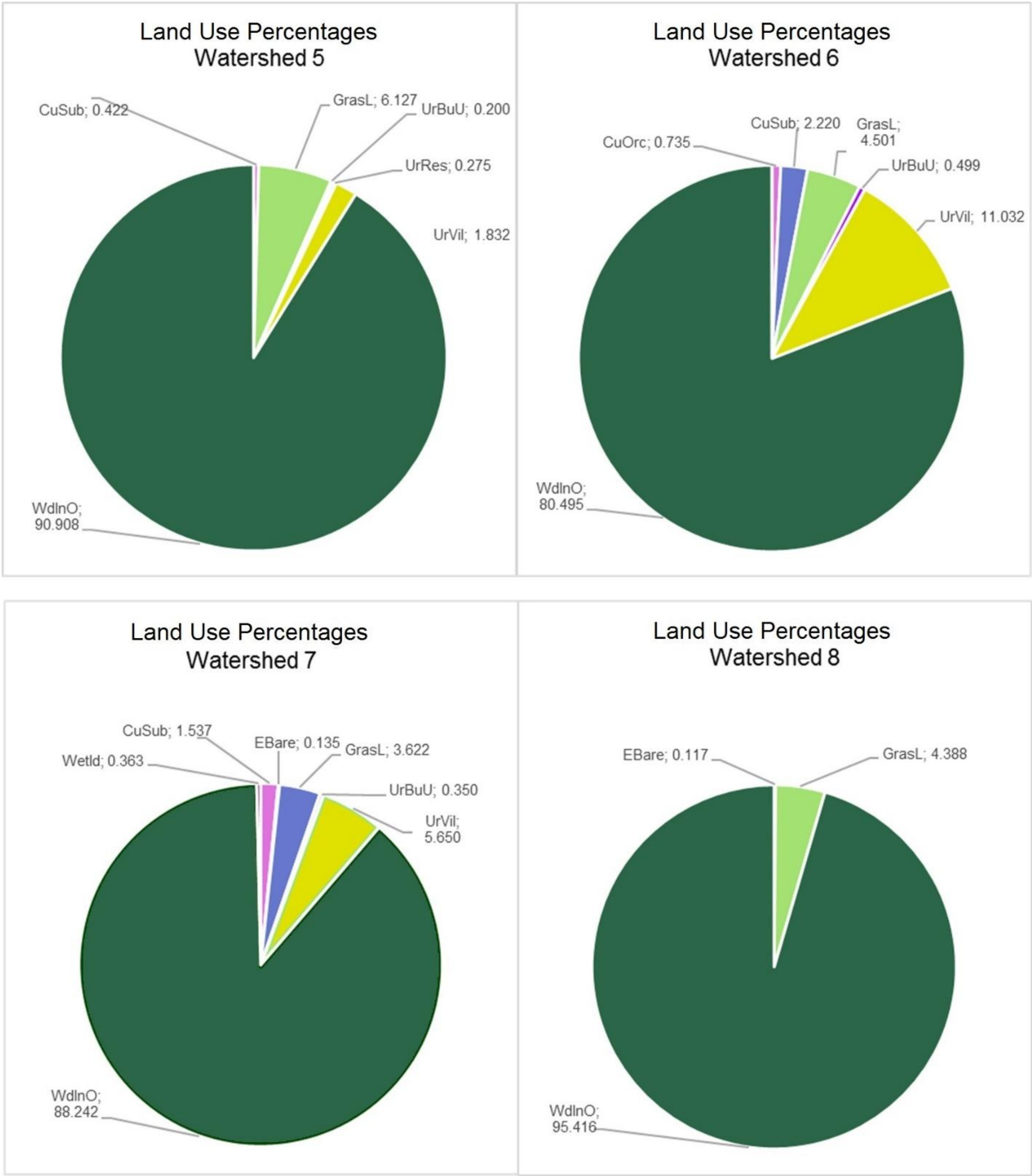
The table depicts the first and second-most dominant land uses of the sub-catchments as percentages in the colours of mustard and faded yellow respectively.

CuCom: Cultivated commercial; CuOrc: Cultivation Orchards; CuSub: Cultivation Subsistence; EBare: Erosion – Bare; GrasL: Grassland – Low Shrubland; IndFo: Indigenous Forest; Mines: Mines; PlanW: Plantation – Woodlots; UrbBuU: Urban Build-up; UrInf: Urban Informal; UrLaw: Urban Lawns; UrRes: Urban Residential; UrbSma: Urban Smallholdings; UrbTsh: Urban Townships;UrbVil: Urban Village;Water: Water; WdlnO: Woodland; Wetld: Wetland



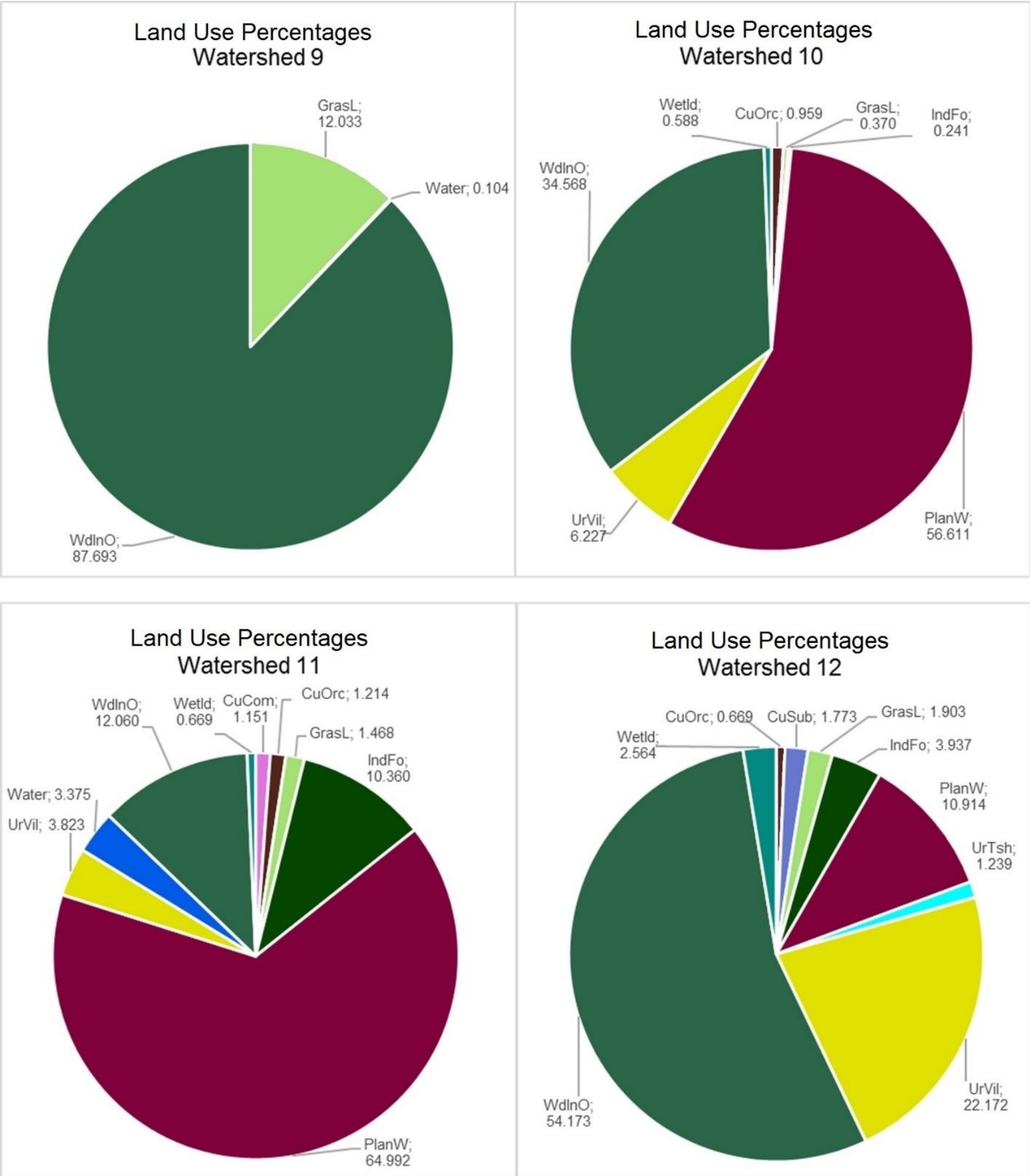
CuCom: Cultivated Commercial; CuOrc: Cultivated Orchards; CuSub: Cultivated Subsistence; EBare: Erosion-Bare; GrasL: Grassland-Low Shrubland; IndFo: Indigenous Forest; Mines: Mines; PlanW: Plantations-Woodlots; UrBuU: Urban Built-Up; UrInf: Urban Informal; UrLaw: Urban Lawns; UrRes: Urban Residential; UrSma: Urban Smallholding; UrTsh: Urban Townships; UrVil: Urban Village; Water: Water; WdlnO: Woodland; Wetld: Wetlands.

Figure 3-11: Pie charts representing land-use results in percentages of sub-catchment areas 1-4



CuCom: Cultivated Commercial; CuOrc: Cultivated Orchards; CuSub: Cultivated Subsistence; EBare: Erosion-Bare; GrasL: Grassland-Low Shrubland; IndFo: Indigenous Forest; Mines: Mines; PlanW: Plantations-Woodlots; UrBuU: Urban Built-Up; UrInf: Urban Informal; UrLaw: Urban Lawns; UrRes: Urban Residential; UrSma: Urban Smallholding; UrTsh: Urban Townships; UrVil: Urban Village; Water: Water; WdlnO: Woodland; Wetld: Wetlands

Figure 3-12: Pie charts representing land-use results in percentages of sub-catchment areas 5-8

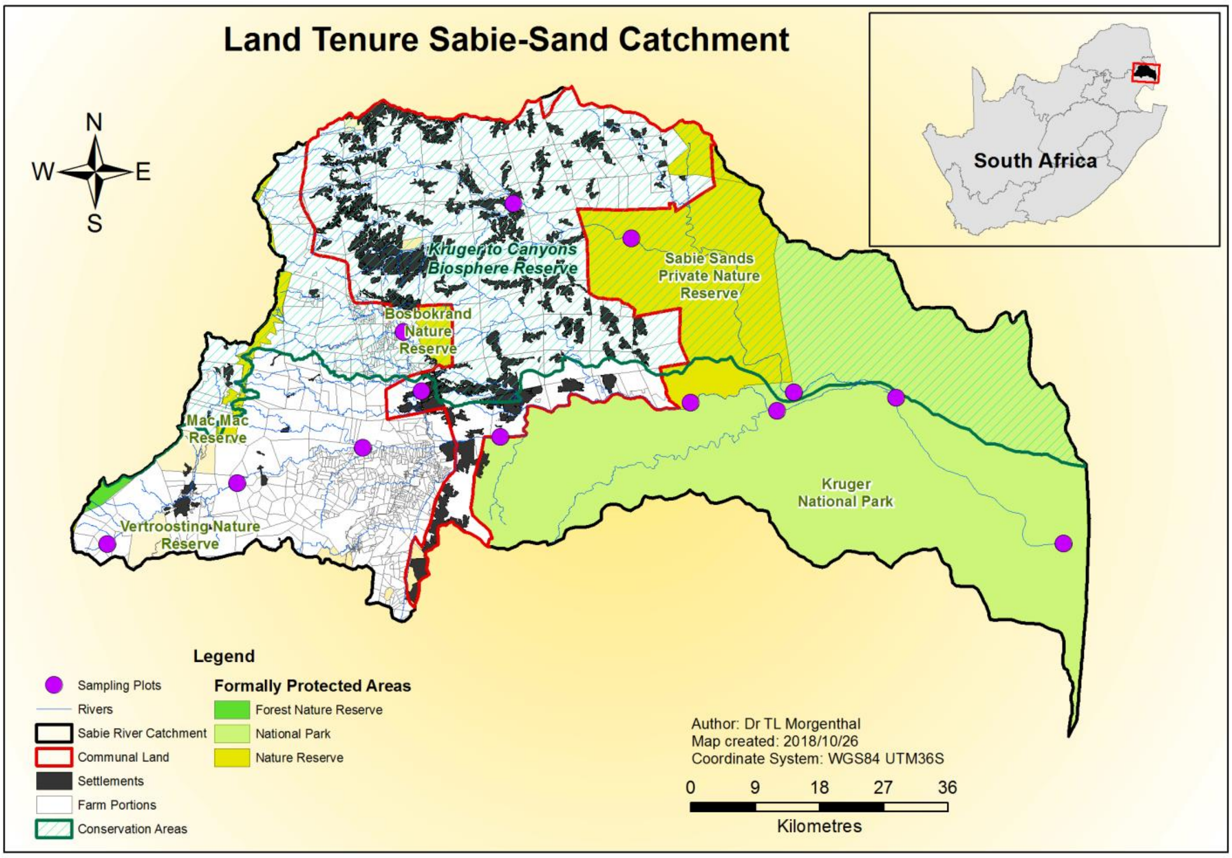


CuCom: Cultivated Commercial; CuOrc: Cultivated Orchards; CuSub: Cultivated Subsistence; EBare: Erosion-Bare; GrasL: Grassland-Low Shrubland; IndFo: Indigenous Forest; Mines: Mines; PlanW: Plantations-Woodlots; UrBuU: Urban Built-Up; UrInf: Urban Informal; UrLaw: Urban Lawns; UrRes: Urban Residential; UrSma: Urban Smallholding; UrTsh: Urban Townships; UrVil: Urban Village; Water: Water; WdlnO: Woodland; Wetld: Wetlands

Figure 3-13: Pie charts representing land-use results in percentages of sub-catchment areas 9-12

Possible cropping system alternatives on these flatter slopes are cultivation of tobacco, grain and vegetables (Woodland, 1995). Steep slopes can also account for cultivation constraints, as experienced in the commercial farming area.

The boundaries of sub-catchment 5 to sub-catchment 10 form part of the conservation tenure class (Figure 3-14). Sampling locality 5, monitored during the present study, is the most upstream site on the Sabie River that is subject to conservation by a national park The western boundaries of sub-catchments 11 and 12 are adjacent to a biosphere reserve called the Blyde River Canyon Nature Reserve, and to the east of sub-catchment 11 is the Bosbokrand Nature Reserve, which is also classified as part of a biosphere reserve. Although protected areas are located in the central to eastern side of the catchment (sub-catchments 5, 6, 7, 8 and 9), rural areas still occur adjacent to these conservation areas within the study area (Figure 3-14).



Map extent indicated as red square in insert map. Conservation and protected areas are from the DEA, (2016)

Figure 3-14: Map of land tenure patterns with the Sabie-Sands River Catchment

Parts of the river tributaries within the study area, especially the tributaries of the Sand River, flow through rural settlements and are subjected to non-conservational elements before reaching the protected areas of the KNP and its surrounding private game reserves. This raised initial concern since the Sand River flows directly through a rural community and converges with the Sabie River within the KNP. The KNP is the largest of South Africa’s protected area in South Africa and was established in 1926 for research and conservation and that is currently also a popular tourist destination. Apart from tourism, other factors also contribute to the existence of a protected area, namely the land being unsuitable for agriculture or forming part of residual areas that do not belong to any specific major land use (Coetzer *et al.*, 2010). Non-conservational influences are inevitable, and Coetzer *et al.* (2010) mentions that land uses and development proposals limit conservation initiatives through continuous population growth and the development of the socio-economic sector that is prioritised by the National Government. Population growth is highest in sub-catchments 11 and 12 (urban village land-use percentage of 22.17% in sub-catchment 12), with increasing Bushbuckridge and Thulamahashe populations. For progression, conservation should explicitly incorporate socio-economic development, especially in the surrounding villages. Such conservation decisions can no longer be made in isolation and thus, the highest priority of the current protected area systems is to address unavoidable land-cover modifications associated with economic growth while still maximising biodiversity protection (Coetzer *et al*., 2010).

Sub-catchments 6, 8 and 9 with dominant land-use percentages comprising woodland-open bush are all within the conservation boundaries of the KNP (Table 3-4). Although this confirms the low impact of land uses mentioned by Roux and Selepe (2011), ecotourism and conservation activities, the authors believe that erosion still occurs in parts of the KNP due to frequent. This may be associated with droughts, and extreme floods and the presence of highly erodible soils to which these areas have been exposed.

The present study identified points regarded as abandoned mines or bare ground in Figure 3-10 within these sub-catchments and areas surrounding the outer boundaries of the KNP. However, the abandoned mines found in this study area were either small or of little concern in regard to pollution of water sources. Operational mines were found to involve sand mining for the construction of houses near the villages and townships. It was decided that pollution emanating from the points that occurred farther away from the sampling locality would experience a 'remedial' effect before reaching the sampling locality. Thus, only WWTP points were regarded as sources of pollution in the main river stream remained (Table 3-4).

Table 3-4: Land tenure classes and distances to the wastewater treatment plants used within the multivariate analysis

Sub-catchment	Tenure	Commercial	Communal	Conservation	Distance (m) WWTP
1	Forestry	1	0	0	5456
2	Forestry	1	0	0	6727
3	Forestry	1	0	0	31555
4	Communal	0	1	0	1264
5	Conservation	0	0	1	38496
6	Conservation	0	0	1	54366
7	Conservation	0	0	1	121330
8	Conservation	0	0	1	139346
9	Conservation	0	0	1	174866
10	Communal	0	1	0	17931.
11	Forestry	1	0	0	36098
12	Communal	0	1	0	477

Eucalyptus and pine plantations dominate the upper Middleveld. According to Kimble *et al*. (2014), the Middleveld is a region of landscape with an intermediate altitude generally ranging between 600 mamsl and 1 200 mamsl. The Middleveld comprises the upper part of the Sabie River to shortly before the town of Hazyview and occupies approximately one-half to two-thirds of the land surface drained by the Sabie River. Exotic forest plantations include pine (*Pinus patula* Schlecht. et Cham., *P. elliottii* Engelm. and *P. taeda* L.) and eucalyptus (*Eucalyptus grandis* Hill ex Maiden). Pine and eucalyptus plantations are most successful in areas with an average rainfall of more than 700 mm/a, which is true for this region (Forest Owners Association, 1994 as cited by Dye, 1996). According to Woodhouse (1995), about 26% or more of the lower Middleveld (north, east and south of Hazyview and including the town) was at that time (1995) occupied by irrigated agriculture, which still holds true for sub-catchments 1, 2, 3, 10, 11 and most of 12. Land use is a dynamic entity and thus, these numbers have gradually changed through the years. Mainly tropical and subtropical crop varieties are cultivated and include mangos, avocados, bananas, pecan nuts and macadamia nuts (Woodhouse, 1995). According to Dye (1996), Smits *et al*. (2004), Tlou (2011) and to some extent Roux and Selepe (2011), the increase in water use due to forestry and plantations is of great concern. Woodhouse (1995) was of the same opinion and stated that yearly fluctuation in water availability leads to a fluctuation in the irrigated areas, especially in regard to the Middleveld.

3.3.2 Soil, geology and slope

According to Gertenbach (1983), soil patterns for this catchment correspond closely with the position in the topography. The dominant slope for the catchment area has a general west-to-east downward gradient with the highest altitude being 1 559.5 mamsl and the lowest being 178.6 mamsl (Table 3-5). Sub-catchment 1 demonstrated the steepest river slope with a 24% rise, whereas sub-catchments 2 and 3 demonstrated a steady downward percentage slope, reaching an even plane at sub-catchments 5-9. Slope analysis as a spatial characteristic on its own was mainly conducted as a means to include runoff influences. Slope influences run off and can, therefore, also influence the number of surface constituents that enter the river. The mean river slope for the sub-catchments followed a similar slope trend to the average slopes of the river segments flowing through them, except within sub-catchments 2, 3 and 12, which indicated a gradual river slope gradient within a more undulating landscape (Table 3-5).

Table 3-5 below presents the mean elevation of each sub-catchment in metres above mean sea level (mamsl), the percentage rise in slope for the river and the percentage rise in slope for each sub-catchment.

Table 3-5: The mean slope for the Sabie-Sand Catchment as derived from the SRTM90 DEM

Sub-catchment	**Mean elevation of sub-catchment**	**Mean slope of river**	**Mean slope of sub-catchment**
	(mamsl)	%	
1	1559.51	24.07	29.69
2	1024.50	10.04	21.66
3	715.98	13.63	18.05
4	481.80	7.14	13.14
5	345.70	4.23	5.88
6	267.14	4.23	4.14
7	327.41	4.10	4.43
8	232.99	4.40	4.01
9	178.59	3.50	4.50
10	652.90	9.27	12.63
11	887.19	10.06	16.21
12	416.63	2.73	9.85

Source: Jarvis *et al.*, 2008

The main geological rock type (Table 3-6) for the study area is granite, which comprises 59% of the lithological layer 1 and occurs at every sub-catchment except sub-catchment 1. Granite is followed by shale and tonalite at 12% and 13.6%, respectively. Shale is a finely stratified, consolidated, sedimentary rock while tonalite is an igneous plutonic rock with the same composition as diorite but with considerable quartz content (SCWG, 1991).

Table 3-7 presents the land type that is used to describe the soil types (Table 3-8) that occur in the area. The dominant land type (Table 3-7) with a percentage of 40% for the entire catchment is Ab and consists predominantly of dystrophic and/or mesotrophic red- or yellow-brown pedal soils (Table 3-8). Red- and yellow-brown apedal soils are freely drained and weakly structured soils that are homogenous in colour through the soil profile (SCWG, 1991). Dystrophic diagnostic soil means that the soil has suffered marked leaching to the extent that the sum of exchangeable Ca^{2+}, K^{+}, Na^{2+} and Mg^{2+} is less than 5 cmol(+) per kg clay compared with mesotrophic soils at 5-15 cmol(+) per kg clay (see cation exchange capacity in definitions) (SCWG, 1991). The Ab land type occurs predominantly in sub-catchments 1-4, 10 and 11 on the lower slopes of the escarpment (Table 3-7). According to Land Type Information (SCWG, 1991), clay percentages are generally high (26-24%) due to their siliceous parent material in parts containing high percentages of 1:1 layered clays (e.g. shale).

The second dominant land type (Table 3-7) with a percentage of 30% for the entire catchment is Fb, which is characterised by soils of the Glenrosa and/or Mispah forms, although more developed soils may be present in specific landscape positions. Glenrosa soil forms are soils with an orthic topsoil A horizon and a lithocutanic B subsoil, which develops *in situ* from underlying parent rock material (SCWG, 1991). The cutanic character develops from heterogeneous weathering expressed as tongues of colour variegation due to illuviation (SCWG, 1991). The Mispah soil form is characterised by an orthic topsoil and hard rock subsoil. According to SCWG (1991), this hard rock cannot be cut with a spade because it is a continuous layer of silcrete or metamorphic, igneous and indurated (hardened) sedimentary rocks. The Fb land type within the Sabie-Sand Catchment is associated with poorly developed soils on Archaean granitoid intrusions (Johnson *et al*., 2006) along the bottom plains of the catchment and covers 16% of the catchment area within sub-catchments 5-9 (Table 3-7).

The third most-dominant land type (Table 3-7) is the Hb land type (9.3% of the catchment) that is characterised by grey regic sands and other soils that are characterised by low to very low clay percentages (7.6%) as seen, for example, in sub-catchment 12. Regic sand is recently deposited, showing little to no evidence of pedogenesis after deposition (SCWG, 1991). There could possibly be a darkening of the topsoil brought about by organic matter from an orthic A horizon. These regic sands are either massive or single grained, have little to no macroscopic structure and are coarse in texture with a loose, friable or soft consistency. The sands do not differ greatly in mineral composition from the parent material and as a result of minimal pedogenesis, little to no clay formation has occurred (SCWG, 1991). Within the catchment, the grey regic sand formation could be the result of deep weathering of granites. This is supported by the statement of Gertenbach (1983) that the low-lying areas along the river are underlain by Archaean granite and gneiss that are intersected by dolerite intrusions. Gertenbach (1983) also mentions that soils from the low-lying areas are normally shallow, and where deeper, they are usually saturated with sodium. This is mainly due to mineral and clay accumulation within the low-lying areas.

Table 3-6: Percentage occurrence of main lithological forms within the Sabie-Sand Catchment representing the geology spatial characteristic used for multivariate analysis

Sub-catchment	Lithological layer 1 of watershed														
	Andesite	Arenite	Basalt	Dolerite	Dolomite	Gabbro	Gneiss	Granite	Granodiorite	Granophyre	Quartzite	Rhyolite	Sedimentary	Shale	Tonalite
1	-	-	-	-	-	-	-	-	-	-	-	-	-	100	-
2	0.29	-	-	-	44.72	-	-	10.94	0.96	-	11.2	-	0.1	31.78	-
3	-	-	-	17.6	12.88	-	-	61.22	1.56	-	5.6	-	-	1.14	-
4	-	-	-	9.43	0.11	0.17	-	71.82	16.89	-	0.9	-	-	0.69	-
5	-	-	-	0.04	-	6.39	-	50.17	-	-	-	-	-	-	43.4
6	-	-	-	0	-	1.65	-	74.76	-	-	-	-	-	-	23.59
7	-	-	-	0	-	0	-	59.1	-	-	-	-	-	-	40.9
8	-	-	-	0.95	-	3.33	-	95.72	-	-	-	-	-	-	-
9	-	3.16	25.11	0	-	0.46	1.61	51.36	-	1.04	-	9.91	-	7.35	-
10	-	-	-	-	-	-	-	90.63	-	-	-	-	-	-	9.37
11	-	-	-	-	0.44	-	-	83.89	-	-	1.34	-	-	4.76	9.56
12	-	-	-	-	0.01	-	-	61.31	-	-	0.26	-	-	2.04	36.38

Table 3-7: Soil summary statistics of average soil depth, percentage clay and percentage occurrence of broad land types (Table 3.8) within the Sabie-Sand Catchment

Sub-catchment	Soil depth (mm)	Soil clay%	Land type percentage of sub-catchment								
			Ab	Ac	Ae	Dc	Ea	Fa	Fb	Hb	Ib
			(%)								
1	918	39.10	27.067	36.395	-	-	-	36.538	-	-	-
2	969	42.20	45.385	44.689	-	-	-	9.925	-	-	-
3	650	33.70	80.488	17.354	-	-	-	-	-	-	2.157
4	421	26.20	91.325	0.417	6.325	-	-	-	0.399	-	1.535
5	318	16.00	7.577	-	17.983	-	-	-	45.481	-	-
6	318	16.00	-	-	2.147	-	6.694	-	90.553	0.605	-
7	318	16.00	-	-	-	-	2.676	-	70.756	26.568	-
8	318	16.00	-	-	-	0.754	0.000	-	99.246	-	-
9	347	16.80	-	-	-	14.679	24.301	-	61.021	-	-
10	650	33.70	100.00	-	-	-	-	-	-	-	-
11	836	38.50	91.427	2.228	-	-	-	-	-	-	6.345
12	933	7.60	41.766	-	-	-	-	-	-	55.209	3.025

Source: Land Type Survey Staff, 2002

Table 3-8: Land type descriptions within the Sabie-Sand Catchment

Land types	Soil description
Ab	Red-yellow apedal, freely drained soils; red, dystrophic and/or mesotrophic
Ac	Red-yellow apedal, freely drained soils; red and yellow, dystrophic and/or mesotrophic
Ae	Red-yellow apedal, freely drained soils; red, high base status, >300 mm deep (no dunes)
Dc	Prismacutanic and/or pedocutanic diagnostic horizons dominant. In addition, one or more of vertic, melanic, red structured diagnostic horizons
Ea	One or more of vertic, melanic, red structured diagnostic horizons, undifferentiated
Fa	Glenrosa and/or Mispah forms (other soils may occur), lime rare or absent in the entire landscape
Fb	Glenrosa and/or Mispah forms (other soils may occur), lime rare or absent in upland soils but generally present in low-lying soils
Hb	Grey regic sands and other soils
Ib	Miscellaneous land classes, rocky areas with miscellaneous soils

Source: Land Type Survey Staff, 2002

4 WATER QUALITY

4.1 Introduction

Healthy ecosystems are dependent on the services provided by healthy rivers. However, the high ecological flow requirements of the Kruger National Park (KNP) together with the need to support rural development and improved service delivery to the rural sector may lead to the Sabie-Sand River system as a whole becoming water stressed. Improved operation of the system will be necessary if all the water requirements and the Ecological Reserve are to be met (Beumer & Mallory, 2014). Both decrease flows and an increase in rural development lead to a decrease in water quality. Currently, the water quality of the Sabie River is rated as good within the confines of the KNP. The Sand River, a main tributary of the Sabie River, converges with the Sabie River within the park. The ecostatus of the Sand River is rated as moderately impaired, mainly due to the rural transformation of the upper reaches and the conservation land uses in the lower reaches (Roux & Selepe, 2011).

Monitoring water quality and the anthropogenic disturbances on water resources is essential to indicate the quantities of clean water required for domestic use, the sustainable ecological flow of rivers and the source water qualities for these uses. This is particularly true during times of extreme climate conditions such as the drought experienced during 2015-2016. Droughts are increasing in frequency worldwide due to climate change. Weather conditions and low rainfall result in reduced runoff, reduced river flows and low dam levels that can lead to significant changes in water quality. Over the past decade, there has been an increasing number of studies conducted on the effects of drought on water quality. However, these were mostly done in North America, Europe and Australia. In general, droughts and the immediate post-drought periods were found to have great effects on water quality. These effects are varied and depend on the characteristics of the waterbody and its catchment. However, droughts usually result in deterioration of the water quality in rivers and dams due to increased salinity (Yan *et al.*, 1996), acidification (Mosley *et al.*, 2014), temperature (Van Vliet & Zwolsman, 2008) and eutrophication (Mosley *et al.*, 2014).

Moreover, drought periods are beneficial for cyanobacterial growth. As water levels in waterbodies fall, the water column reaches a higher temperature, which promotes cyanobacterial growth. In addition, point source pollution (PSP) such as domestic septic systems will not be diluted as occurs in wetter periods, and non-point source pollution during a drought can result in large discharges once the drought breaks. Droughts can lead to water quality problems but above normal rainfall at the end of a drought period can also cause problems such as sediments becoming suspended. Runoff from agricultural lands can increase nutrients and sediments, resulting in increased growth of bacteria, algae and cyanobacteria (Eslamian & Eslamian, 2017).

Although numerous studies have focused on the spatial and temporal variability of water quality (Mayer *et al.*, 2010; Olds *et al.*, 2011), little information is available on the comparative assessment of water quality that covers both drought and post-drought periods (Li *et al.*, 2018; Mosley, 2015). This is crucial in understanding the water quality impacts of drought and thus water quality management, given the responsibility towards the conservation practices of the KNP, the international water agreement between South Africa, Swaziland and Mozambique and the protection of the catchment's water resources.

This water-quality study was initiated during the height of the drought period (2016) and the immediate post-drought period (2017). By conducting water-quality assessments in terms of algal biomass, physical and chemical water-quality parameters and land utilisation, source water quality and the influence of land use can contribute to catchment management, water purification and community development under extreme conditions.

4.2 Materials and methods

4.2.1 Sample collection and analyses

Sampling of chemical and physical variables occurred seasonally from January 2016 to October of 2017. The 12 samplings sites are described in Section 2.

A grab sample of nine litres of surface 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 samples were then transferred to the allocated containers. Table 4.1 presents the physical-chemical parameters that were determined *in situ*.

Table 4-1: Physical-chemical parameters measured *in situ* at each sampling site

Quality Variable	Symbol	Unit
Barometric pressure	mmHg	mmHg
Dissolved oxygen	DO	mg/l
Electrical conductivity	EC	µS/cm
Percentage dissolved oxygen	%DO	%
pH	pH	
Water temperature	Temp	ºC

Parameters measured with a YSI 556 handheld field multimeter

All chemical, microbiological and hydro-biological analyses were carried out by Rand Water Analytical Services. The standard methods of the American Public Health Association (APHA) (2013) were used, and the laboratory is accredited according to the South African National Accreditation System (SANAS) that is affiliated to the International Laboratory Accreditation Cooperation (ILAC). Table 4-2 shows a summary of the chemical, microbiological and hydro-biological variables that were determined, and indicates the method number listed, the unit of measurement and the reporting limit for each variable.

Table 4-2: Summary of the physical-chemical variables measured by Rand Water Analytical Services

Method Number	Quality Variable	Symbol	Unit	Reporting Limit
** Method not accredited by SANAS*				
2.2.2.02.10*	2-Methylisoborneol	2-MIB	ng/l	<0.5
2.1.4.03.1 (Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Aluminium	Al^{3+}	µg/l	<25
2.1.8.04.2	Ammonia	NH_3^-	mg/l as N	<0.2 (Feb, Apr) <0.05 (Jul, Oct)

Method Number	Quality Variable	Symbol	Unit	Reporting Limit
2.1.4.03.1 (Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Calcium	Ca^{2+}	mg/l	<0.90
2.1.3.03.1	Chemical oxygen demand	COD	mg/l	<10
2.1.7.01.1	Chloride	Cl^{-}	mg/l	<0.5
1.1.2.01.1	Chlorophyll-*a*	Chl-*a*	µg/l	<2
2.2.1.01.2	Dissolved organic carbon	DOC	mg/l as C	<0.2
1.2.2.09.1	*Escherichia coli*	*E. coli*	MPN/100 ml	0
2.2.2.02.10*	Geosmin	Geo	ng/l	<0.5
2.1.4.03.1 (Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Hardness	Hard	mg/l $CaCO_3$	<5
2.1.4.03.1 (Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Iron	$Fe^{2+}/^{3+}$	µg/l	<5
2.1.4.03.1 (Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Magnesium	Mg^{2+}	mg/l	<1.5
2.1.4.03.1 (Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Manganese	Mn^{2+}	µg/l	<10
2.1.3.01.2	Methyl orange alkalinity (total alkalinity)	M alk	mg/l $CaCO_3$	<5
1.1.2.09.1 (Feb, Oct, Apr)	Microcystin	Mic_n	µg/l	<0.36
2.1.7.01.1	Nitrate	NO_3^{2-}	mg/l as N	<0.1
2.1.8.01.2	Nitrite	NO_2^{-}	mg/l as N	<0.03
2.1.8.03.2	Orthophosphate	PO_4^{3-}	mg/l	<0.1 (Apr) <0.2 (Feb, Jul, Oct)
1.1.2.01.1	Phaeophytin-a	Phaeo	µg/l	<2
2.1.4.03.1 (Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Phosphorus	P^{3-}	mg/l	<0.5
2.1.4.03.1 (Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Potassium	K^{+}	mg/l	<1.5

Method Number	Quality Variable	Symbol	Unit	Reporting Limit
2.1.4.03.1 (Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Silica	Si	mg/l	<1
2.1.8.05.2 (Feb, Apr, Jul, Oct)	Silicon dioxide	SiO_2	mg/l	<0.5
2.1.4.03.1 (Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Sodium	Na^+	mg/l	<2.0
2.1.7.01.1	Sulphate	Sulph or SO_4^{2-}	mg/l	<1
2.1.2.05.1	Suspended solids	SS	mg/l	<15
1.2.2.09.1	Total coliforms	Coli	MPN/100 ml	0
2.1.2.04.1	Total dissolved solids	TDS	mg/l	<15
2.1.8.02.2	Total Kjeldahl nitrogen	TKN	mg/l as N	<1
2.2.3.02.1	Total organic carbon	TOC	mg/l as C	<0.2
2.1.8.06.2*	Total phosphate	TPO_4^{3-}	mg/l	<0.036
2.1.4.03.1 (Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Total silica	Tsi	mg/l	<0.15
2.2.2.10.1*(Apr)	Total solids	TS	mg/l	<15
2.1.2.02.1	Turbidity		NTU	<0.25
2.1.4.03.1(Feb, Apr, Jul) 2.1.4.01.1 (Oct)	Zinc	Zn^{2+}	µg/l (Feb, Apr, Jul) mg/l (Oct)	<0.015 (Feb, Apr, Jul) <0.15 (Oct)

NTU: Nephelometric Turbidity Units
The method for Total phosphates converts naturally occurring forms of inorganic and organic phosphorous to ortho-phosphate (PO_4^{3-})*, regardless of whether they occur in the solid or liquid phase.
The method for Ortho-phosphates determines dissolved ortho-phosphate
The method for Phosphorus determines all dissolved forms of phosphorous both organic and inorganic.

4.2.2 Statistical analysis

The water quality dataset consisted of biological, chemical and physical parameters. Results that were below the reporting limit were assigned a value of one-half the reporting value in order to be included in data processing. Missing data were treated as gaps, and 0 was used where the variable was measured as zero. All statistical analyses were carried out using Statistica version 13, Dell Inc. (2016). Initially, the Kolomogorov-Smirnov and Lilliefors tests for normality were conducted to determine if the data were distributed parametrically. The data did not meet the assumptions of normality in the distribution of all variables and thus, non-parametric statistics were applied. The Kruskal-Wallis analysis (comparison of multiple groups) was used to compare multiple independent groups. The significance of the results of a Kruskal-Wallis ANOVA can be determined as a *z*-value and/or a 2-tailed *p*-value. The *p-values* of these comparisons are listed in Appendix B, table B-1.

Cluster analysis was also done using Statistica version 13, Dell Inc. (2016). An agglomerative hierarchical cluster analysis was conducted on the total dataset for 2016 and 2017. The squared Euclidean distances were used to measure similarity, and the linkage distance was reported on an x-axis. Ward's method was used as an evaluation criterion (Kändler *et al.*, 2017). One of the reasons for using the complete-linkage algorithm is that the result is more ecologically interpretable (Lepš & Šmilauer, 2003). When a new cluster forms during the complete-linkage, the method uses the (dis)similarity between the farthest two members (points) of each group or single object (e.g. those with the smallest similarity). All members in the cluster, therefore, fall within a region of maximum similarity relative to one another (Buttigieg & Ramette, 2014). When a new cluster forms during the Ward's method, a 'cost' of merge is determined against an objective function. At each stage of the algorithm, merges with the minimum cost are performed. Minimum cost would be clusters with the smallest values when the sum of the squared deviations from the cluster centroids are calculated (Buttigieg & Ramette, 2014).

The components that caused the most variance in the water quality data and their positive and negative correlations with their component variables were determined through principal component analysis (PCA) using the Canoco 4.5 software program (Ter Braak & Šmilauer, 2002). A constrained form of the linear ordination method of PCA, otherwise known as a redundancy analysis (RDA), was also performed using Canoco 4.5 (Ter Braak & Šmilauer, 2002). The RDA is the key method used when determining environmental quality and landscape relationships. The RDA method summarises the variation in a set of response variables (e.g. water-quality variables) explained by a set of explanatory/predictor variables (e.g. catchment percentage land use) (Buttigieg & Ramette, 2014). Log transformation of the dataset, that is, log(y+1) was applied. A Monte Carlo permutation test (499 permutations) was used to determine the statistical validity of the RDAs.

4.3 Results

4.3.1 Rainfall and river flow

The study area falls within a summer rainfall region with an average rainfall of 700 mm/a, which varies from west to east. The catchment experiences a higher rainfall in the western sub-humid (sub-tropical) section than in the eastern semi-arid part of the catchment. The average annual rainfall decreases along a topographical gradient from the mountainous areas through the foothills and towards the lower, flatter reaches of the Sabie River, ranging between 1 500 mm/a and 900 mm/a to the west and between 600 mm/a and 348 mm/a to the east of the catchment. The rainfall season is usually from October to April. Monthly and daily rainfall data were obtained from DWS (2017a), and the monthly data were used for final analysis. Only one of the rainfall stations (Station X3E005) at Inyaka Dam was regularly updated by DWS during this study. The total rainfall for 2016 at this rainfall station was 888 mm compared with the total of 1 073 mm during 2017. Flow data (Figure 4-1) obtained from the Inkomati Catchment Management Agency (IUCMA) show that flow during 2016 varied significantly from the flow measured during 2017, especially in the lower Sabie (site 8) and at the Exeter measuring station that is located in the Sand River between site 12 and site 7. The average hydrological flow measured in the Sand River at Exeter flow gauge was 16 times higher during 2017 that the average flow during 2016. The Sabie River also experienced higher flows, the flow increased 2.5 times at the Sabie flow gauge and 4 times at the flow station in the lower Sabie River.

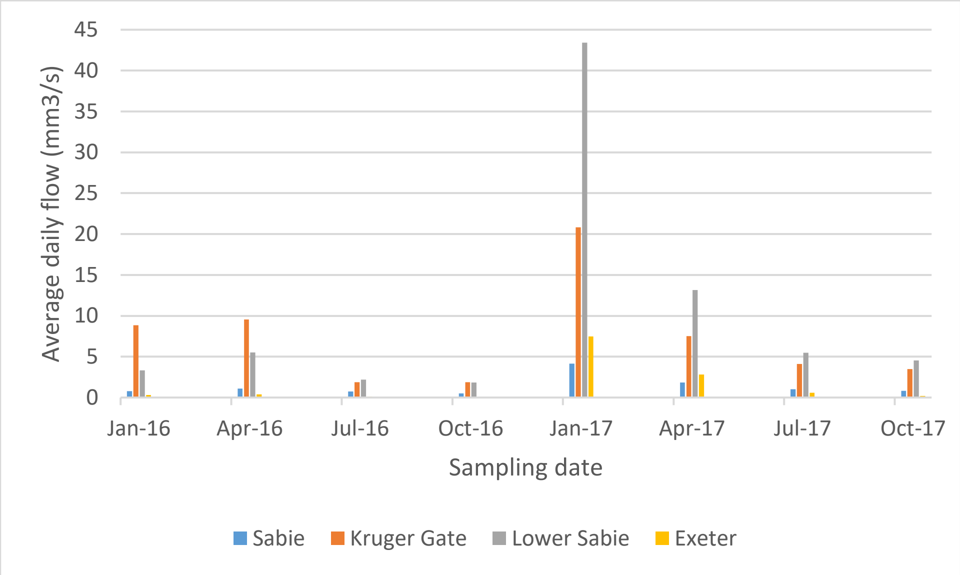


Figure 4-1: Flow data for the Sabie and Sand rivers for 2016 and 2017

4.3.2 Water quality 2016

Table 4-3 lists the values and ranges of the water-quality variables determined during the study period compared with (1) the target water quality range (TWQR); and (2) the resource quality objectives (RQOs) for all the sampling sites. The average value for each water-quality parameter is listed as the first value in each cell with the range values (minimum to maximum) presented as the second value in the cell. The values that exceeded the TWQR and the RQOs are shaded.

Most of the variables measured during the study for 2016 complied with the TWQR prescribed by the South African Water Quality Guidelines (DWAF, 1996a, 1996b). However, a few of the measured variables did not comply with the TWQR. The measured concentrations of aluminium did not comply with the TWQR of 0-0.01 mg/l. The highest concentrations of aluminium were found at site 7 (maximum of 460 µg/l) and the second highest concentrations were observed at site 10 in the Marite River (maximum of 185 µg/l). The average concentration of aluminium determined at both sampling sites were higher than the acute effect value of 150 µg/l. Aluminium is least soluble in the neutral pH range (6.5-7.5). The pH of the water at these sites varied from a minimum value of pH 5.9 determined at site 10 to a maximum of pH 7.58 determined at site 7. Hence, site 10 may be at risk. The ammonia concentrations measured at all of the sites did not comply with the set TWQR of 0.007 mg/l. Site 12 in particular showed much higher concentrations than the target range, with an average of 5 mg/l and a maximum value of 11 mg/l. Since the data only represent single measurements every three months, the potential effects that ammonia may have on the aquatic environment could be modified by other factors. Chloride concentrations at all the sites exceeded the TWQR by a large margin during 2016. This same tendency also reflected by the electrical conductivity (EC) values that exceeded the RQO set for the Sabie-Sand Catchment. Zinc exceeded the TWQR at sites 5, 10, 11 and 12, but due to the reporting limit set by Rand Water, it is not certain if the zinc concentrations at the remaining sites complied with the TWQR or not.

Only site 12, located in the Sand River within the urban township of Thulamahashe, exhibited an average concentration of dissolved oxygen (DO) below the TWQR. Low concentrations of DO are usually associated with agriculture, forest harvesting, sewage treatment plants, pulp mills, etc. (RIC, 2017). However, the low average DO concentration (3.7 mg/l) observed at site 12 can probably be ascribed to the anthropogenic influence of sewage treatment plant effluent (RIC, 2017), as was evident from the high ammonia concentrations measured at site 12.

The only other variable that did not comply with the TWQR was the concentration of *Escherichia coli* (*E. coli*) found in the water at most of the sampling sites. Only sites 1, 3 and 4 in the Sabie River and site 11 (Inyaka Dam) complied with the TWQR. Site 12 in the Sand River had the highest concentrations of *E. coli*, with an average of 26 425 MNP/100 ml. Although there is no TWQR set for total coliforms, the average concentrations observed were very high at all the sampling sites except site 1. The highest average concentration was again observed at site 12 in the Sand River (143 593 MPN/100 ml).

The RQOs are defined for each prioritised resource unit in terms of water quantity, habitat and biota, and water quality (South Africa, 2016). The RQO for the Sabie River only specifies phosphates under the objective for nutrients, and the numerical objective states that the 50th percentile of the data must be <0.015 mg/l. Due to the method of detection used in addition to the reporting limit set by Rand Water, it was decided to report the concentration of total phosphates. Unfortunately, the reporting limit of <0.036 mg/l is more than double that of the RQO set. Therefore, in cases such as sites 5, 8 and 9 in the Sabie River, sites 7 and 12 in the Sand River and site 10 in the Marite River, it is not possible to say with certainty that the total phosphate concentration complied with the RQO. The concentrations of total phosphates at sites 1-4 and site 6 in the Sabie River and site 11 in the Inyaka Dam did not comply with the RQO. The RQO for the Sand River also only specifies phosphates under the objective for nutrients, and the numerical objective states that the 50th percentile of the data must be <0.125 mg/l. Both sites located in the Sand River (sites 7 and 12) had a median concentration of 0.018 mg/l. The average concentrations of inorganic nitrogen (DIN=NH_3^+ + NO_3^- + NO_2^-) measured at all the sites during 2016 were <0.5 mg/l and were indicative of oligotrophic conditions, except at site 12. At site 12, the average dissolved inorganic nitrogen (DIN) concentration was typical of eutrophic conditions and was mostly due to the very high ammonia levels.

Table 4-3: Average values and ranges (minimum to maximum) of the measured water-quality parameters at sampling sites 1-12 from January 2016 to October 2016

Variable	TWQR/RQO	Sampling localities (mean value above and range [minimum-maximum] below)											
Site		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Alkalinity	*NA*	14.50 8.2-11	59.50 54-64	56.50 51-61	45.25 39-50	55.00 45-66	61.75 45-81	66.25 55-83	56.00 44-66	60.50 49-72	24.00 21-28	21.50 20-24	105.30 68-150
Aluminium	*0-10 µg/l*	12.5 12.5-12.5	17.38 12.5-32	15.88 12.5-26	83.00 66-110	41.38 12-83	61.38 12.5-105	158.75 12.5-460	54.88 12.5-100	118.25 45-190	132.75 56-185	34.13 12.5-61	31.30 12.5-60
Ammonia	*0.007 mg/l*	0.07 0.03-0.1	0.06 0.02-0.1	0.06 0.03-0.1	0.06 0.03-0.1	0.06 0.03-0.1	0.06 0.3-01	0.06 0.03-0.1	0.06 0.03-0.1	0.06 0.03-0.1	0.06 0.03-0.1	0.20 1.3-6.8	5.0 0.1-11
Calcium	*NA*	1.98 1.2-2.5	12.75 11-14	12.25 11-13	8.60 6.8-11	6.09 0.45-9.4	9.73 6.4-12	9.90 7.9-13	8.95 5.8-12	9.58 5.5-13	3.23 2.1-4.4	2.60 2.3-3.3	14.80 10-21
Chloride	*0.002 mg/l*	0.81 0.69-0.91	1.85 1.8-1.9	1.98 1.8-2.2	3.43 3.3-3.7	12.40 5.3-33	13.90 5.1-38	24.10 6.4-35	6.78 6-7.9	8.28 7.4-10	3.31 0.25-4.7	2.64 0.25-3.8	24.20 1.6-40
Chl-*a*	*NA*	2.35 1-4.4	2.92 1-5.4	3.15 1-6.2	1.98 1-3.6	1.80 0.5-4.7	3.45 1-5.3	3.75 1-7.2	2.88 1-6.9	1.78 1-2.8	1.83 1-2.8	3.88 2.5-7.5	62.20 6.7-170
DOC	*NA*	0.96 0.5-1.6	0.90 0.52-1.6	1.22 0.72-2.4	1.53 1.3-1.9	1.85 1.4-2.5	1.62 0.88-2.8	2.58 1.7-4.2	1.85 1.3-2.3	2.45 1.9-2.8	2.05 1.5-2.7	2.20 1.6-2.9	6.20 4.2-9.6

Variable	TWQR/RQO	Sampling localities (mean value above and range [minimum-maximum] below)											
Site		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
DO	*5-9 mg/l*	8.1 7.1-9.83	7.8 6.62-9.5	8.4 7.2-10.76	7.7 5.38-10.45	7.2 5.9-8.5	7 5.3-9.12	6.8 6.3-7.62	7.8 6.7-9.53	6.6 4.71-8.4	7.1 5.81-9.66	6.45 5.3-8.2	3.7 1.54-7.2
E. coli	*0-130 counts/ 100 ml*	9.75 0-17	225.25 4-548	35.0 3-67	69.75 9-93	356.0 63-866	207.75 32-365	83.67 4-236	387.25 241-613	273.75 185-461	125.25 68-231	1.50 0-2	26425.3 1986-98040
EC	95th percentile of the data must be ≤300 µS*/cm in the Sabie, Sand and Marite rivers*	46.78 41.4-49	143.38 122-157	130.68 115-142	124.63 119.2-132-6	126.90 71.1-159	155.93 148.1-170.1	292.63 243.5-329.4	148.63 130.7-158.3	161.88 133.9-177.2	76.93 58.6-100.4	62.05 53.3-71.1	389.20 276.2-602
Geosmin		0.77 0.25-1.76	1.45 0.91-2.4	2.80 2-3.8	4.10 2.9-5.3	4.89 0.25-15	2.67 0.52-8.8	1.26 0.25-3.5	3.32 0.99-7.1	7.85 1.7-17	3.85 1.8-7.3	2.13 1.5-3.4	6.80 4.1-8.2
Hardness	*NA*	10.05 8.2-11	58.50 51-63	54.75 51-59	39.00 31-48	33.38 7.5-47	49.00 36-59	48.50 44-58	47.00 35-59	50.25 37-63	13.75 10-18	11.50 11-13	62.00 46-86
Iron	*NA*	20.13 2.5-34	77.25 65-89	125.00 105-140	338.75 220-395	153.63 2.5-285	172.50 135-245	288.75 105-680	142.50 115-195	318.75 270-400	545.00 280-640	540.00	161.0 24-300

Variable	TWQR/RQO	Sampling localities (mean value above and range [minimum-maximum] below)											
Site		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
												200-1440	
Magnesium	*NA*	0.94 0.75-1.5	22.70 7.7-67	7.00 6.2-7.6	5.08 4.1-6	4.99 0.75-6.9	7.13 5.8-8.5	6.80 5.9-7.3	7.13 6-8.4	7.58 6.7-8.7	1.35 0.75-2.1	0.63 0.25-0.75	7.20 5.7-9.6
Manganese	*0-180 µg/l*	5.00	10.50 5-20	6.50 5-11	19.50 5-35	6.75 5-12	13.00 5-32	16.50 5-51	5.00	9.50 5-15	10.00 5-14	117.75 5-435	11.00 5-29
2-MIB		0.25	0.25	0.25	0.25	0.25	0.25	0.250	0.250	0.25	0.25	0.25	5.70 0.25-22
Nitrate + Nitrite		0.07	0.33 0.65-0.47	0.37 0.23-0.53	0.18 0.07-0.3	0.13 0.065-0.21	0.143 0.07-0.24	0.065	0.12 0.07-0.29	0.22 0.07-0.66	0.17 0.07-0.370	0.07	0.60 0.07-1.6
Inorganic nitrogen	*<0.5 mg/l Oligotrophic* *25.-10 mg/l Eutrophic conditions*	0.13 0.09-0.17	0.39 0.09-0.53	0.43 0.33-0.55	0.24 0.17-0.32	0.2 0.09-0.3	0.21 0.09-0.34	0.13 0.09-0.17	0.18 0.09-0.39	0.28 0.09-0.76	0.23 0.09-0.4	0.26 0.17-0.44	5.6 1.65-11.6
pH	*6.0-9.0*	6.18	7.38	7.23	6.93	6.97	6.82	7.24	7.11	6.74	6.53	6.49	6.9

Variable	TWQR/RQO	Sampling localities (mean value above and range [minimum-maximum] below)											
Site		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
	pH units	5.9-6.55	6.53-8.16	6.6-8.2	6.6-7.37	6.58-7.25	6.55-7.1	6.59-7.58	6.59-7.7	6.57-6.9	5.9-7.47	5.96-7.25	6.56-7.1
Silica	*NA*	4.25 2.9-4.8	4.78 3.4-5.4	4.53 3.4-5.1	4.93 3.7-5.8	3.88 0.5-5.9	5.80 4.1-8.4	7.33 4.5-12	4.65 3.2-6.7	5.03 3.4-8.2	6.50 4.1-8.8	5.05 2.9-5.9	7.40 5.1-10
Sodium	*NA*	1.00	2.78 2.4-3.7	3.88 3.1-5.6	5.65 5.2-6.4	6.1 1-8.5	15.15 7.9-35	27.65 8.6-38	9.25 8.9-10	10.45 9.8-11	7.40 6.2-8.4	5.80 5.5-6.3	44.00 31-67
Sulphate	*NA*	0.50	5.48 4.6-6.8	4.25 3.3-5.5	3.15 2-3.7	4.28 3.6-5.5	3.93 2.5-5.7	5.93 3.5-9.2	3.65 2.3-4.4	4.10 2.5-5.7	0.56 0.05-1.2	0.50	7.30 2.1-13
Total coliforms		507 31-1 145	2065 1789-2420	2099.7 727-3790	1230.33 727-1644	1719.7 1187-1986	2360 866-3 990	1195.5 435-1956	4670 1203-6867	4962.33 1450-6867	2779 2430-2987	326.33 99-554	143593.7 15531-241960
TDS	*0-450 mg/l*	33.00 16-67	90.00 63-150	51.00 17-71	48.00 40-63	64.50 49-82	96.25 52-170	159.25 82-225	110.25 33-245	86.50 53-170	67.75 32-165	98.75 43-220	161.00 69-285
Total K N		1.7 0.5-4.6	1.65 0.5-4.1	1.65 0.5-3.9	1.9 0.5-4.5	2.25 1.6-3.7	4.13 1.6-10	2.18 1.2-3.3	2.6 1.8-3.8	4.5 1.8-8.2	3.7 1.6-5	3.7 1.3-6.8	13.1 1.5-31
TOC	*<30 mg/l*	0.82	0.93	1.09	1.70	2.00	1.90	2.80	1.95	2.65	2.00	2.20	8.20

Variable	TWQR/RQO	Sampling localities (mean value above and range [minimum-maximum] below)											
Site		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
		0.56-1.3	0.65-1.4	0.8-1.7	1.4-2.1	1.5-2.4	1.3-2.9	1.9-4.6	1.4-2.3	2-3.2	1.6-2.2	1.9-2.5	4-16
*Total Phos-phates	*≤0.015 mg/l (Sabie and Marite rivers)* *<0.125 mg/l (Sand River)*	0.07 0.018-0.1 **0.08**	0.06 0.018-0.1 **0.06**	0.06 0.018-0.1 **0.06**	0.07 0.018-0.09 **0.08**	0.05 0.018-0.1 **0.04**	0.06 0.018-0.09 **0.06**	0.05 0.018-0.1 **0.04**	0.05 0.018-0.1 **0.04**	0.05 0.018-0.09 **0.04**	0.05 0.018-0.09 **0.04**	0.05 0.018-0.09 **0.05**	0.05 0.018-0.09 **0.05**
Turbidity	*<5>55 NTU*	0.705 0.45-1.1	1.03 0.6-1.6	1.045 0.72-1.6	2.60 1.4-4.5	2.80 1.8-3.5	2.79 0.85-6.2	3.35 2-5.9	2.25 1.6-3.9	7.15 2.6-15	7.48 1.5-21	9.95 1.7-34	3.70 1.5-6.9
Zinc	*<0.002 mg/l*	0.01	0.01	0.01	0.01	0.33 0.01-1.3	0.01	0.01	0.01	0.01	4.76 0.01-19	4.78 0.01-16	7.12 0.01-15

2-MIB: 2-Methylisoborneol; Chl-*a*: Chlorophyll-*a*; *E. coli*: *Escherichia coli;* EC: Electrical conductivity; DO: Dissolved oxygen; DOC: Dissolved organic carbon; NTU: Nephelometric turbidity unit; TDS: Total dissolved solids; TOC: Total organic carbon

*The median values of the Total Phosphates are listed in **bold**. The RQO for this variable states that 50th percentile of the data must be ≤0.015 mg/l for the Sabie River and <0.125 mg/l for the Sand River.

**Shaded cells indicate the values that exceed the set limits according to the RQOs and TWQR

Source: DWAF, 1996a, 1996b; South Africa, 2016

4.3.3 Water quality for 2017

Table 4-4 presents the values and ranges of the water-quality variables determined during the period in addition to the TWQR and the RQOs for all the sampling sites. The average value for each water-quality parameter is listed as the first value in each cell with the range values (minimum to maximum) as the second value in the cell. The values that exceeded the TWQR and RQOs are shaded.

Most of the variables for the year 2017 as measured complied with the TWQR, as was the case in 2016. The measured concentrations of aluminium and ammonia again did not comply with the TWQR of 0-0.01 mg/l and 0.007 mg/l respectively. During 2017, the concentrations of aluminium determined at all the sampling sites except site 1 were higher than the acute effect value of 150 µg/l. The highest concentrations of aluminium were determined again at site 10 in the Marite River (maximum of 14.3 mg/l) and site 7 in the Sand River (maximum of 5.35 mg/l). These values are considerably higher than the values obtained during 2016. No toxicity was observed, but since the toxicity and bio-availability of aluminium is governed by complex interactions with other water-quality variables, these may not have been fully accounted for in this study. Aluminium is least soluble in the neutral pH range (6.5-7.5), and the pH of the water at these sites varied from a minimum of pH 6.6 to a maximum of pH 8.2. Due to the reporting limit for ammonia at Rand Water (<0.5 mg/l), most of the data again indicated that the concentrations of ammonia did not comply with the TWQR. However, site 12 in particular showed much higher concentrations than the target range, with an average of 0.175 mg/l and a maximum value of 0.45 mg/l. Despite exceeding the TWQR, these values are, however, much lower than the values determined during 2016. Again, the chloride concentrations did not comply with the TWQR of 0.002 mg/l, and the average values at all the sites except sites 7 and 12 in the Sand River increased during 2017.

The only other variable that did not comply with the TWQR during 2017 was *E. coli*, which was found in the water at all of the sampling sites except site 1 in the headwaters of the Sabie River and site 7 in the Sand River. Site 2 in the Sabie River and site 12 in the Sand River had the highest concentrations of *E. coli*, with an average of 1 085 CFU/100 ml and 2 083 CFU/100 ml respectively. The average concentrations for total coliforms were also very high at all the sampling sites. The highest average concentrations were observed at site 9 in the Sabie River and site 12 in the Sand River, with 9 456 MPN/100 ml and 64 513 MPN/100 ml respectively.

Due to the method of detection used and the reporting limit set by Rand Water, it was decided to report the concentration of total phosphates. Unfortunately, the reporting limit of <0.036 mg/l is more than double the RQO set. Therefore, in cases such as sites 8 and 9 in the Sabie River and site 10 in the Marite River, it is not possible to state with certainty that the total phosphate concentration complied with the RQO. In regard to the total phosphates at sites 1-6 in the Sabie River and site 11 in the Inyaka Dam, the concentrations did not comply with the RQO. In addition, the RQO for the Sand River only specifies phosphates under the objective for nutrients, and the numerical objective states that the 50th percentile of the data must be <0.125 mg/l. Both sites located in the Sand River (sites 7 and 12) had a median concentration of 0.018 mg/l, which represents one-half of the reporting limit. The average concentration of inorganic nitrogen (DIN=NH_3^+ + NO_3^- + NO_2^-) measured at all the sites during 2017 was <0.5 mg/l, which is indicative of oligotrophic conditions. Sites 2 and 3 in the Sabie River and site 12 in the Sand River were the only sampling locations that showed maximum inorganic nitrogen concentrations (>0.5 mg/l).

Table 4-4: Average values and ranges (minimum to maximum) of the measured water-quality parameters of the sampling sites 1-12 from January 2017 to October 2017

Variable	TWQR/RQO	Sampling localities (mean value above and range (minimum-maximum) below)											
Site		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Alkalinity	*NA*	15.25 10-21	48 31-61	42.5 28-52	40.25 30-47	48.5 35-59	36.38 2.5-61	61.75 56-76	59.75 39-89	56.67 43-74	24 22-26	17 15-20	65.25 46-88
Aluminium	*0-10 µg/l*	12.5 12.5-12.5	65.75 28-92	131.5 36-215	174.5 53-365	129.63 12.5-290	141.5 27-375	2008.25 62-5350	141.5 34-320	1186 73-3170	3671.75 87-14300	172.25 32-500	894.5 53-2740
Ammonia	*0.007 mg/l*	0.03 0.03-0.03	0.03 0.03-0.03	0.03 0.03-0.03	0.03 0.03-0.	0.03 0.03-0.03	0.03 0.03-0.03	0.03 0.03-0.03	0.03 0.03-0.03	0.03 0.03-0.03	0.03 0.03-0.03	0.03 0.025-0.05	0.17 0.03-0.4
Calcium	*NA*	1.64 0.45-2.7	9.53 5.6-12	8.65 5.1-11	7.65 5.1-9.1	8.4 5.6-9.6	8.5 6.2-10	9.1 8.2-11	8.68 6.6-10	9.9 7.7-11	3.25 2.3-4.5	1.98 1.2-3	10.33 7.7-14
Chloride	*0.002 mg/l*	5.4 0.66-16	5.68 1.4-14	6.8 1.8-17	15.9 3.9-49	16.93 5.7-48	22.48 6.9-68	20.25 16-28	28.4 8-88	11.17 8.5-14	15.33 5-44	10.5 3-29	18.1 1.4-30
Chl-a	*NA*	1 1-1	1.45 1-2.9	1 1-1	1 1-1	1.83 1-2.8	1.48 1-2.9	2.5 1-4.8	2.1 1-2.8	3.4 1-6	2.1 1-3.4	2.1 1-3.1	2.85 1-5.9

Variable	TWQR/RQO	Sampling localities (mean value above and range (minimum-maximum) below)											
Site		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
DOC	*NA*	0.4 0.1-0.6	0.52 0.1-0.84	0.67 0.1-1.3	1.2 0.62-1.8	1.43 0.8-1.7	1.26 0.76-2	2.03 1.6-2.9	1.43 1.1-2	1.5 1.4-1.7	2 1-2.8	1.55 1.1-1.9	3.23 2.2-4.4
DO	*5-9 mg/l* *80-120% saturation*	9.16 8-11.3	8.78 7.42-11	8.58 7.64-9.87	5.6 0.07-9.08	5.28 0.5-7.9	7.39 5.75-8.43	7.71 5.8-10.78	6.66 6.13-7.8	7.36 5.98-8.5	7.65 6.8-8.6	6.3 5.1-8.22	5.7 4.84-6.9
E. coli	*0-130 counts/100 ml*	24.75 2-58	1085 548-2420	720 27-1120	659 114-1300	1231 80-4106	304 144-504	128 86-169	278.5 107-435	240.67 75-455	291 107-464	150 1-387	6083 3282-11690
EC	95th percentile of the data must be *≤300 µS/cm in the Sabie, Sand and Marite rivers*	31.18 23.6-40.6	104.53 78-120	102.33 82.1-115.5	104.5 90.3-111	128.65 120.6-139.6	100.33 13.2-139.3	200.5 174.9-239.6	152.45 135.3-193.1	155.43 142.2-167.5	70.95 62.1-81.2	49.88 48.5-52.4	216.45 167.6-290.3
Geosmin		1.85 0.25-6.4	0.79 0.25-1.1	0.9 0.25-1.1	2.5 0.89-4.7	1.7 0.56-3.10	0.77 0.25-1.4	0.8 0.25-2.2	1.94 0.65-4.8	0.86 0.25-1.8	3.83 1.6-6	1.15 0.25-3	5.92 0.96-16
Hardness	*NA*	9.8 7.5-13	43.5 26-54	39.5 24-48	35.25 24-41	40.5 28-47	41.5 30-49	40 37-48	41.5 32-48	45 35-51	14.25 11-19	10.28 8.2-13	43 32-58

Variable	TWQR/RQO	Sampling localities (mean value above and range (minimum-maximum) below)											
Site		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Iron	*NA*	17.5 11-23	146.25 110-175	234.75 130.305	458.75 345-630	358.75 190-510	306.25 125-570	498 82-930	262.5 120-445	370 230-530	4857.5 720-16 920	468.75 285-640	2 262.5 310-7 390
Magnesium	*NA*	0.99 0.75-1.7	5.7 3.6-6.9	5.18 3.2-6.4	4.63 3.2-5.20	5.63 3.9-6.5	5.85 4.3-6.9	4.98 4.6-6.9	5.75 4.5-6.6	5.87 4.5-6.9	1.59 0.75-2.2	0.94 0.75-1.5	4.98 3.7-6.5
Manganese	*0-180 µg/l*	5 5-5	25.5 21-31	6.5 5-11	16.25 10-29	5 5-5	6.5 5-11	5 5-5	5 5-5	5 5-5	8 5-11	16 5-42	5 5-5
2-MIB		12.3 0.25-48	0.66 0.25-1.90	0.66 0.25-1.9	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	0.25 0.25-0.25	0.79 0.25-2.4	1.54 0.25-5.4	1.09 0.25-3.6
Nitrate + Nitrite		0.2 0.07-0.28	0.34 2.4-0.56	0.3 0.19-0.5	0.25 0.15-0.34	0.26 0.19-0.31	0.25 0.13-0.38	0.13 0.07-0.24	0.22 0.07-0.32	0.23 0.07-0.4	0.25 0.15-0.38	0.23 0.07-0.36	0.28 0.07-0.7
Inorganic nitrogen	*<0.5 mg/l* *Oligotrophic*	0.21 0.09-0.30	0.36 0.24-0.58	0.32 0.21-0.52	0.27 0.17-0.36	0.27 0.21-0.33	0.27 0.15-0.4	01.5 0.09-0.24	0.23 0.09-0.34	0.19 0-0.42	0.27 0.17-0.4	0.26 0.09-0.41	0.45 0.09-0.95

Variable	TWQR/RQO	Sampling localities (mean value above and range (minimum-maximum) below)											
Site		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
pH	*6.0-9.0* *pH units*	6.62 6.17-6.92	7.45 6.48-8.14	7.1 6.37-7.59	7.07 6.67-7.66	7.1 6.62-7.78	7.37 6.69-8.03	7.69 7.13-8.19	7.54 7.03-8.24	7.23 6.96-7.8	6.88 6.59-7.15	6.78 6.37-7.27	6.93 6.58-7.2
Silica	*NA*	3.75 3.1-4.1	4.33 3.5-4.9	4.75 3.7-5.5	5.25 3.7-6.3	5.28 3.2-7.1	5.33 3.1-7.3	7.6 3.6-11	5.4 2.9-7.6	6.47 4-8	24.03 4.2-73	4.7 3.5-6	8.43 4.8-11
Sodium	*NA*	1 1-1	1.95 1-2.4	2.88 2.2-3.3	5.25 5-5.90	6.85 6.4-7.6	7.5 6.6-8	24 20-30	9.7 8.7-11	11.27 9.8-14	7.45 6.4-8.7	4.85 4.5-5.2	25.75 20-35
Sulphate	*NA*	2.52 0.5-4.3	4.56 3.2-7.1	4.73 3.4-7.2	4.1 2.6-6.2	4.3 2.7-6.2	4.68 3.2-6.6	5.38 3.9-7.2	4.68 3.3-6.6	5.37 4.1-6.7	2.2 0.5-4.6	1.92 0.5-4.5	5.78 3.6-7.9
Total coliforms		843 172-1300	8 570 5730-10120	8 095 579-5689	9 776 1046-24196	6 028 1986-14136	8 183 5380-10462	8 500 2420-14670	7 624 2420-14136	9 456 2420-17329	5 539 2420-12997	860 173-1725	64 513 38730-111900
TDS	*0-450 mg/l*	50.75 27-87	56.5 27-87	72.5 53-88	62.25 45-77	69.25 31-110	84.25 50-110	98.75 53-155	67.75 39-125	79.33 36-130	72.5 63-81	31.15 7.5-64	132 83-170
TKN		0.72 0.05-1.8	0.64 0.05-1.5	0.85 0.5-1.9	0.78 0.5-1.6	0.5 0.5-0.5	0.63 0.5-1	0.68 0.5-1.2	0.5 0.5-0.5	0.5 0.5-0.5	1.25 0.5-3.5	0.8 0.5-1.7	1.03 0.5-2.6
TOC	*<30 mg/l*	0.53	0.66	0.87	1.6	1.56	1.5	2.78	1.78	2.3	2.58	2.13	4.28

Variable	TWQR/RQO	Sampling localities (mean value above and range (minimum-maximum) below)											
Site		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
		0.1-1	0.3-1	0.59-1.2	1-2	1-2.2	1-2.4	1.9-4.1	1-2.7	1.9-2.70	2-3.6	2-2.3	3.4-5.3
*Total Phosphates	*≤0.015 mg/l (Sabie River)* *<0.125 mg/l (Sand River)*	0.08 0.018-0.12 **0.09**	0.05 0.018-0.1 **0.036**	0.06 0.018-0.1 **0.06**	0.054 0.018-0.1 **0.05**	0.06 0.018-0.1 **0.06**	0.05 0.018-0.1 **0.04**	0.04 0.018-0.1 **0.018**	0.04 0.018-0.1 **0.018**	0.018 0.018-0.018 **0.018**	0.036 0.018-0.09 **0.018**	0.05 0.018-0.09 **0.04**	0.03 0.02-0.1 **0.018**
Turbidity	*<5->55 NTU*	0.6 0.4-0.92	1.88 1-2.6	5.85 1.3-12	6.88 2.2-14	8.1 1.6-19	13.7 4.4-32	17.75 2.3-36	16.95 2.9-40	27.87 7.6-58	11.25 4.1-30	3.43 1.8-7	16.23 3.6-28
Zinc	*<0.002 mg/l*	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075	0.0075

2-MIB: 2-Methylisoborneol; Chl-*a*: Chlorophyll-*a*; *E. coli*: *Escherichia coli;* EC: Electrical conductivity; DO: Dissolved oxygen; DOC: Dissolved organic carbon; NTU: Nephelometric turbidity unit; TDS: Total dissolved solids; TOC: Total organic carbon

*The median values of the Total Phosphates are listed in **bold**. The RQO for this variable states that 50th percentile of the data must be ≤0.015 mg/l for the Sabie River and <0.125 mg/l for the Sand River.

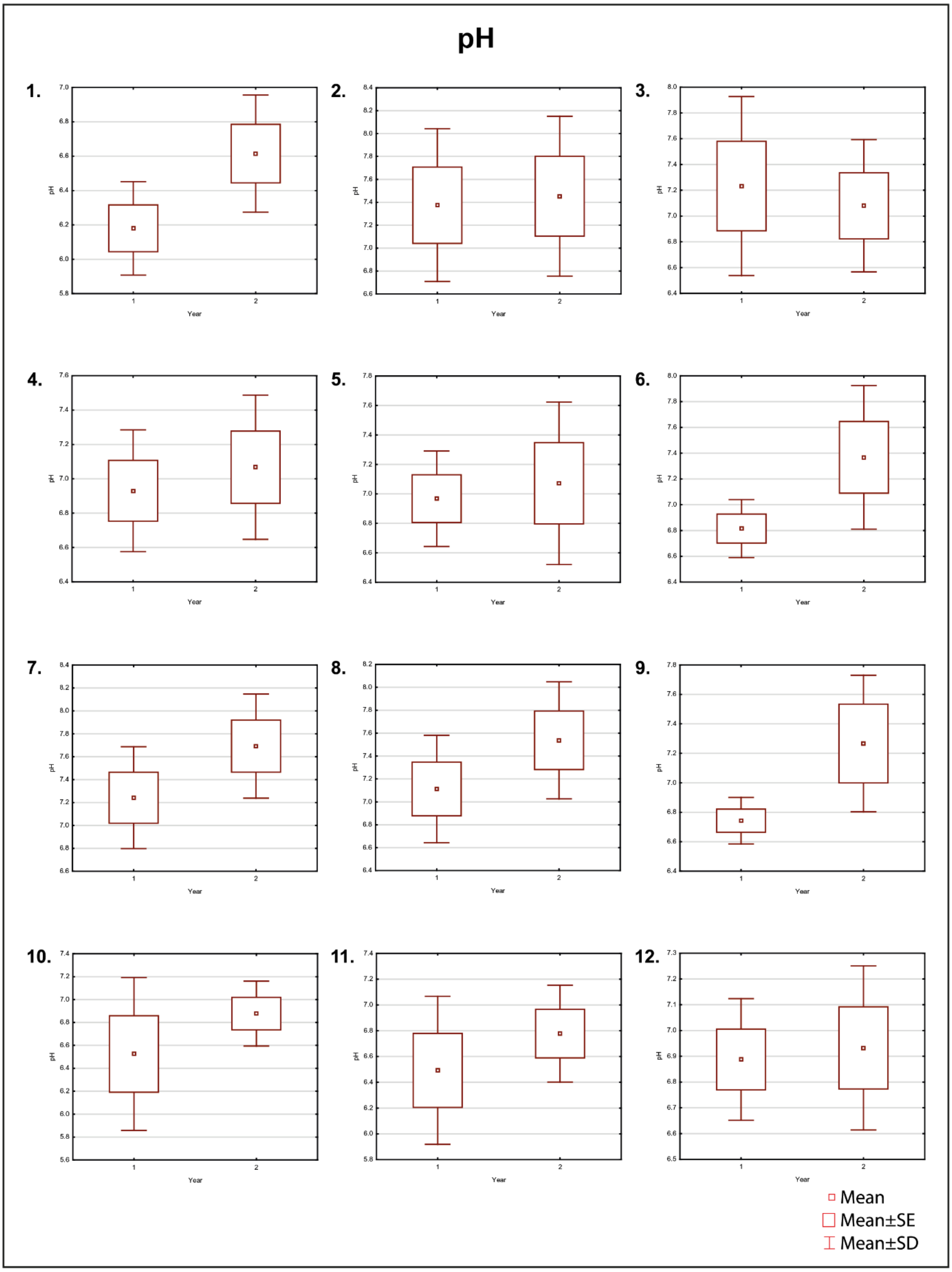
**Shaded cells indicate the values that exceed the set limits according to the RQOs and TWQR

Source: DWAF, 1996a, 1996b; South Africa, 2016

4.3.4 Spatial comparison of water-quality parameters determined during the drought (2016) and immediately after the drought (2017)

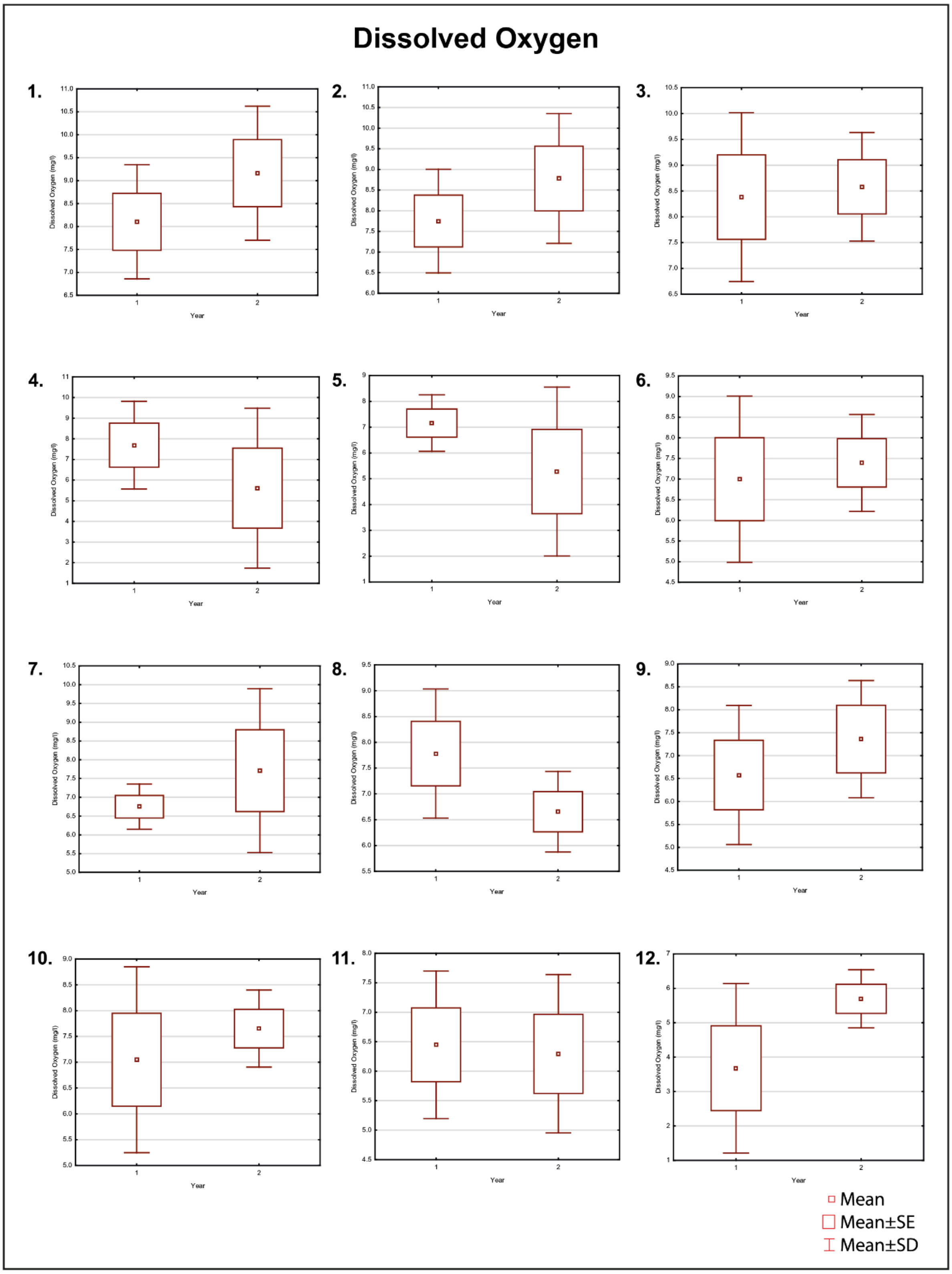
During 2016, site 1 in the Sabie River experienced the lowest range in pH (5.90-6.55) compared with the other sites (Figure 4.2). The lower pH observed at site 1 was possibly the result of the forestry practices and the decomposition of organic materials surrounding site 1. These decomposed material reach the water either via the increased runoff due to the forestry that often occurs on steep slopes, or by leaching through the soil and subsequently entering the water. The sites that demonstrated the nearest pH values to site 1 in 2016 were located on the Marite River. These were sites 10 and 11 with pH values of 6.53 and 6.49 respectively. These sites are also strongly influenced by forestry practices since the inflow into the Inyaka Dam (site 11) is surrounded by forest plantations and site 10 is downstream of the dam. An increase (although not statistically significant) in the pH measured at all the sampling sites except site 3 was observed (Figure 4-2) in the immediate post-drought period of 2017. This increase was persistent during the entire study period at sites 6-9, which are all located within the conservation land tenure class (Figure 4.2). Site 1 in the headwaters of the Sabie River still exhibited the lowest pH with an average pH of 6.62. The highest average pH was observed at site 7 (pH 7.69) in the Sand River.

The dissolved oxygen (DO) concentrations during 2016 were all within the TWQR except for the very low DO levels observed at site 12 in the Sand River. The DO concentrations showed mixed results during the immediate post-drought period (Figure 4-3). Most of the sites showed increased concentrations of DO during 2017, while sites 4, 5 and 8 in the Sabie River showed decreased concentrations of DO during 2017. Again, there were no significant differences between the DO concentrations measured during 2016 and 2017 at any of the sampling sites. Very low DO concentrations were measured during October 2017 at sites 4 and 5 (0.07 mg/l and 0.5 mg/l respectively). This demonstrated an overall decrease in the DO concentrations observed at these sites when compared with the concentrations of 2016. At site 4, a truck was observed that appeared to be dumping something into the river just ahead of sampling. This could possibly have affected the water quality. Site 5 is located downstream of site 4, and this could also explain the low DO concentration in the sample obtained during the sampling trip at site 5 (sites were not sampled in consecutive order).



n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-2: Box and whisker plots illustrating the mean pH observed at the sites



n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-3: Box and whisker plots illustrating the mean dissolved oxygen concentrations (mg/l) observed at the sites

The highest average turbidity levels in 2016 were observed at site 9 (Sabie River), site 10 (Marite River) and site 11 (Inyaka Dam). Inyaka Dam experienced a very high average turbidity (9.95 NTU) compared with the other sites. This could be the result of the high iron concentration (540.00 µg/l) and high manganese concentration (117.00 µg/l) found at this site (Khadse *et al*., 2015). It is speculated that the high turbidity value (7.48 NTU) determined at site 10, which is downstream of the Inyaka Dam in the Marite River, could also be the result of the high average iron concentration (545.00 µg/l) observed at this site. An overall increase in turbidity was observed at all the study sites during 2017 (Figure 4-4), except for site 1 where the turbidity remained similar to that observed during 2016. The highest turbidity at all the sites was observed during January 2017 following high flow conditions. Site 9 in the Sabie River exhibited the highest turbidity values with an average of 27.87 NTU and a maximum of 58 NTU. Sites 3, 6 and 8 in the Sabie River showed significant increases in their turbidity values during 2017, increasing more than five times. The iron concentrations increased from 2016 to 2017, especially during the January and April sampling occasions when high rainfall and high flows were experienced. However, there was no significant increase determined for the mean iron concentrations between 2016 and 2017 except at sites 2, 10 and 12 (Figure 4-5).

The Spearman's rank correlation coefficient indicated a significant positive correlation between turbidity and total dissolved solids (TDS) during 2016. Even though the TDS concentrations for the sampling localities on the Sabie River were quite similar, the average TDS values for the Sand River at site 7 (159.25 mg/l) and site 12 (161.00 mg/l) were significantly higher than those observed in the Sabie River, the Marite River and the Inyaka Dam during the dry period of 2016. This can be ascribed to the concentrations of the major ions, Ca^{2+}, Mg^{2+}, Na^{+} and Cl^{-} being significantly different among these sites. The major ion measured in the Sand River was sodium, and the TDS value for site 12 (161.00 mg/l) positively correlated with the higher sodium concentration of 44.00 mg/l at this site. During 2017, the study area received higher rainfall and, therefore, higher runoff and complex patterns of salinity and TDS were observed (Figure 4-6). Sites 1, 3, 4 and 5 in the Sabie River and site 10 in the Marite River all experienced an increase in TDS, while sites 2, 6, 8 and 9 in the Sabie River and sites 7 and 12 in the Sand River experienced a decrease in TDS.

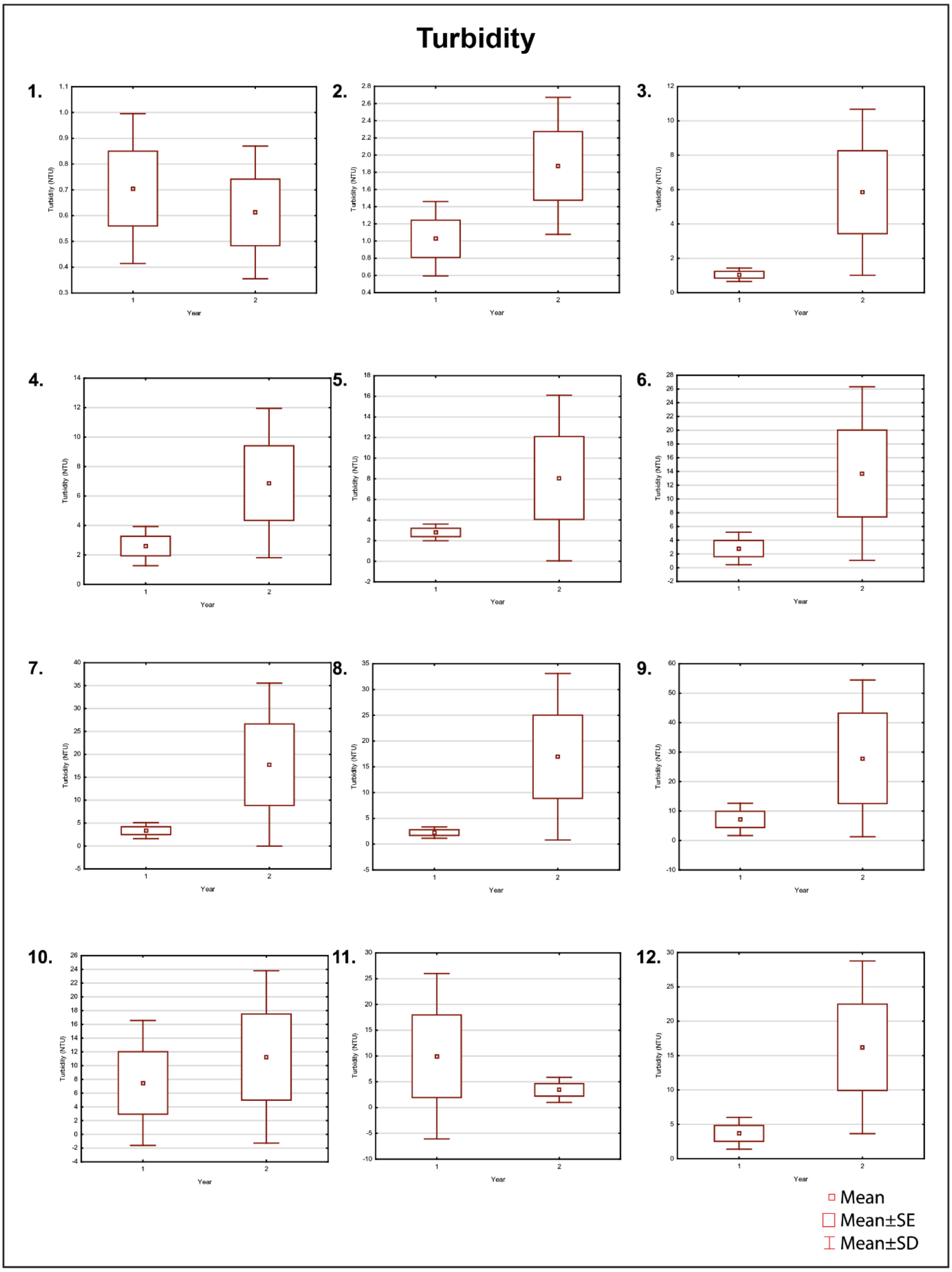
Most sites experienced an increase in chloride, except sites 7 and 12 in the Sand River. The increase in TDS observed at sites 1, 3, 4, 5 and 10 can mainly be attributed to the increase in sulphate and chloride concentrations (Figure 4-7). Although the other sites also showed an increase in chloride concentrations, it was less than the increase demonstrated in the latter sites. Because the TDS properties in water are governed by dissolved salts, TDS is closely related to the total hardness of water, scaling and the corrosion potential of water (DWAF, 1996b). The decrease in TDS shown at sites 2, 6, 7, 8, 9 and 12 could be attributed to the decrease in calcium and magnesium, which was also reflected in the decrease in hardness at these sites. The methyl orange alkalinity (M alkalinity) also decreased at all of the sites except sites 1 and 8 (Figure 4-8). This observed decrease was mainly due to the low alkalinity observed during January 2017 at most of the sites. This was also the case for sites 1 and 8. The largest decrease was observed at site 11 at the Inyaka Dam. The concentrations of aluminium (Figure 4-9) and iron increased at all of the sampling sites. However, the concentrations of manganese decreased at all the sites except site 2 in the Sabie River. These decreases observed for manganese are mainly due to an outlier of very high concentration measured during July 2016.

There was no significant variation observed in electrical conductivity (EC) levels within the Sabie River, the Marite River and the Inyaka Dam during 2016. Site 1 had the lowest average EC value (46.78 mS/m). As expected and similar to the TDS, the EC values in the Sand River at sites 7 and 12 were significantly higher than site 1 in the Sabie River, site 10 in the Marite River and site 11 in the Inyaka Dam. During 2016, the EC values showed a significant positive correlation with the major ions (Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}, Cl^{-}, SO_4^{2-}) and hardness. An overall decrease in the EC values was observed during 2017 (Figure 4-10), except at sites 5 and 8 in the Sabie River. The sites located in the Sand River (sites 7 and 12) exhibited the highest average EC values of 200.5 µS/cm and 216.45 µS/cm respectively. The minimum EC values at most sites were measured during January 2017. The TDS values measured during 2017, however, did not correlate with the EC values during 2016. The difference from one year to the other is much rather the result of the dilution effect of higher rainfall.

During 2016, the nitrate and nitrite concentrations for the Sabie River sites were similar down the gradient of the river, with site 1 having the lowest average nitrate concentration of 0.05 mg/l. Site 2 and site 3 in the Sabie River had the highest nitrate concentrations (0.31 mg/l and 0.35 mg/l respectively), which could possibly be the result of runoff from the fruit orchards, where the application of fertilizer will be standard practice, surrounding these sites. Other sites with relatively low nitrate concentrations were site 11 in the Inyaka Dam and site 7 in the Sand River. The ammonia concentrations at site 12 were very high during the height of the drought as reflected during the July and October sampling occasions. The DIN concentrations increased during 2017 at most sites located in the Sabie, Sand and Marite rivers (except sites 3, 2 and 12), and this was mostly due to the increase in nitrite and nitrate during the immediate post-drought period (Figure 4-11). Despite this increase in DIN concentrations, the ammonia concentrations decreased at all the study sites during 2017 together with the concentrations of total Kjeldahl nitrogen (TKN). The highest phosphate concentrations were observed at site 12 in the Sand River during 2016, which was indicative of eutrophic conditions. During 2017, the total phosphate concentrations increased at all of the sites except at site 12 in the Sand River (Figure 4-12). This will be due to increased runoff and the associated sediment and adsorbed phosphorous.

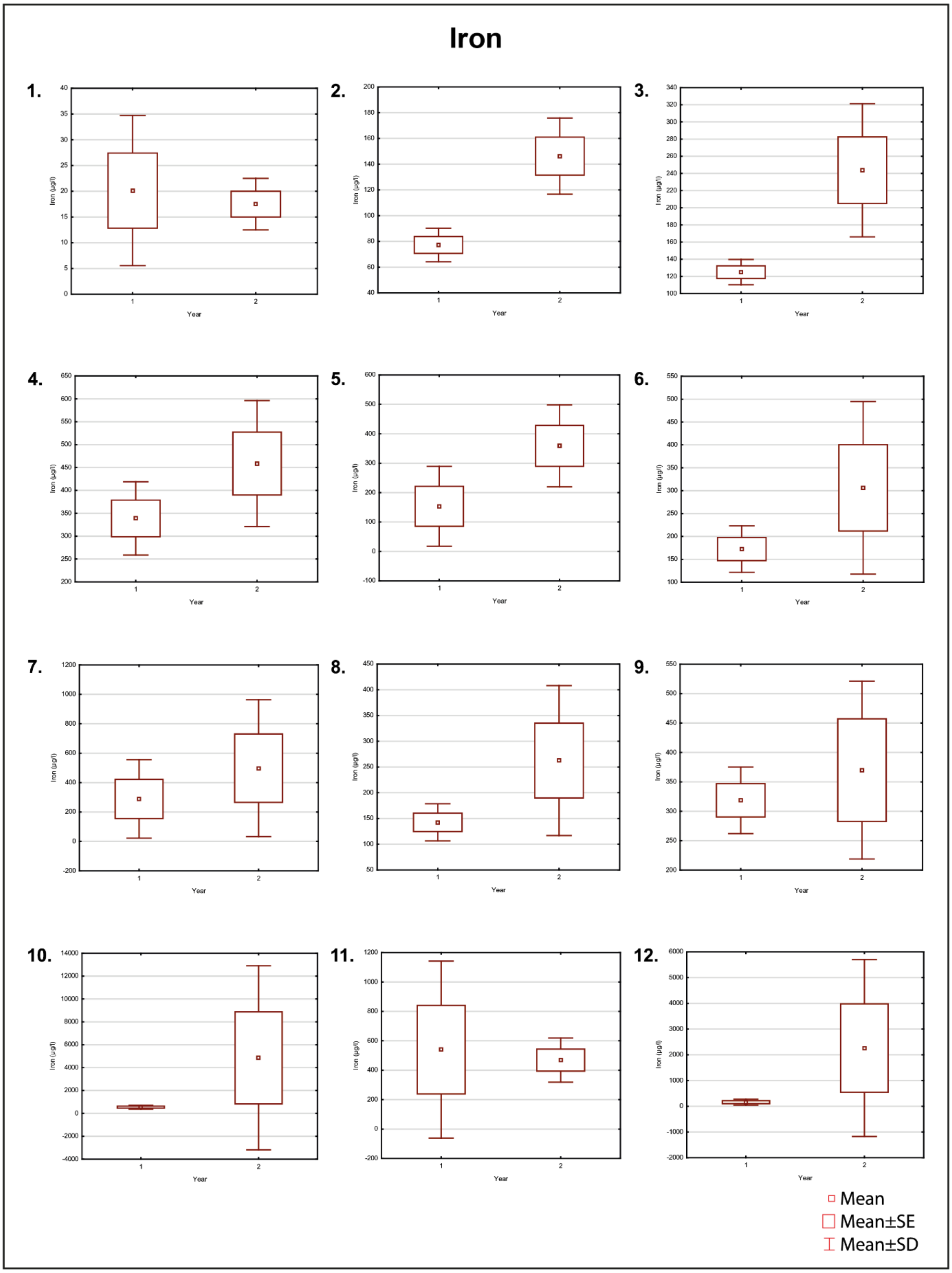
Both total organic carbon (TOC) and dissolved organic carbon (DOC) concentrations decreased at all the study sites except at site 10 in the Marite River (Figure 4-13) during the immediate post-drought period of 2017. Site 12, however, still exhibited the highest average DOC and TOC levels (3.23 mg/l and 4.28 mg/l respectively). These values were almost one-half the value determined during 2016 when a mean DOC concentration of 6.2 mg/l and a mean TOC concentration of 8.2 mg/l were determined. During 2016, very high concentrations of *E. coli* and total coliforms were observed, especially at site 12 (Figure 4-14). During 2017, the average concentrations of both *E. coli* and total coliforms increased at all sites except site 12.

Chlorophyll-*a* (chl-*a*) concentrations also decreased significantly at site 12 (Figure 4-15) during 2017. Other sites that experienced a decrease in chl-*a* concentrations were sites 1-4, site 6 and site 8 in the Sabie River, site 7 in the Sand River and sites 10 and 11 in the Marite River. This can be due to an increased turbidity during higher flows. Only sites 5 and 9 in the Sabie River experienced an increase in chl-*a* concentrations. The Spearman's rank correlation coefficient of the whole dataset showed a significant correlation between 2-Methylisoborneol (2-MIB) and the cell concentrations of the Dinophyceae as well as significant correlations between geosmin and the cell concentrations of the Cyanophyceace, Bacillariophyceae and the Euglenophyceae. Geosmin and 2-MIB can be produced by a number of microorganisms including algae such as *Dinobryon*, cyanobacteria and bacteria such as *Streptomyces* and myxobacteria, and fungi (Jiang *et al.*, 2007). Site 12 in the Sand River experienced the greatest problems with taste and odours. The odour threshold concentration for MIB/geosmin ranges from 4 ng/l to 20 ng/l (Srinivasan & Sorial, 2011).



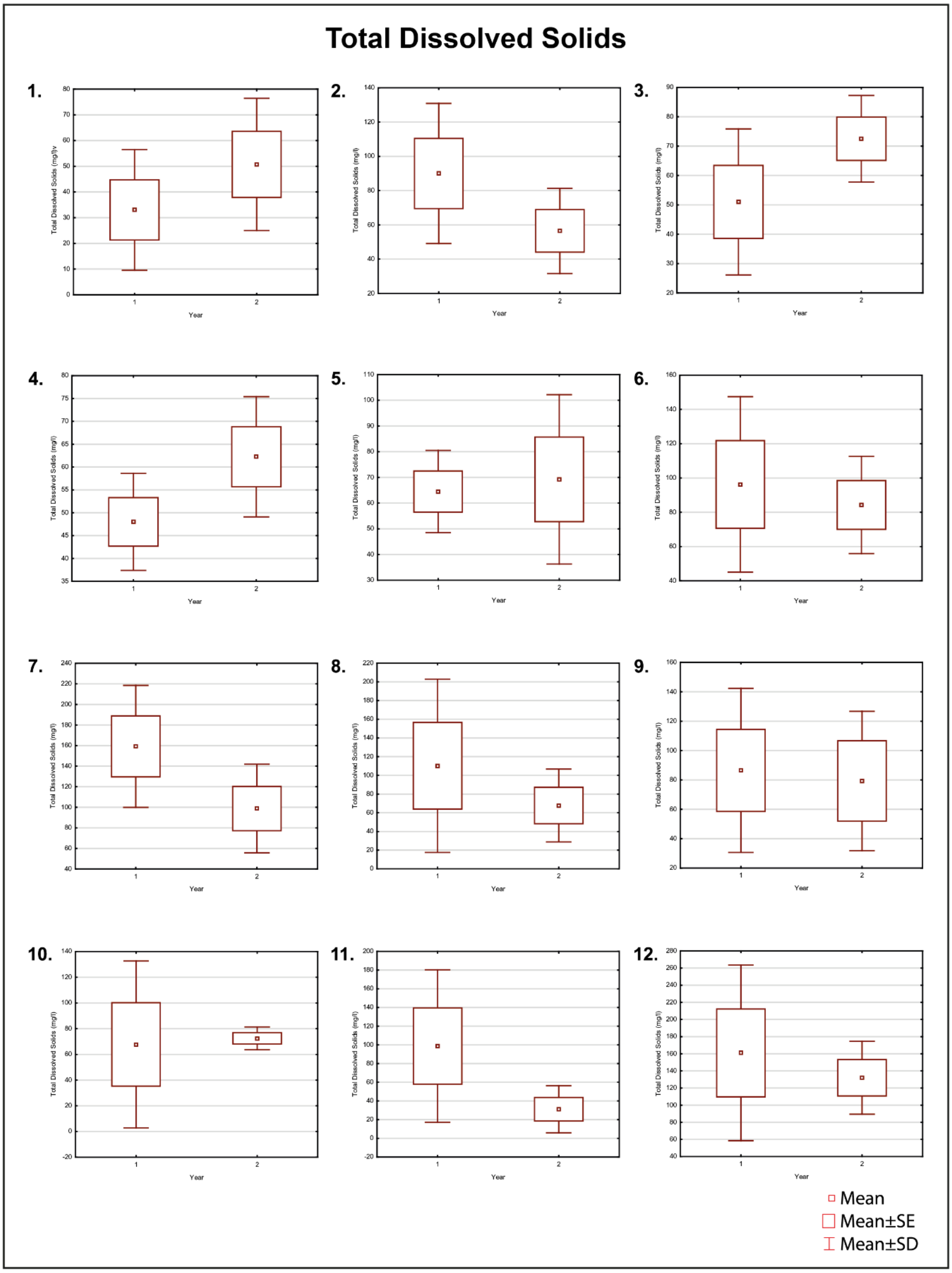
n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-4: Box and whisker plots illustrating the mean turbidity (in NTU) observed at the sites



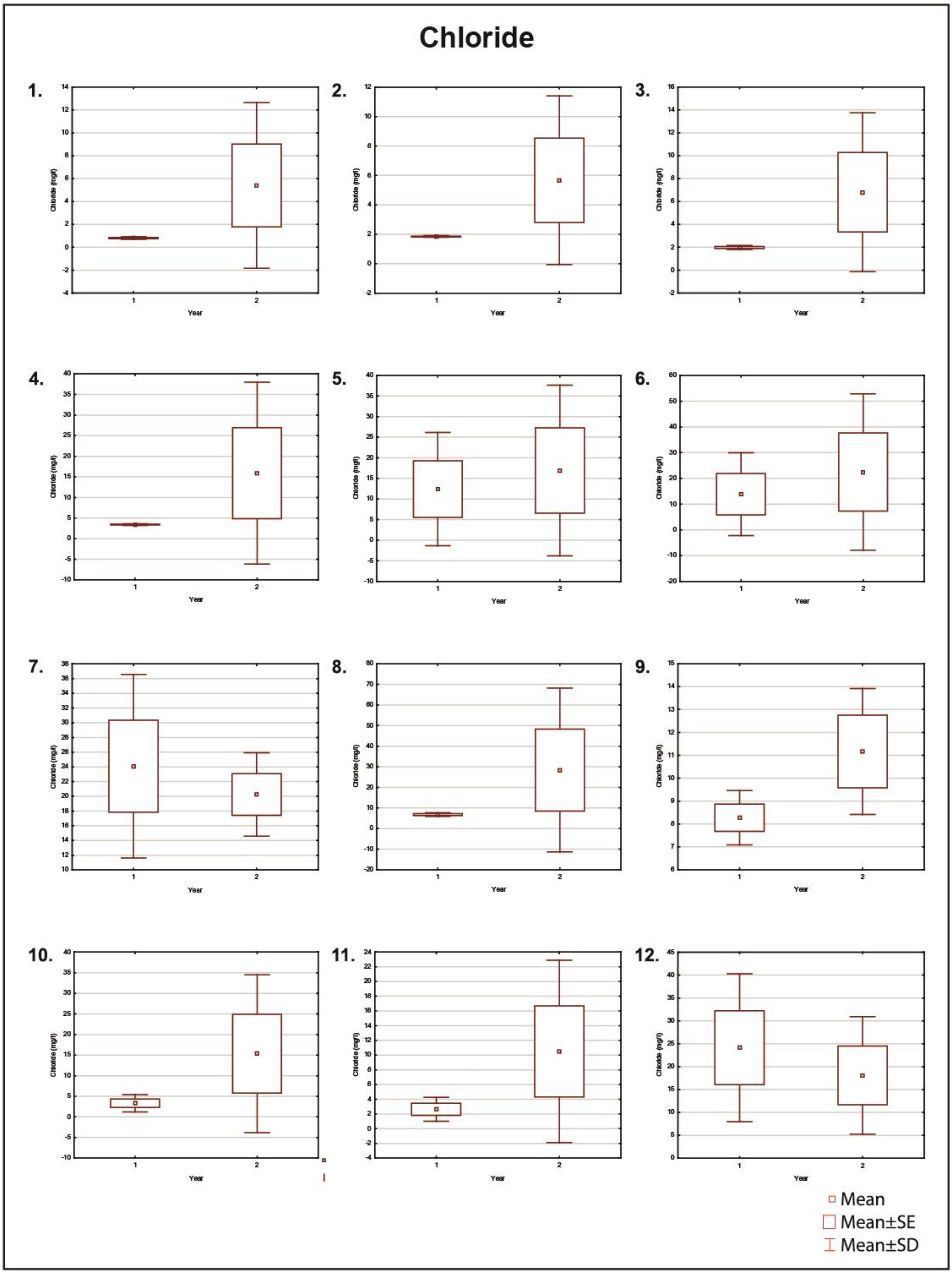
n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-5: Box and whisker plots illustrating the mean iron concentrations (in μg/l) observed at the sites



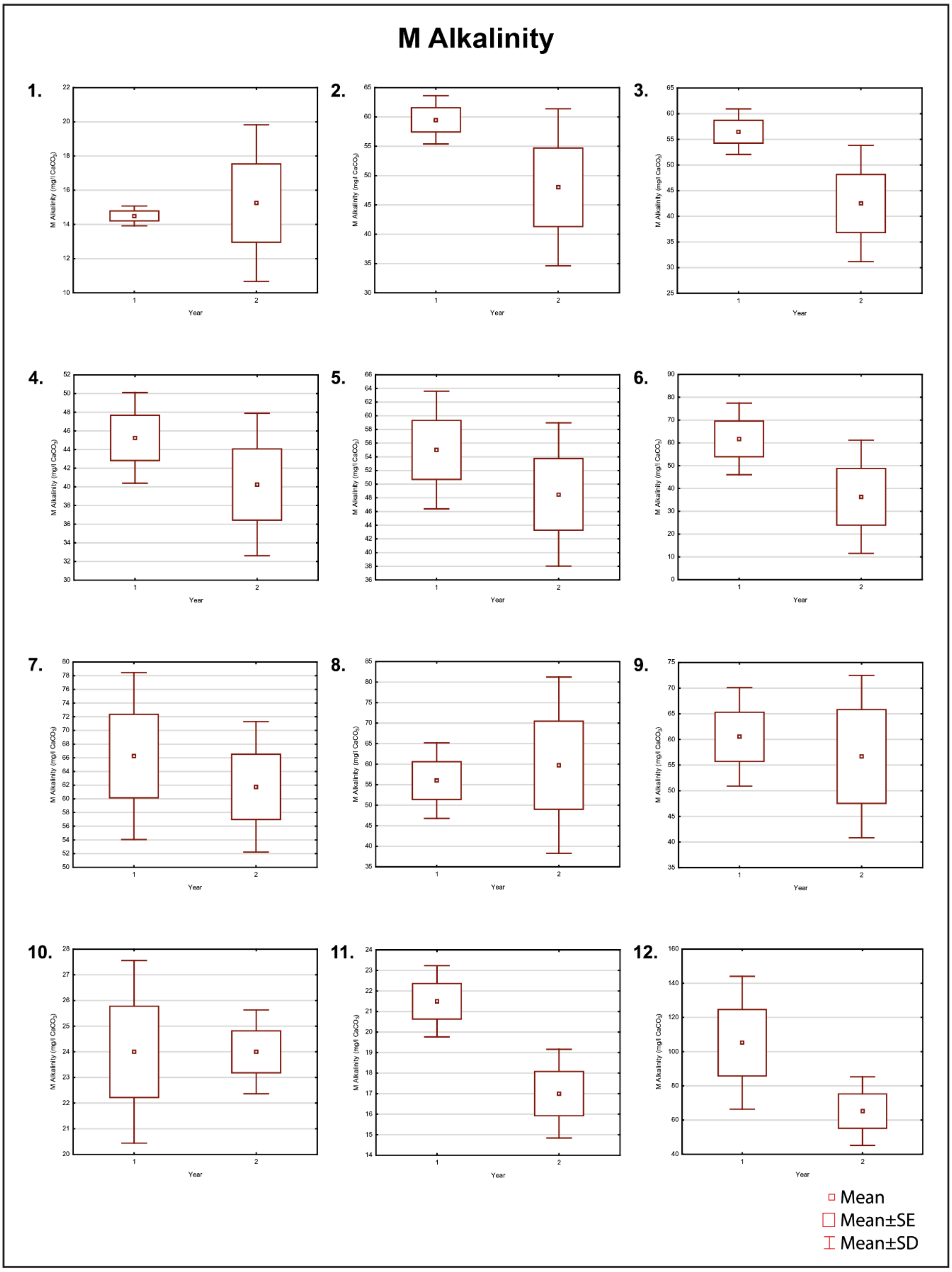
n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-6: Box and whisker plots illustrating the mean concentrations of total dissolved solids (in mg/l) observed at the sites



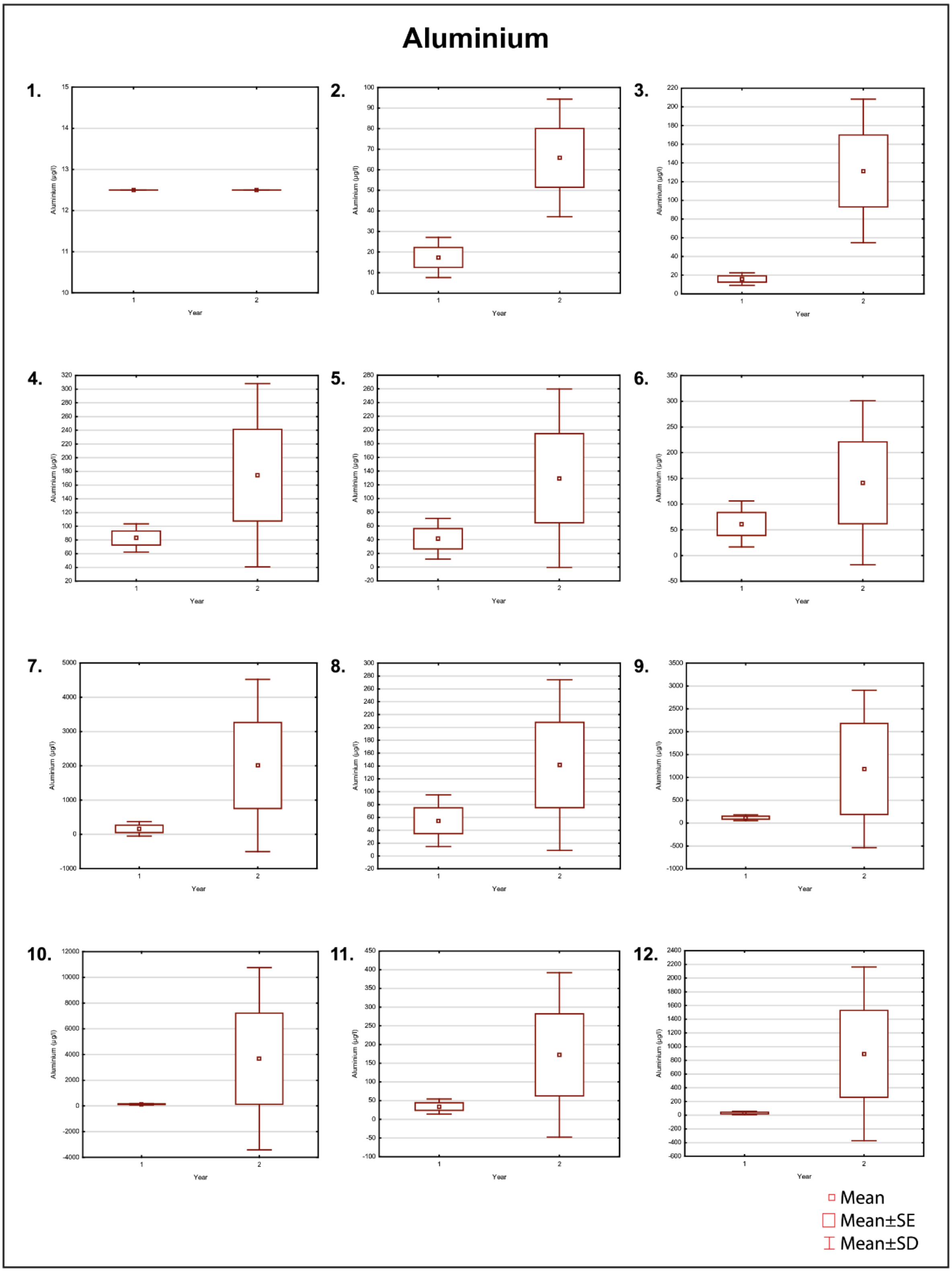
n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-7: Box and whisker plots illustrating the mean concentrations of chloride (in mg/l) observed at the sites



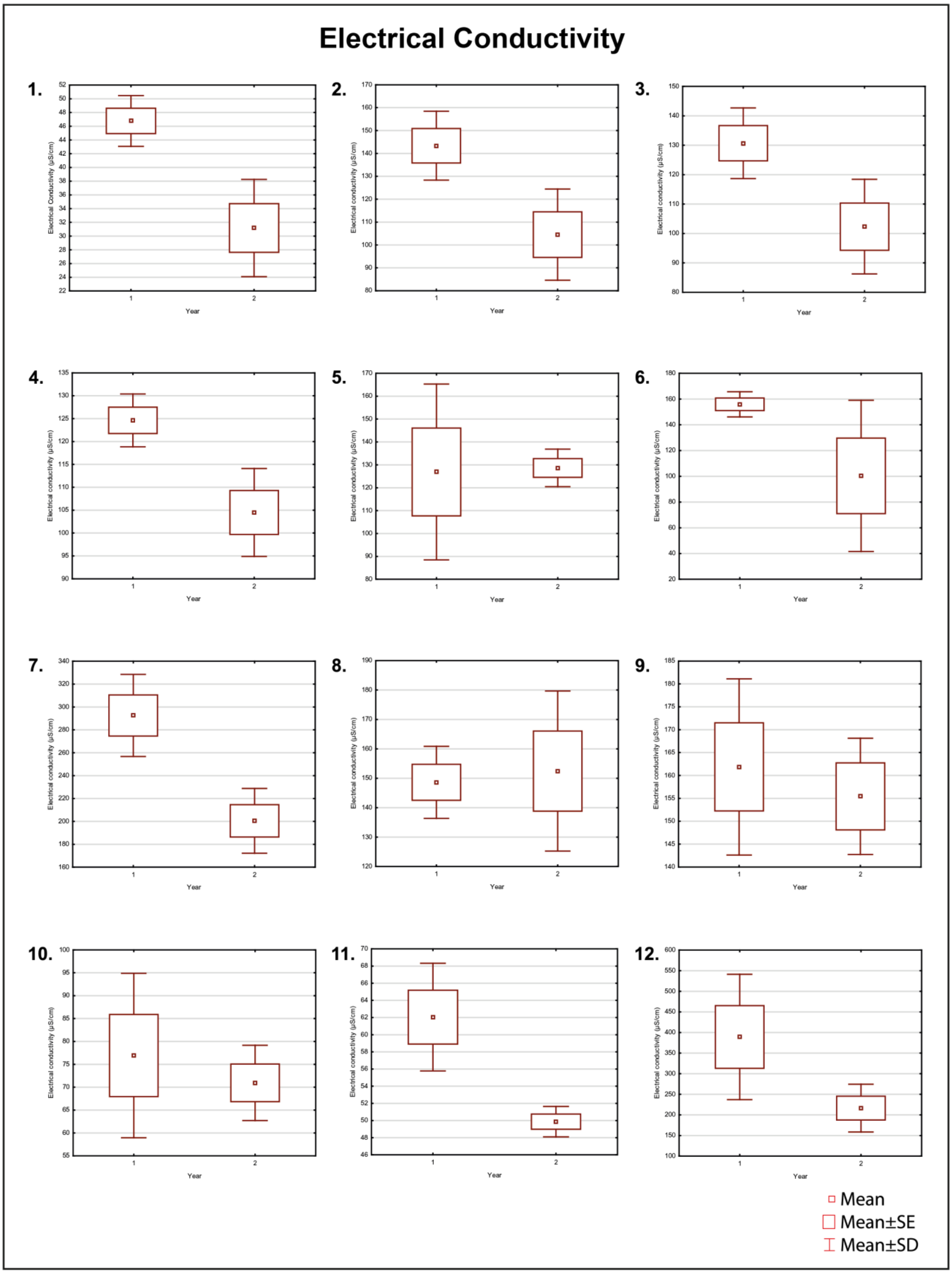
n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-8: Box and whisker plots illustrating the mean M alkalinity (mg/l as $CaCO_3$) observed at the sites



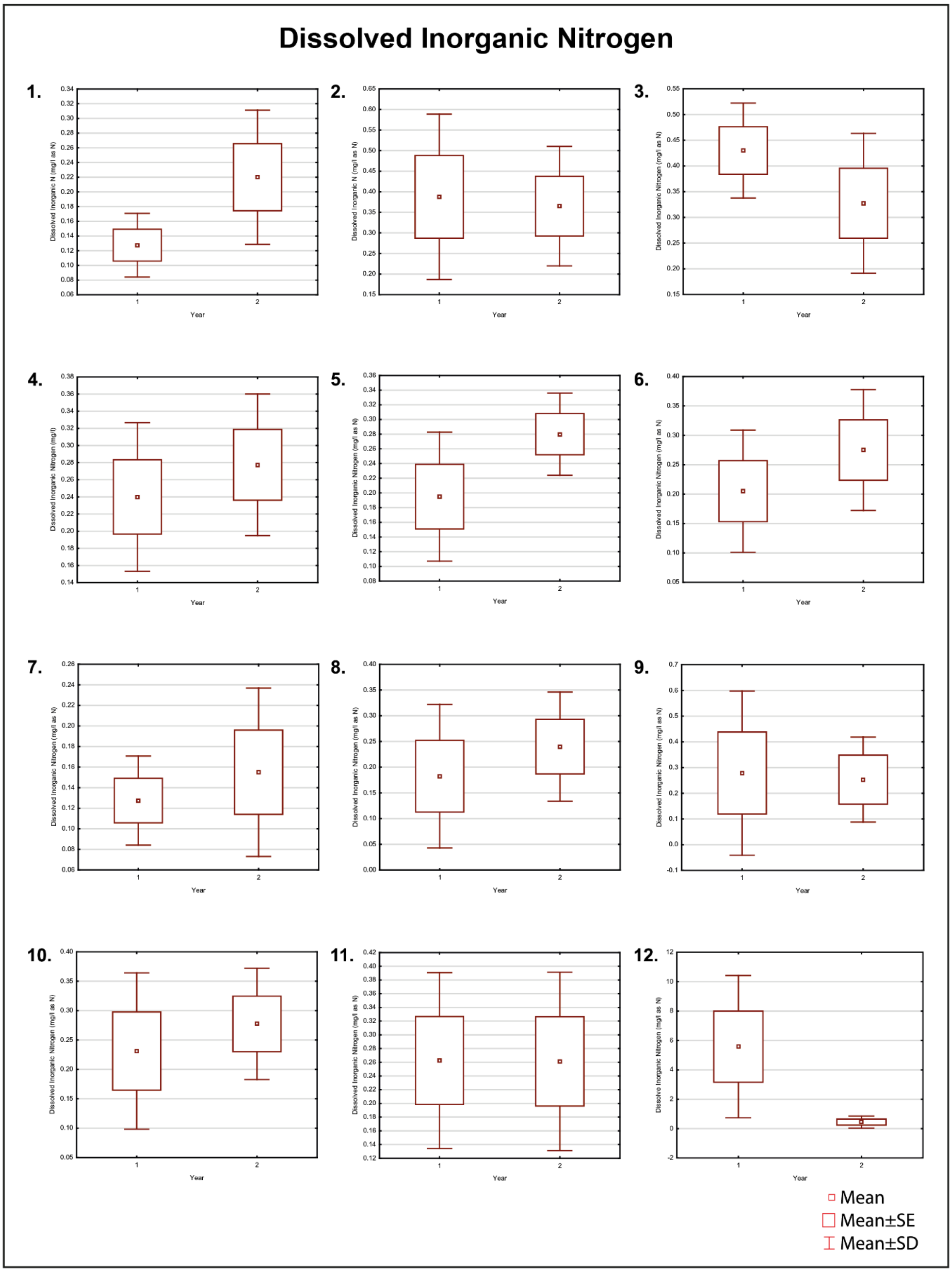
n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-9: Box and whisker plots illustrating the mean concentrations of aluminium (in µg/l) at the sites



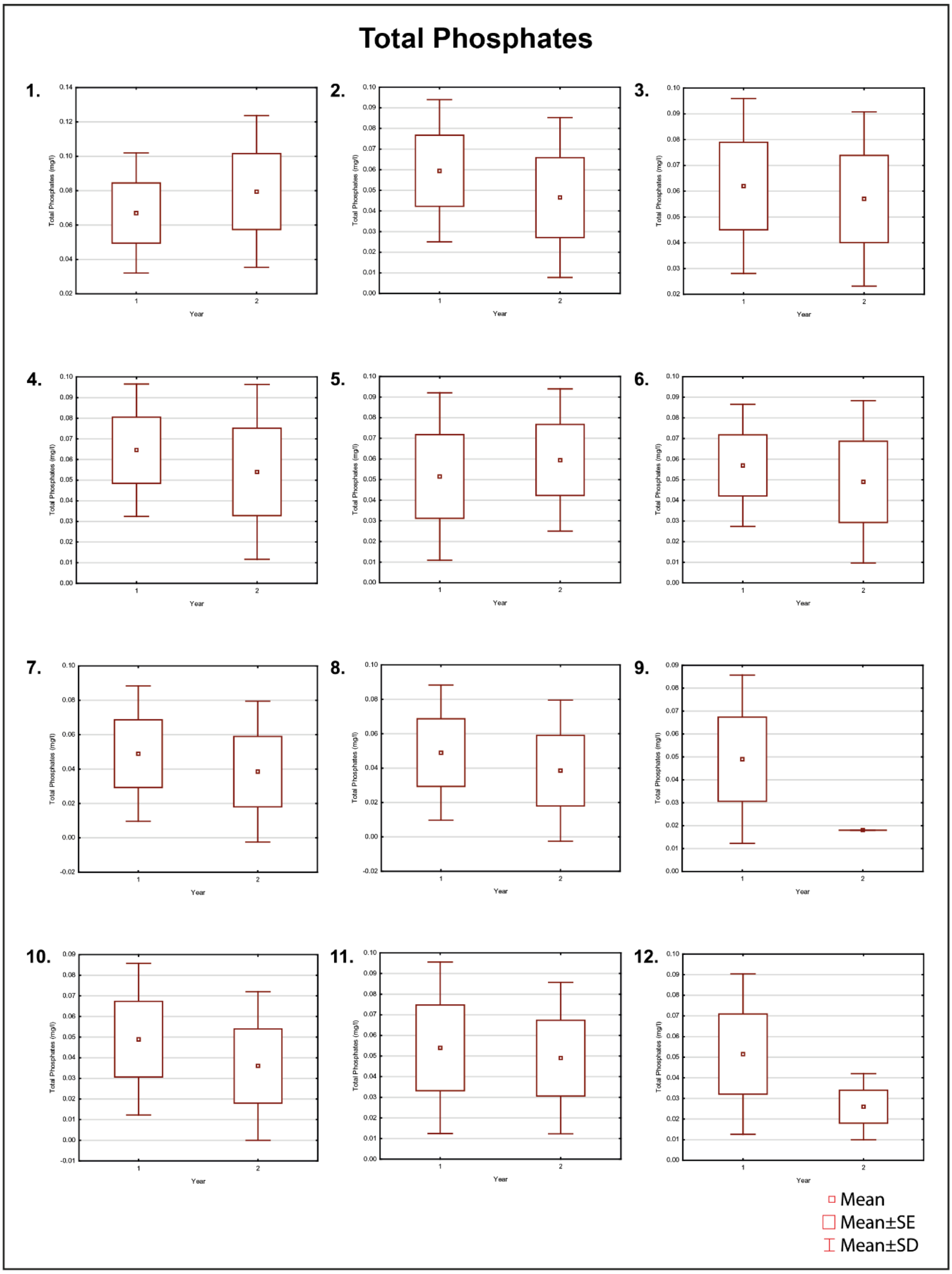
n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-10: Box and whisker plots illustrating the mean electrical conductivity (in mS/m) at the sites



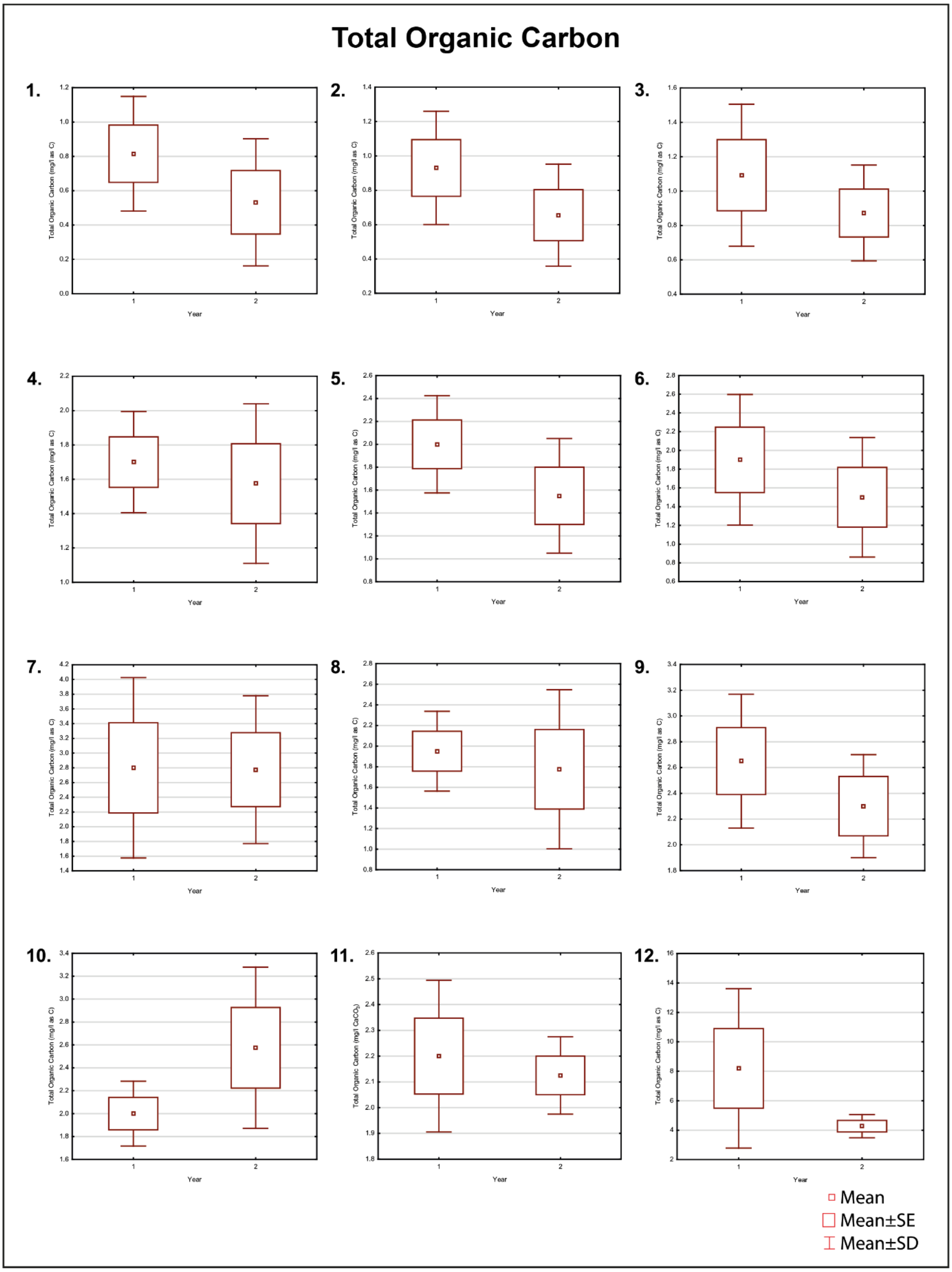
n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-11: Box and whisker plots illustrating the mean dissolved inorganic nitrogen concentrations (mg/l as N) at the sites



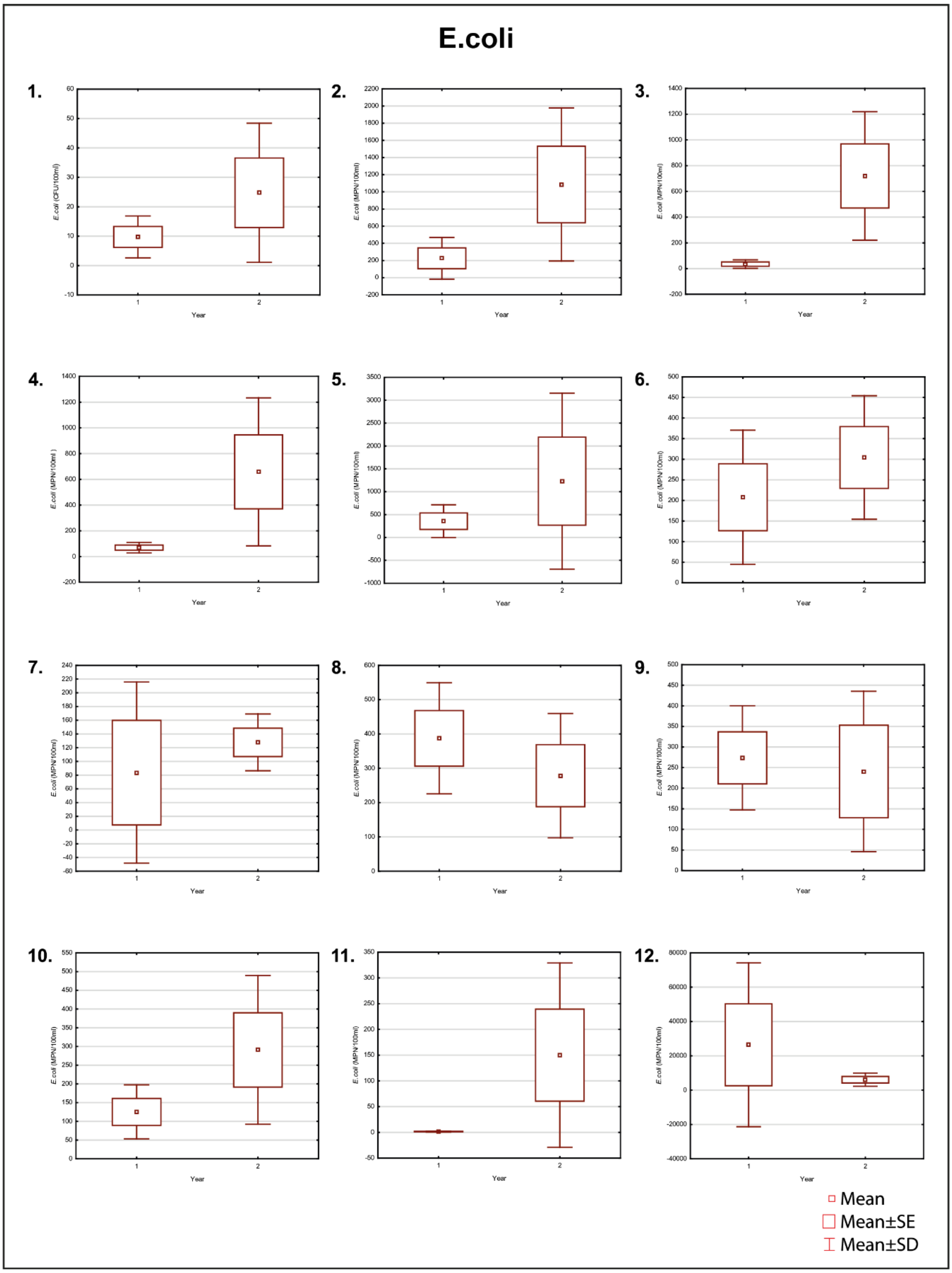
n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-12: Box and whisker plots illustrating the mean total phosphate concentrations (in mg/l) at the sites



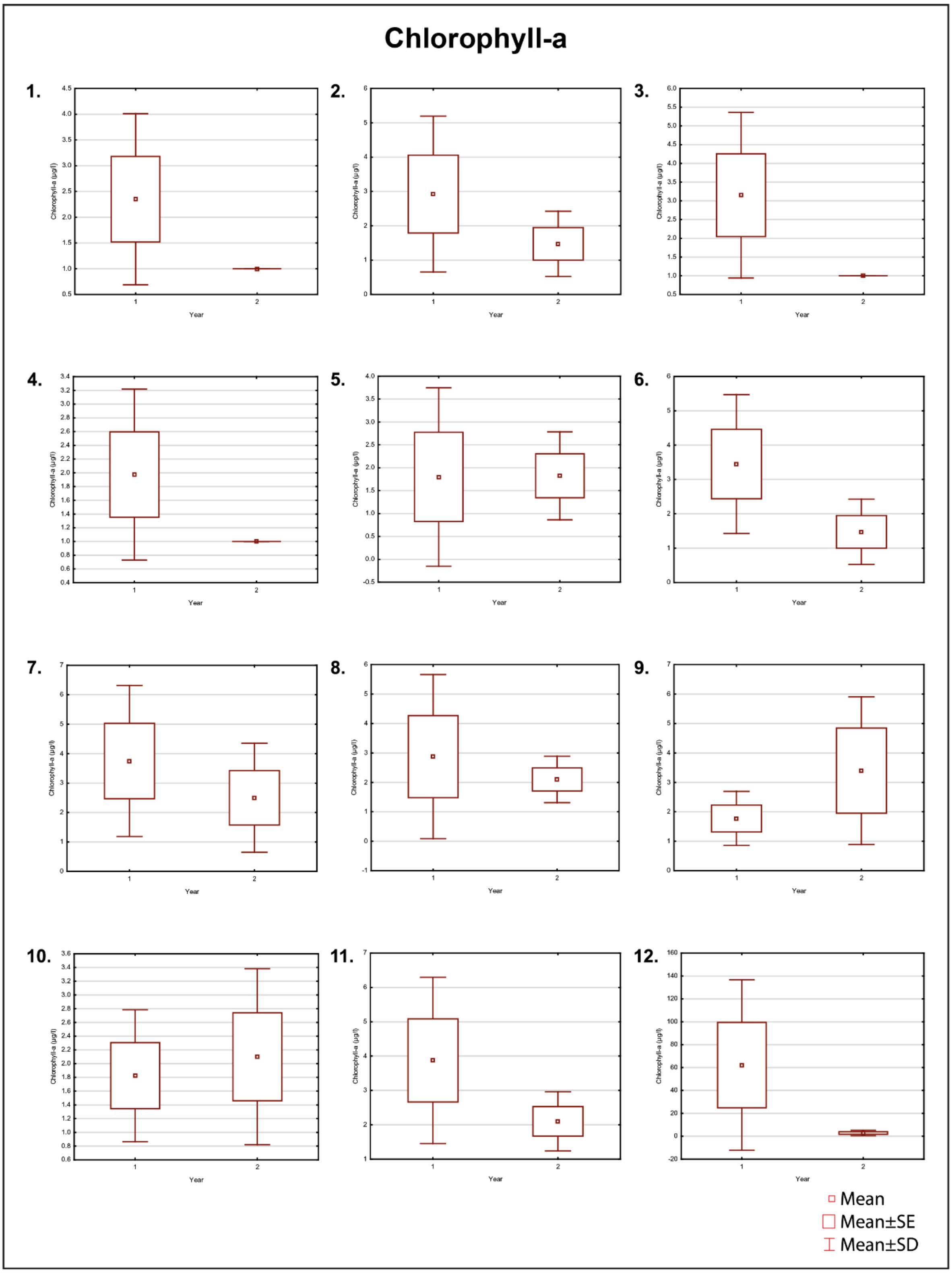
n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-13: Box and whisker plots illustrating the mean total organic carbon concentrations (mg/l as C) at the sites



n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-14: Box and whisker plots illustrating the mean *E. coli* concentrations (in MPN/100 ml) at the sites

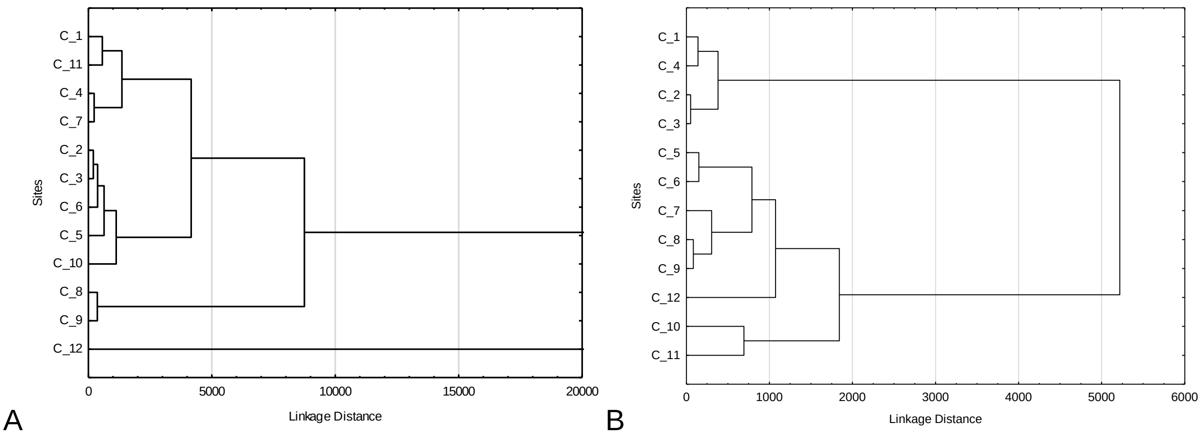


n = 4; SD: Standard deviation; SE: Standard error; 1 (2016); 2 (2017)
Sites 1-9 (Sabie River); Site 10 (Marite River); Sites 7 and 12 (Sand River); Site 11 (Inyaka Dam)

Figure 4-15: Box and whisker plots illustrating the mean chlorophyll-*a* concentrations (in µg/l) at the sites

4.3.5 Multivariate analysis

A cluster analysis is able to classify near and similar objects of a system into a cluster. The analysis demonstrated that the sites were more similar during 2017 than 2016, with a linkage distance of 5 230 in 2017 compared with a linkage distance of 26 000 in 2016 (Figure 4-16). The dissimilarity responsible for the large linkage distance in 2016 was mainly due to conditions determined at site 12. Site 12 clustered separately from the other sites. The other sites formed three separate clusters comprising (1) sites 8 and 9; (2) sites 2, 3, 5, 6 and 10; and (3) sites 1, 11, 4 and 7. During 2017, two main clusters could be distinguished; clustering sites 1-4 and sites 5-12. Within the second cluster, the sites located within the KNP could be distinguished from site 12 but were also grouped separately from the sites located in the Marite River, namely site 10 and site 11 (Inyaka Dam).



A: Represents the year 2016; B: Represents the year 2017

Figure 4-16: Dendrogram showing the cluster classification of the 12 sampling sites in the Sabie-Sand Catchment according to their land-use influences and water-quality parameters

The PCA showed differences between samples collected during Year 1, which represented the drought conditions of 2016, and Year 2, which represented the immediate post-drought conditions of 2017 (Figure 4-17). The principal components extracted illustrate the most meaningful parameters in the whole dataset. The first component explained 37.26% of the variation in the data, and the variable that showed the highest correlation with this component was total coliforms (Table 4-5). The second component showed the highest correlation with M alkalinity and calcium (Table 4-5) and explained 12.98% of the variance in the data. A very strong correlation existed between hardness and M alkalinity as well as the components affecting these two variables, namely calcium and magnesium. Component 2, therefore, also has a high correlation with calcium concentrations. The change in flow during the study period had the highest correlation (Table 4-5) with the third principal component that explained 10.33% of the variation in the data. Aluminium had the highest correlation with the fourth principal component (Table 4-5), which explained 9.4% of the variation in the data. Cell concentrations of the different groups of algae correlated with turbidity, 2-MIB, chl-*a* and TOC.

The cell concentrations of the group Bacillariophyceae correlated strongly with silica concentrations as well as EC and TDS. Increase in flow correlated strongly with the increase in sulphate, total phosphates and chloride concentrations.

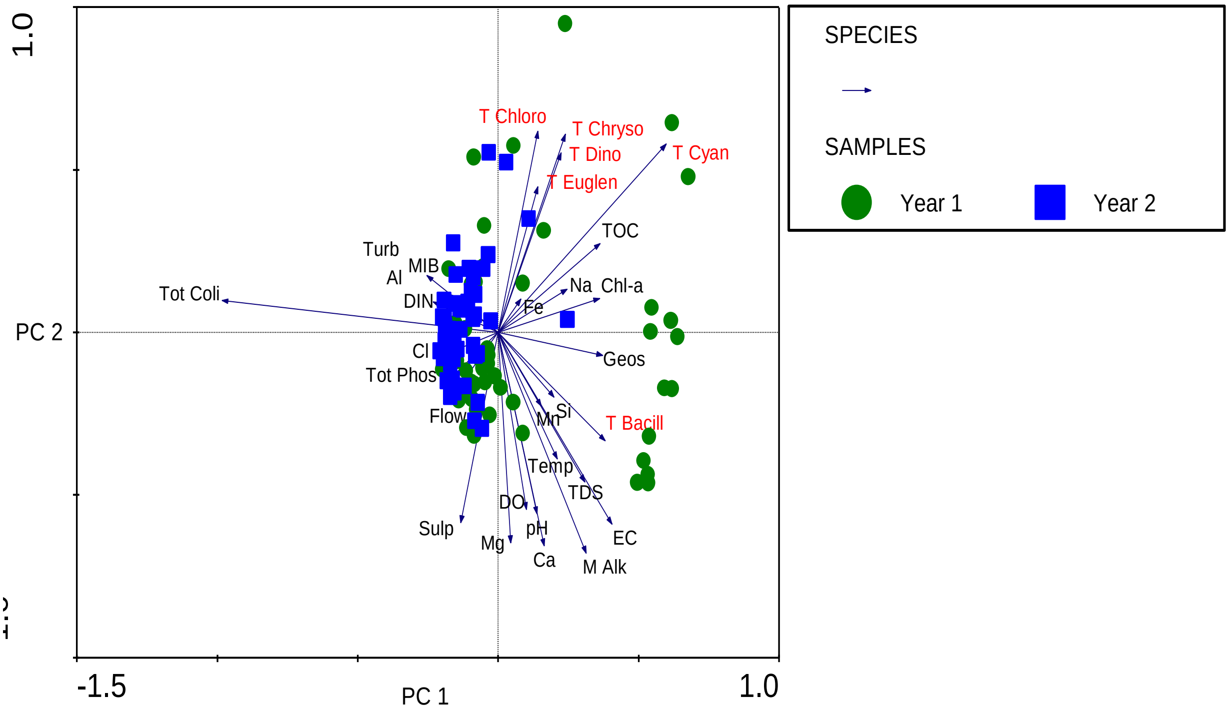


Figure 4-17: PCA ordination illustrating correlations between the principal variables and the samples collected at the sites during 2016 (Year 1) and 2017 (Year 2)

Table 4-5: Component variable correlations for the four extracted principal components

Variable	**PC1**	**PC2**	**PC3**	**PC4**
Eigen value	0.3726	0.1298	0.1033	0.094
Flow	-0.1793	-0.2153	0.8962	-0.2152
Chl-a	0.3611	0.1042	0.2292	0.3274
Total Coliforms	-0.9835	0.0974	-0.077	0.1039
Turbidity	-0.2538	0.1741	0.1164	-0.5226
TDS	0.3084	-0.4604	-0.328	0.1028
M Alkalinity	0.314	-0.679	-0.3115	0.3327
pH	0.138	-0.5583	-0.1474	-0.1584
Temperature	0.2108	-0.3897	-0.3169	-0.25
DO	0.1007	-0.5449	-0.1285	-0.2128

Variable	PC1	PC2	PC3	PC4
EC	0.4048	-0.59	-0.4288	0.2704
Aluminium	-0.2318	0.094	-0.236	-0.6912
Calcium	0.164	-0.6573	-0.0529	0.3485
Iron	0.0808	0.1029	-0.597	-0.5516
Magnesium	0.0449	-0.647	0.0926	0.372
Sulphate	-0.1338	-0.5851	0.1313	0.2708
Manganese	0.1532	-0.2272	-0.3001	-0.1853
Sodium	0.2452	0.1332	-0.0964	0.1857
Silica	0.1992	-0.199	-0.1341	-0.3966
Chloride	-0.1896	-0.0675	-0.0561	0.1338
Total Phosphates	-0.1911	-0.1587	0.6726	-0.2278
DIN	-0.1145	0.0773	0.6001	0.2512
TOC	0.363	0.2736	0.2609	-0.1387
2-MIB	-0.1819	0.1189	0.354	-0.0579
Geosmin	0.3725	-0.0708	0.0118	0.1327
T Cyanophyceae	0.5982	0.5787	-0.0587	0.263
T Bacillariophyceae	0.3807	-0.3337	-0.1219	0.42
T Chlorophyceae	0.142	0.618	-0.0073	0.4426
T Chrysophyceae	0.2386	0.6089	0.0532	-0.392
T Dinophyceae	0.2242	0.5517	0.168	-0.3754
T Euglenophyceae	0.1414	0.4479	0.3463	0.3757

According to Hair *et al*. (2009), variables indicating (±0.7 and higher) display the highest correlation to the component. Those equal to or greater than ±0.5 are considered significant, and variables that display (±0.3-±0.4) may not be regarded as significant but may aid in the identification of the component (Hair *et al*., 2009).

4.4 Discussion

Studies across the world have reported a decline in all aspects of the water quality of rivers and catchments due to an increase in population that results in an increase in urbanisation, agriculture, industrial activities and mining (Ding *et al*., 2016; Mei *et al*., 2014; as cited by Van der Hoven *et al*., 2017). The Sabie-Sand River catchment has also been experiencing an increase in population (Tlou, 2011). Furthermore, the effects of climate change add to the deterioration of water quality (Munzhedzi & Mgquba, 2013). The Sabie-Sand Catchment experienced one of its worst droughts during the 2015-2016 rainfall season (Smit, 2017), with sampling sites in the KNP experiencing the lowest rainfall recorded in history. For the first time, Skukuza received less than 200 mm within a climatic year (Smit, 2017). Rainfall and hydrological flow increased dramatically during 2017, providing the opportunity to compare the water-quality parameters during a drought with the parameters measured under immediate post-drought conditions.

It is evident that hydrological changes resulted in complex variations in water-quality parameters on both temporal and spatial scales within the study area. However, as was the case in 2016, the water quality determined at the different sites during 2017 still mostly complied with the TWQR and RQOs set, except for the concentrations of aluminium, ammonia, chloride and *E. coli*.

Site 12 is located in the Sand River downstream of a WWTP and is at the edge of a densely populated and busy urban township. As demonstrated by the PCA, this sampling site was associated with the worst water-quality conditions observed during the study. Site 12 exhibited the highest levels for most of the determined variables. This sampling site is most probably adversely affected due to its close location to a densely populated (1 265 people per km^2) (Census, 2011), low-income settlement. Such settlements are often negatively influenced by neglected water resource management and failing sewage treatment infrastructures (Van der Hoven *et al*., 2017). The water quality variables of concern are the observed high *E. coli* and total coliform concentrations that correlated with the high DIN, chl-*a*, chemical oxygen demand (COD), TOC and DOC concentrations and the low DO concentration. The significant negative correlation of DO with *E. coli*, TOC and DOC during 2016 could be the result of human waste pollution and low flow that favoured the rapid growth of the bacteria, leading to a depletion of DO, as was found by Van der Hoven *et al*. (2017). This was furthermore supported by the high level of COD. Most sites experienced an increase in *E. coli* concentrations during 2017, which could be the result of the increased runoff and drainage during the wetter season. This was also demonstrated in other studies conducted during post-drought conditions (Mosley, 2015 and as cited by Mosley, 2015).

Large increases in the concentration of aluminium were observed in 2017, especially at sites 7 and 12 that are located in the Sand River. Other studies have shown both increases and decreases in concentrations of metals during the post-drought conditions (Mosley, 2015). Elevated concentrations of bio-available aluminium in water are toxic to a wide variety of organisms, especially fish. There is, however, uncertainty as to the form(s) of bio-available aluminium and the mechanism(s) of toxicity (DWAF, 1996a). Current studies did not determine the form of available aluminium. Above pH 6.5, aluminium primarily exists as an insoluble form of mainly aluminium hydroxide. Below pH 4, aluminium becomes soluble and toxic and, therefore, there is no health risk associated with the higher levels of aluminium observed in the Sabie, Marite and Sand rivers or the Inyaka Dam. The increase in aluminium and iron could be ascribed to sediment runoff during the higher rainfall experienced during 2017 and thus could be related to the geology of the area surrounding the sampling sites. There is also the potential impact of acid rain during the rainfall events, as the catchment is just north of the Olifants River catchment which is known for the acid rain impacts.

The RQO for the Sabie River for phosphates states that the 50th percentile of the data must be <0.015 mg/l and <0.125 mg/l for the Sand River. Due to the reporting limit set by Rand Water, it was decided to report the concentration of total phosphates. Unfortunately, the reporting limit of <0.036 mg/l is more than double that of the RQO set for the sites located in the Sabie River. According to Wetzel (2001) the mesotrophic-eutrophic boundary for streams are 75 µg/l total Phosphorous, and again unfortunately the reporting limit set by Rand Water of 0.5 mg/l would thus make it not be possible to use P (phosphorus) as indication of the trophic state of the rivers either. It is, therefore, difficult to determine the trophic condition of the Sabie, Sand and Marite rivers because although the total phosphate concentration may indicate eutrophic conditions according to Van Ginkel *et al*. (2000) as developed for impoundments, the inorganic nitrogen concentrations reflect an oligotrophic-mesotrophic condition at all the sampling sites. This is also supported by the range of chl-*a* concentrations determined at all of the sites, which was consistently <10 µg/l. Furthermore, only site 11, the Inyaka Dam, showed >20% dominance by the group Cyanophyceae during 2017 (see Section 5). Chlorophyll-*a* concentrations decreased during 2017, which was probably due to the dilution effect of increased water volumes. As well as increased turbidity that will limit light for algal growth. The higher flows also cause in-favourable conditions for cyanobacterial growth which prefer relatively stagnant waters and is thus not prone to develop to bloom conditions in relatively fast flowing streams as is the case at most of the sampling sites. An increase in the total phosphates during 2017 might be due to the higher flows, which can cause nutrients leaching from the soils, under normal conditions, but especially also in the case where fertilizer applications are standard However, due to the reporting limits of the nutrients (ammonia and total phosphates), it is difficult to reach an accurate conclusion.

The overall decrease in ammonia concentrations observed during 2017 is most probably due to the flushing of effluent sources that caused the level of ammonia to increase during low flow/drier conditions. According to DWAF (1996a), ammonia can also be toxic at concentrations >0.03 mg/l, especially to fish. However as discussed earlier, the reporting limit for ammonia set by Rand Water is <0.05 mg/l and, therefore, most of the data show that the concentration of ammonia does not comply with the TWQR. The relevant ammonia concentration is also pH and temperature dependent. Only site 12 showed average ammonia concentrations of >0.03 mg/l. There was, however, a decrease in the average ammonia concentrations during 2017 from 5.0 mg/l to 0.17 mg/l at site 12 as compared to 2016. The increase observed in nitrate-nitrite concentrations during 2017 at most sites could be the result of flushed catchment soils due to the stimulation of mineralisation and nitrification processes during wetter conditions, as was noted by Mosley (2015).

Although an increasing trend was observed in the pH for the entire study period, there was no statistically significant increase observed in the pH values at any of the sites. A decrease in M alkalinity was observed during 2017, but this could be related to the decrease observed in calcium concentrations during 2017. This is contrary to most other studies that have shown decreases in pH and alkalinity in river systems during drought periods (Mosley, 2015). Furthermore, increases in both nitrite-nitrate and sulphate concentrations were observed at most sites during 2017. This is consistent with increases in acidity, as was also found by Stets *et al*. (2014) and which can contribute to the decrease in M alkalinity.

Most studies reviewed by Mosley (2015) showed little change in DO levels during drought conditions but also reported decreases in DO levels during the post-drought time frame. The increase in DO levels observed at most of the sampling sites during the immediate post-drought conditions of 2017 could possibly be the result of better aeration during high flow conditions.

During 2016, all the sites exhibited relatively low turbidity values. The increase observed in turbidity values at most sites during 2017, although not statistically significant, can be attributed to the increase in runoff in the catchment due to higher rainfall. During the drought conditions of 2016, the TDS values for the Sand River at sites 7 and 12 were significantly higher than those observed in both the Sabie and Marite rivers and the Inyaka Dam. Both increases and decreases were observed in the levels of TDS at the various sites during the immediate post-drought period. The flushing of individual solutes such as chlorides, sulphates and sodium under immediate post-drought conditions due to different hydrological pathways and sediment-solution characteristics have been reported in several studies (as cited by Mosley, 2015) and could explain the changes in TDS observed at the different sites during 2017. Since site 3 is located just below the confluence of the Sabie, Mac-Mac and Sabaan rivers in a highly cultivated area, the increase in TDS could be the result of agricultural runoff, while the decrease in TDS at sites such as 6, 7, 8, 9 and 12 could be due to the flushing off of accumulated solutes. An overall decrease in EC was observed at all sites, most probably due to higher runoff.

Usually, an increase in TOC and DOC is observed during the immediate post-drought period due to the mobilisation of organic carbon in the catchment, as was seen in Australia during the flooding of the Murray-Darling Basin (Whitworth *et al*., 2012). However, in his review, Mosley (2015) also noted higher concentrations of organic carbon during periods of drought. An overall decrease in TOC and DOC levels was observed at all the sampling locations during the immediate post-drought period, which can be an indication of lower aquatic biomass production. As was noted, chl-*a* decreased during 2017. Levels of the taste and odour compound geosmin also decreased during 2017 at most sampling sites. Most sites, however, showed an increase in the compound 2-MIB.

In a comparison according to land use and water quality, cluster analysis indicated that sites were more similar during 2017 than during 2016. This is also evident from the results of the PCA in which the samples of 2017 were ordinated much closer. This could possibly be the result of higher river flows from the upper reaches, leading to better mixing in the lower reaches. This is also indicated by the clustering of sites 1-4, which stretch from the headwaters above the town of Sabie to the foothills at Hazyview. Sites 5-9 and 12 formed a second cluster. These sites fall within the KNP, with the exception of site 12 that is located just outside the KNP. Site 10 in the Marite River and site 11 in the Inyaka Dam clustered together, unlike the results obtained during the drought conditions when the water quality at site 1 clustered closer to that of the Inyaka Dam.

The most important drivers of water quality as indicated by the PCA were total coliforms and *E. coli*. There was an increase in both these parameters during 2017, and this increase was statistically significant at sites 2, 4 and 6 in the Sabie River. Although site 12 experienced a decrease in total coliform concentrations during 2017, it still had the highest concentration. This emphasises the importance of adequate and functioning sewerage systems and wastewater treatment plants (WWTP) to prevent water quality deterioration. To prevent the deterioration of water quality in this area, development, management and maintenance of sewerage systems are required to ensure that socio-economic and environmental values are not threatened.

4.5 Conclusion

Climate change probably increases the frequency in change between low river flows and high river flows, which will affect both water quality and quantity. Although the impacts on water quantity are well known, the impacts on water quality are not. During this study, the effect of higher river flows on water quality during the immediate post-drought period was investigated. The continuance compliance to most of the water-quality parameters to the TWQR and RQOs indicates the resilience of the Sabie-Sand Catchment. However, the long-term effects of successive droughts occurring over multiple years or decades with longer durations as a result of climate change may be much more severe, and this requires further research and modelling.

The findings of this study are consistent with many other studies on droughts and the immediate post-drought conditions experienced during high rainfall. This study demonstrated the adverse effects of the immediate post-drought conditions due to the increase in nutrient concentrations, total coliform and *E. coli* concentrations and the concentrations of metalloids such as aluminium and iron. Variable effects were observed for DO, TDS and chl-*a*. However, many of these effects depend on the characteristics of the waterbody and its catchment.

5 ALGAL ASSEMBLAGES

5.1 Introduction

Algae are cosmopolitan and occur ubiquitously in all aquatic ecosystems. They are highly successful primary producers in aquatic habitats such as streams with high allochthonous inputs. In these habitats, the primary energy source for higher trophic levels besides macrophytes are algae (Wehr *et al.*, 2015). Algae are critical components of lotic water bodies such as the Sabie River in that they participate in biogeochemical cycles, for example, the transformation of nitrogen and phosphate fluxes (Lamberti, 1996). The catchment of a river includes various types of stagnant water bodies such as small pools (as was observed at sites 6, 7 and 9 in this study), ponds, connecting marshlands, the shallows of rivers and artificial impoundments (i.e. the Inyaka Dam in this study), which continuously enrich the phytoplankton community of the stream (Bolgovics *et al.*, 2017; Borics *et al.*, 2007). Therefore, riverine phytoplankton appears to be a mixture of algal species that are characteristic of these different aquatic environments (Bolgovics *et al.*, 2017).

According to the Department of Water and Sanitation (DWS) (DWS, 2018), the main aim of environmental management is to protect and enhance the environmental state of a system and to sustain the economic and social well-being of those depending on the ecosystem. The spatial and temporal changes observed in the algal communities of a system are of extreme importance in understanding the functioning of the ecosystem. Algae can affect the processes, functioning and stability of an ecosystem and can, therefore, reflect major shifts in environmental conditions (Wehr *et al.*, 2015). The distribution of phytoplankton strongly correlates with not only hydrological factors but also environmental factors such as physical and chemical parameters (Wu *et al.*, 2011). According to Wu *et al.* (2011), some researchers conclude that river phytoplankton is regulated by nutrient concentrations while others believe that hydrological factors are of greater importance. Although there is a wealth of scientific information about the phytoplankton assemblages of lakes, knowledge regarding riverine phytoplankton is still limited (Bolgovics *et al.*, 2017).

The Sabie, Sand and Marite rivers are the main potable water resources for towns such as Sabie, Hazyview and Bushbuck Ridge and form a crucial part of the tourism, agricultural and mining industries of the area. To the author's knowledge, the algal assemblages of the Sabie-Sand River systems have not yet been thoroughly analysed, especially in terms of land use and a drier rainfall year, that is, under low or no-flow circumstances. The Sabie-Sand Catchment has a highly variable rainfall distribution due to its geographical distribution and has always experienced irregular rainfall with floods and extreme droughts (Romano, 1963). Downstream of the mountains, the river basin is vast. The flow is reduced by permeability into the ground, and the groundwater has a sizeable regulatory effect (Romano, 1963).

Although cyanobacterial blooms previously received much attention within the confines of the KNP (Bengis *et al.*, 2016; Masango *et al.*, 2010), very little research has been published on phytoplankton assemblages in the rest of the Sabie River and its tributaries. With an increase in the population and considering the droughts experienced in South Africa, harmful algal blooms pose a real threat to the health of rural communities. Not only does an algal bloom negatively affect both domestic and wild animals, but it also has the potential to cause numerous problems within water treatment plants, thus affecting the drinking water quality and the health of the communities served by these plants.

5.2 Materials and methods

5.2.1 Sample collection

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 surface water (nine litres from each sampling site) was then transferred to the allocated containers. Samples for algal identification and enumeration (250 ml) were preserved on site with formaldehyde (final concentration of 2%).

5.2.2 Phytoplankton sample preparation and enumeration

The sedimentation technique described by Utermöhl (1958) and Swanepoel *et al.* (2008) was followed. The gas vacuoles of the cyanobacteria were pressure-deflated in a special container using a mechanical deflation tool. After deflation of the gas vacuoles, up to 6 ml of the sample were transferred into marked sedimentation chambers depending on the density of the algae and cyanobacteria. The sedimentation tube was filled with distilled water, covered with a cover slip and left for a minimum of three days in a desiccator to allow the cells to settle. Algae and cyanobacteria were identified up to genus level and enumerated using an inverted microscope (Zeiss Primovert) at 400x magnification. The Whipple-Grid method (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 fell inside the grid. The chamber was then turned, 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 identification were the studies of Ettl *et al.* (1999), Hindák (2008), Hüber-Pestalozzi (1961), Janse van Vuuren *et al.* (2006), John *et al.* (2002), Komárek and Anagnostidis (2005), Prescott (1964) and Wehr and Sheath (2003).

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. Each sample was allowed to settle, and the supernatant was removed without disturbing the diatom cells at the bottom of the container. The sample was mixed, and 5-10 ml was transferred to a beaker. Ten millilitres of saturated potassium permanganate ($KMnO_4$) solution was added, and the mixture was left to stand for 24 hours. Using a fumehood, 5-10 ml concentrated HCl (32%) was subsequently added, and the mixture was heated on a hot plate (90°C) for 1-2 hours until the solution was clear. To determine if any organic matter remained, 1 ml hydrogen peroxide was added. The sample was then transferred to centrifuge tubes and rinsed by centrifuging with distilled water at 2 500 rpm for one minute. The supernatant was discarded, and the rinsing procedure was repeated four times.

One drop of a 10% ammonium chloride (NH_4Cl) solution was added to the pellet to decrease the electrostatic charges on the diatoms in order to ensure decreased aggregation and even cell 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.

The slide was allowed to cool and then examined using a differential interference contrast (DIC) light microscope at 1 000x magnification. All diatoms were identified to genus level according to Taylor *et al.* (2007b) and Taylor and Cocquyt (2016).

5.2.3 Biodiversity indices

The Shannon-Wiener index (Shannon & Wiener, 1949) is based on the number of species and their equability, thus representing each species in a sample (Fedor & Spellerberg, 2013). The index uses the species richness and the evenness to determine the biodiversity of a system and is directly proportional to the evenness and the species richness.

The Shannon-Wiener index is determined as follows:

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

Where:

H – 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 natural logarithm to base

The Margalef index (Margalef, 1958) 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 is determined as follows:

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

S – Number of species
N – Number of organisms in the sample
In – Natural logarithm

The Margalef and Pielou (Pielou, 1966) 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 is determined by the following equation:

$$e = H/In\,S$$

H – Shannon-Wiener Diversity index

S – Total number of species present in the sample

5.2.4 Statistical analyses

The water quality dataset consisted of biological, chemical and physical parameters. Results that were below the reporting limit were assigned the value of one-half the reporting value in order to be included in data processing. Missing data were treated as gaps and 0 was used where the variable was measured as zero. All statistical analyses were carried out using Statistica version 13, Dell Inc. (2016). Initially, the Kolomogorov-Smirnov and Lilliefors tests for normality were conducted to determine if the data were distributed parametrically. The data did not meet the assumptions of normality in the distribution of all variables and thus, non-parametric statistics were applied. The Kruskal-Wallis ANOVA (comparison of multiple groups) was used to compare multiple independent groups. The significance of the results of a Kruskal-Wallis ANOVA can be determined as a *z*-value and/or a *p*-value.

A canonical correspondence analysis (CCA) is a constraint ordination method used to elucidate the relationships between biological assemblages of species and their environment. The CCA was also used during this study and performed using the Canoco 4.5 software program (Ter Braak & Šmilauer, 2002). Log transformation of the data, that is log(y+1) was applied to deal with zero values in the data set for the CCA. A Monte Carlo permutation test (499 permutations) was used to determine the statistical validity of the CCA.

5.3 Results

5.3.1 Biodiversity of algae and cyanobacteria

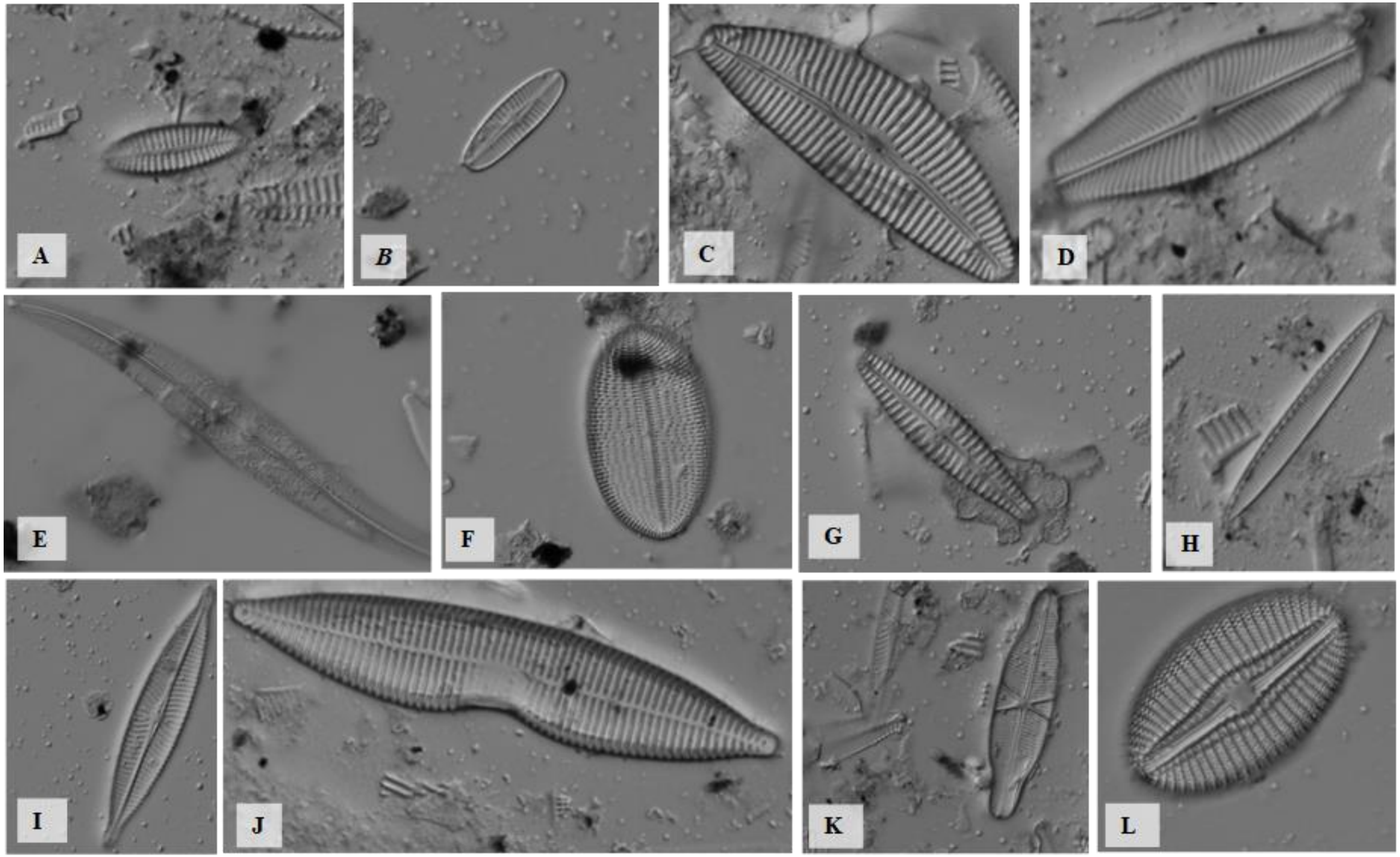
A list of all the cyanobacteria and algae genera detected during the survey was compiled for both 2016 and 2017 and is presented in Appendix C (Table C-1 and C-2). Although the genera observed during the study periods differed, there was no significant difference (p=0.29) in the total number of genera observed for the two sampling periods at the different sites. (Total of 86 genera for 2016 and 88 genera for 2017). Six phytoplankton groups or classes were represented during both sampling years. For 2016, these groups included 14 genera from the class Cyanophyceae, 33 genera from the class Bacillariophyceae (Figure 5-1), 32 genera from the class Chlorophyceae (Figure 5-2), 1 genus from the class Chrysophyceae, 3 genera from the class Dinophyceae and 3 genera from the class Euglenophyceae (Figure 5-3), resulting in a total of 86 genera. However, an increase in the genus diversity was observed in 2017 for all of the classes except the class Chlorophyceae. The 2017 groups included 35 genera from the class Bacillariophyceae (Figure 5-4), 30 genera from the class Chlorophyceae (Figure 5-5), 15 genera from the class Cyanophyceae, 4 genera from the class Euglenophyceae (Figure 5-6), 3 genera from the class Dinophyceae and 1 genus from the class Chrysophyceae (Figure 5-7), resulting in a total of 88 genera.

The Bacillariophyceae and Chlorophyceae were the most diverse groups during both sampling periods. Bacillariophyceae genera such as *Aulacoseira*, *Caloneis*, *Luticola* and *Mayamaea* were only found during the 2016 sampling period, while *Fallacia*, *Hantzschia*, *Neidium*, *Placoneis*, *Planothidium*, *Surirella*, *Tryblionella* and *Urosolenia* were only found during the 2017 sampling period. Chlorophyceae genera such as *Microspora, Mougeotia, Nephrocytium, Schroederia, Selenastrum* and *Spirogyra* were only observed during the 2016 sampling period, while *Dictosphaerium, Kirchneriella, Tetrastrum, Treubaria* and *Ulothrix* were only found during the 2017 sampling period.

Cyanophyceae genera such as *Chroococcus*, *Geitlerinema, Pseudanabaena, Snowella and Spirulina* were observed during the 2016 sampling period but not during the 2017 sampling period, while genera such as *Aphanothece*, *Cylindrospermopsis*, *Gloeocapsa*, *Radiocystis* and S*ynechocystis* were only found during the 2017 sampling period. During the dry sampling year, site 12 in the Sand River had the most cyanobacterial genera (ten) present but that changed under the immediate post-drought conditions in 2017, when less than five genera were observed.

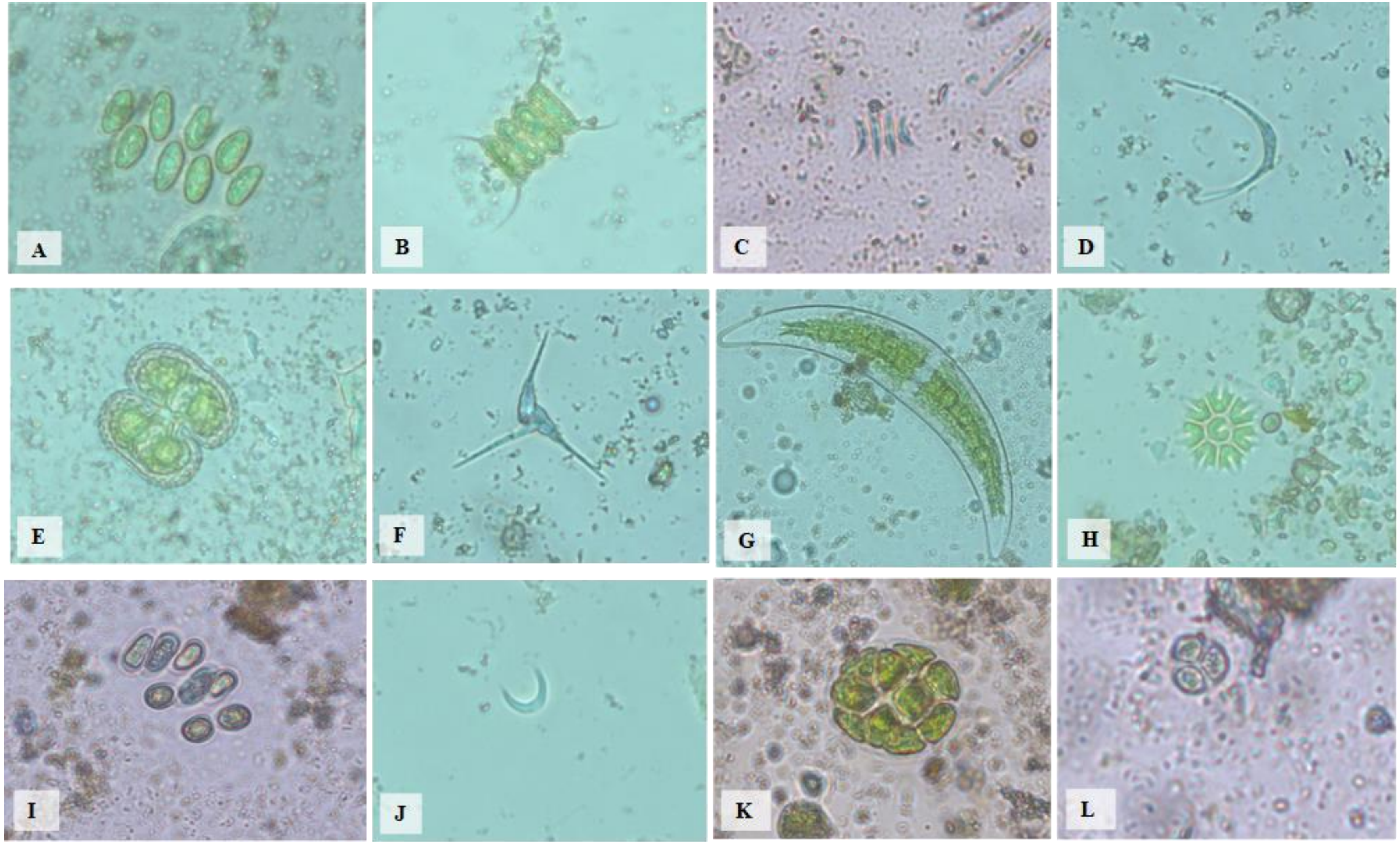
Only one genus of the class Chrysophyceae, *Dinobryon,* was observed during both the drought (2016) and the immediate post-drought period (2017) at sites 5, 10 and 11. The three genera from the class Dinophyceae, *Ceratium* (sites 4, 8 and 12), *Peridiniopsis* (site 11) and *Perindinium* (site 11) were present in both 2016 and 2017. *Euglena* and *Trachelomonas* from the class Euglenophyceae were present at low levels at most sites in both 2016 and 2017, but *Phacus* was only observed at sites 4 and 5 during 2017. In addition, *Strombomonas* was only found in 2017 at sites 2, 7, 9 and 10.

Understandably, the algal population of the Inyaka Dam (site 11) differed somewhat from the rest of the river system, with Bacillariophyceae genera such as *Achnanthes* and *Cymbella* being absent at site 11 but observed at all the other sites during 2016. During the 2017 survey, *Cocconei*s was found at all the sites except Inyaka Dam.



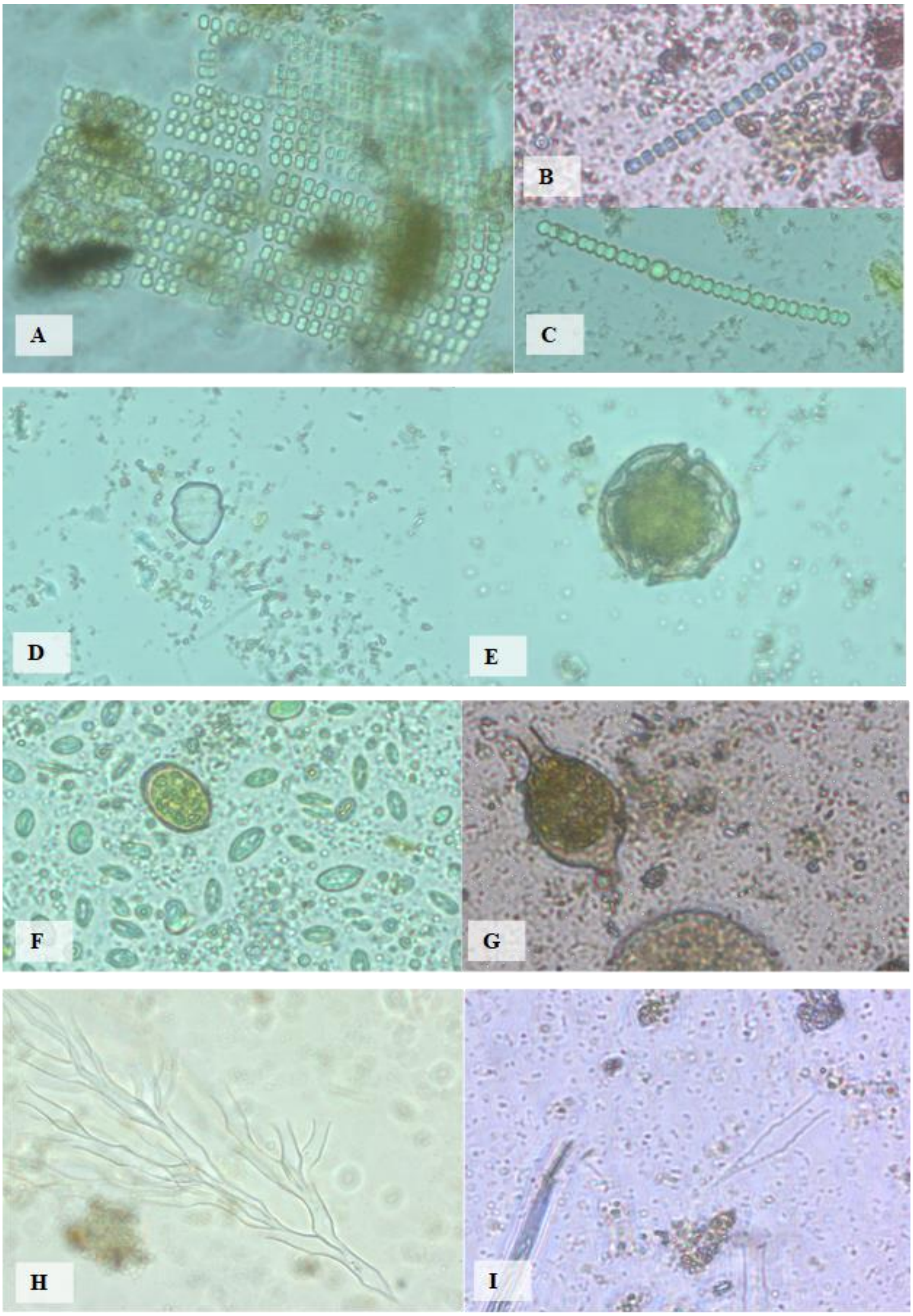
Achnanthes (A); *Achnanthidium* (B); *Cymbella* (C); *Sellaphora* (D); *Gyrosigma* (E); *Cocconeis* (F); *Gomphonema* (G); *Nitzschia* (H); *Navicula* (I); *Synedra* (J); uncommon genera: *Capartogramma* (K) and *Diploneis* (L)

Figure 5-1: Light microscopy photographs (1000x magnification) of Bacillariophyceae observed in samples during 2016



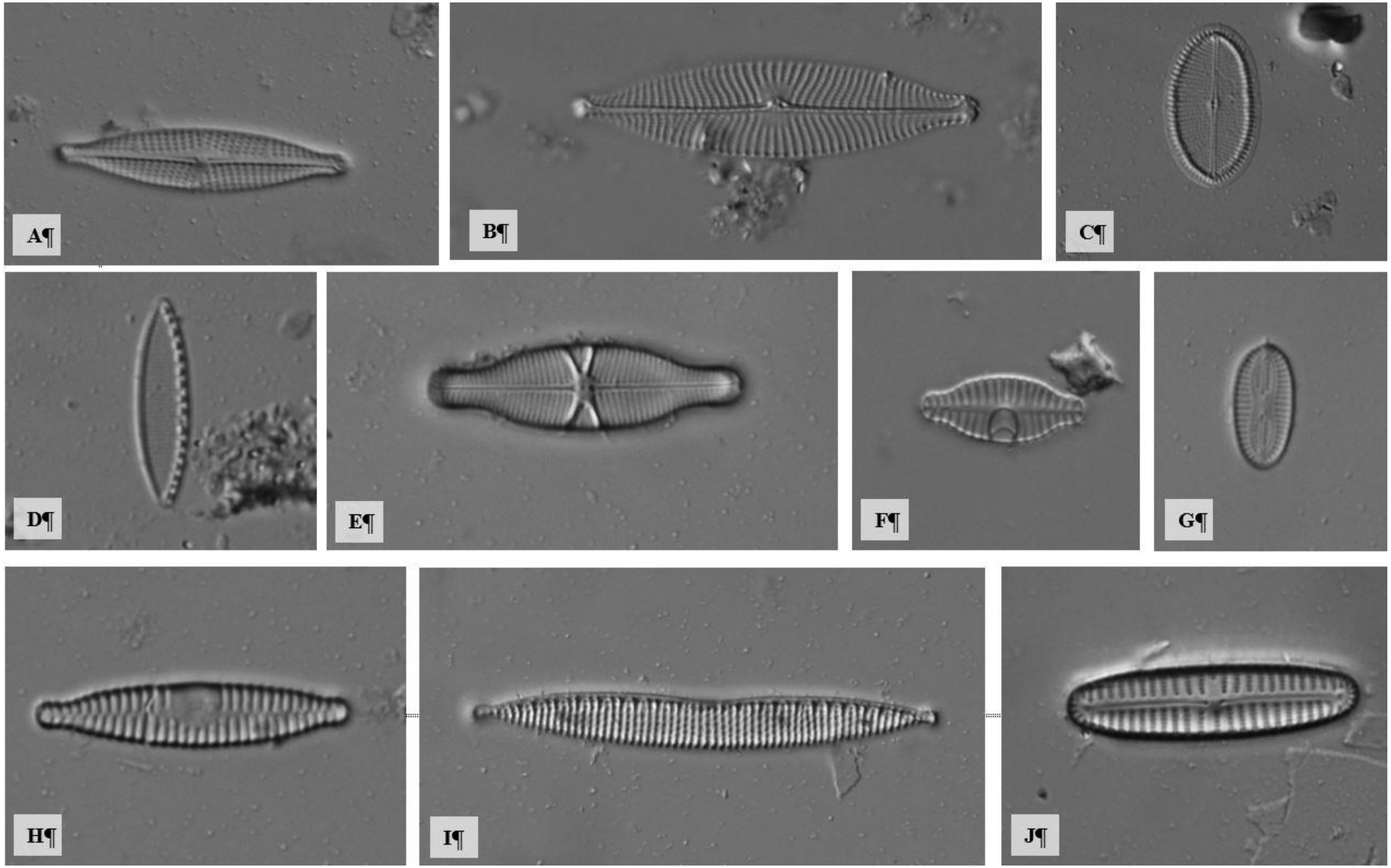
Chlorophyta – *Scenedesmus* (A); *Desmodesmus* (B); *Acutodesmus* (C); *Schroederia (*D); *Cosmarium* (E); *Treubaria* (F); *Closterium* (G); *Pediastrum* (H); *Nephrocytium* (I); *Selenastrum* (J); *Pandorina* (K); *Oocystis* (L)

Figure 5-2: Light microscopy photographs (400x magnification) of Chlorophyceae observed in samples during 2016



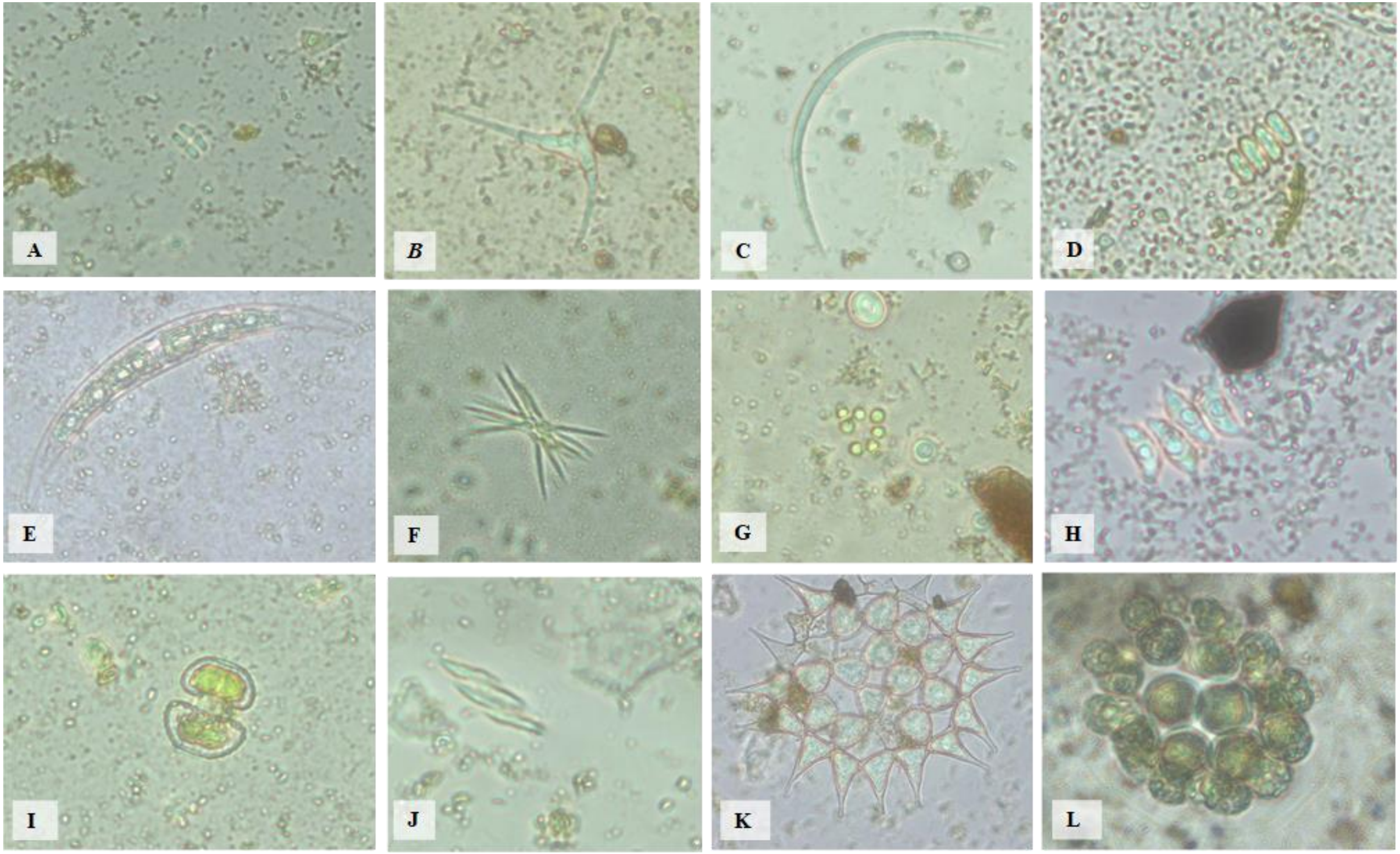
Cyanophyceae (A-C); Dinophyphyceae (D-E); Euglenophyceae (F-G); Chrysophyceaea (H-I). The genera found in the Cyanophyceae group included *Merismopedia* (A), *Komvophoron* (B) and *Anabaena* (C). The class Dinophyceae included *Peridiniopsis* (D) and *Peridinium* (E). The class Euglenophyceae included *Trachelomonas* (F) and *Strombomonas* (G) and one genus of the class Chrysophyceae, *Dinobryon* (H-I)

Figure 5-3: Light microscopy photographs (400x magnification) of other algal groups observed in samples during 2016



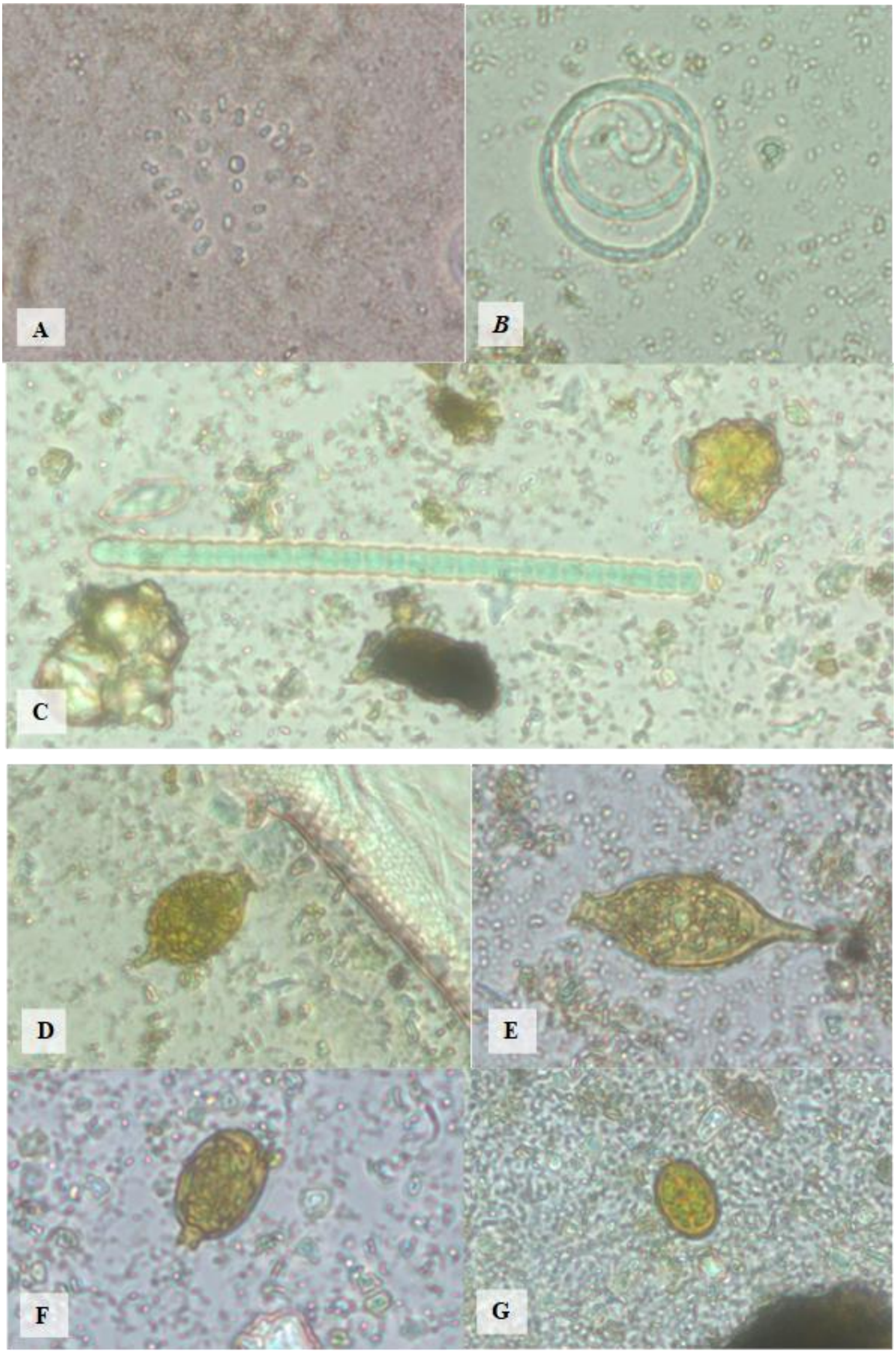
The Bacillariophyta genera commonly found included *Navicula* (A), *Navicula* (B), *Cocconeis* (C), *Nitzschia* (D), *Capartogramma* (E), *Planothidium* (F), *Fallacia* (G), *Fragilaria* (H), *Hantzschia* (I) and *Encyonopsis* (J)

Figure 5-4: Light microscopy photographs (1000x magnification) of Bacillariophyceae observed in samples during 2017



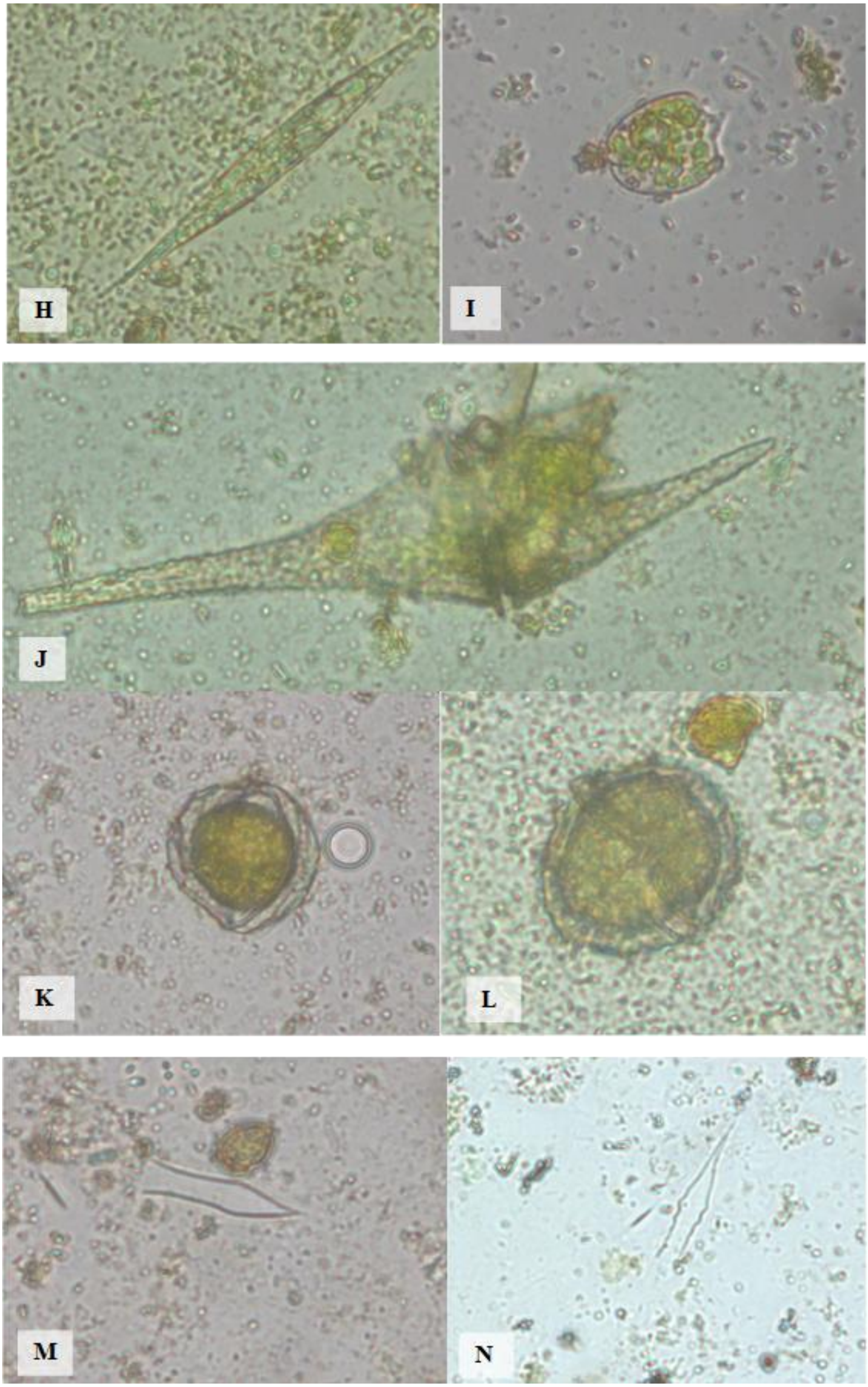
The genera commonly found of the Chlorophyceae group included *Crucigeniella* (A), *Treubaria* (B), *Monoraphidium* (C), *Scenedesmus* (D), *Closterium* (E), *Ankistrodesmus* (F), *Dictyosphaerium* (G), *Acutodesmus* (H), *Cosmarium* (I), *Elakatothrix* (J), *Pediastrum* (K) and *Pandorina* (L)

Figure 5-5: Light microscopy photographs (400x magnification) of Chlorophyceae observed in samples during 2017



The Cyanophyceae genera included *Radiocystis* (A), *Komvophoron* (B) and *Phormidium* (C). The Euglenophyceae included *Strombomonas* (D-E) and *Trachelomonas* (F-G)

Figure 5-6: Light microscopy photographs (400x magnification) of Cyanophyceae (A-C) and Euglenophyceae (D-I) observed in samples during 2017



The Euglenophyceae included *Euglena* (H) and *Phacus* (I). The Dinophyceae included *Ceratium* (J) and *Peridinium* (K-L). Chrysophyceae included *Dinobryon* (M-N).

Figure 5-7: Light microscopy photographs (400x magnification) of Euglenophyceae (D-I), Dinophyceae (J-L) and Chrysophyceae (M-N) observed in samples during 2017

During both study periods, the most diverse group in the river systems was the Bacillariophyceae except for the Inyaka Dam, where the Chlorophyceae was the most diverse group. During the immediate post-drought period, site 4 showed the greatest improvement in species diversity, evenness and richness, followed by site 7 in the Sand River (Table 5-1). This may be an indication of the abolition of an environmental stress. Site 10 in the Marite River had the highest indices scores during 2016, and although the species diversity decreased during 2017, species richness and evenness increased during the same year.

Table 5-1: Scores of the Shannon-Wiener diversity index, Margalef index of evenness and Pielou index of species richness for each site during the study period

Site	**Shannon-Wiener Index Score**		**Margalef Index Score**		**Pielou Index Score**	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**
1	2.46	2.439	5.40	7.105	0.89	0.740
2	2.66	2.571	6.33	6.895	0.74	0.729
3	2.62	2.619	6.12	7.760	0.73	0.715
4	1.40	3.026	6.49	9.523	0.37	0.790
5	2.72	2.753	7.42	8.802	0.75	0.737
6	2.44	2.882	7.17	9.292	0.66	0.766
7	2.29	3.120	6.18	8.852	0.62	0.815
8	2.81	3.055	8.50	8.585	0.72	0.807
9	2.77	2.915	8.28	8.533	0.74	0.785
10	3.35	3.301	9.64	12.037	0.86	0.820
11	1.42	2.527	2.82	5.272	0.44	0.743
12	1.96	2.315	3.08	7.134	0.57	0.628

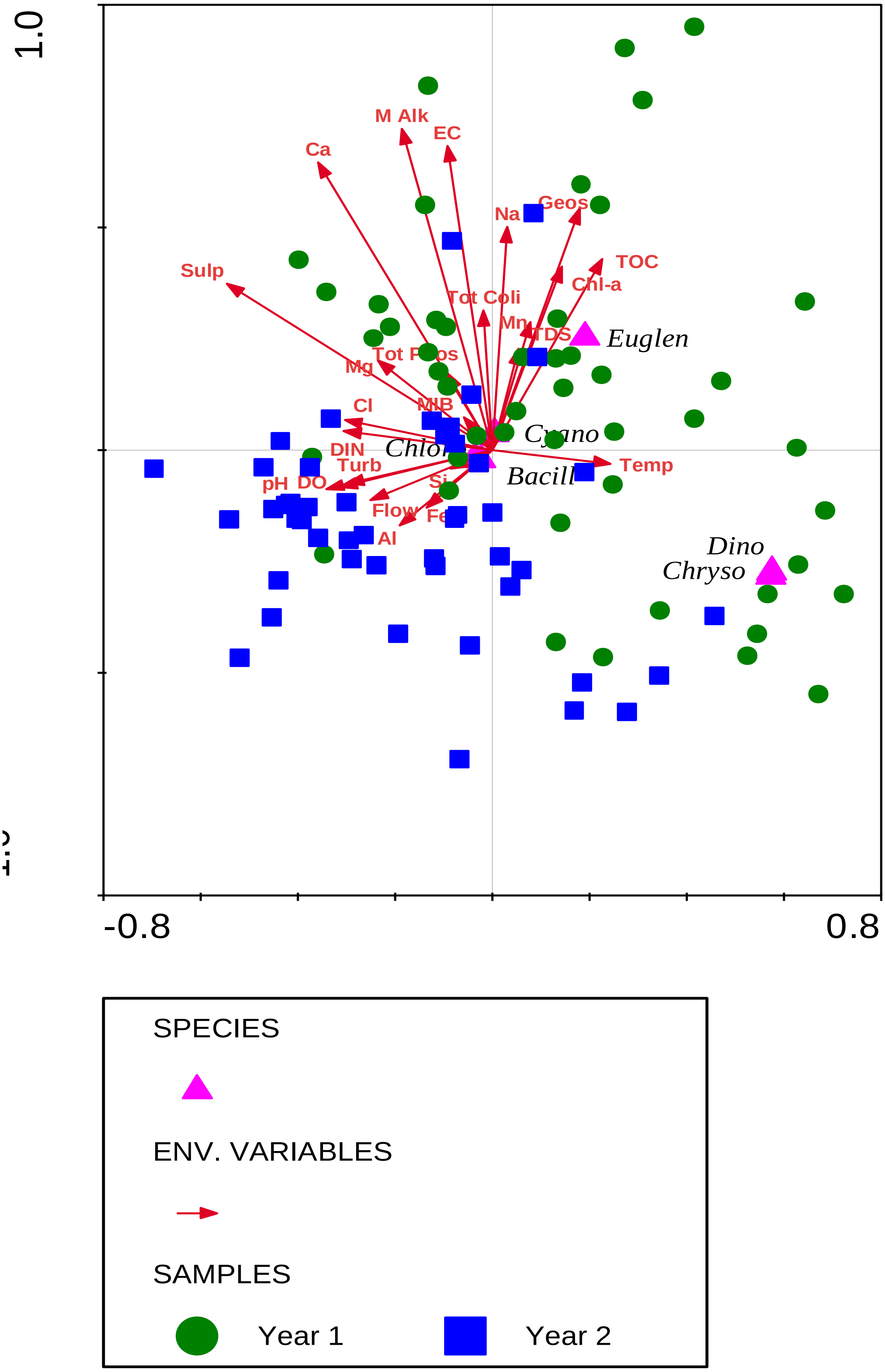


Figure 5-8: Triplot of the CCA ordination illustrating the phytoplankton taxa represented by the different groups with environmental variables during 2016 (Year 1) and 2017 (Year 2)

Table 5-2: Eigen values and species-environment relations of the canonical correspondence analysis

Axes	1	2	3	4	Total inertia
Eigenvalues	0.088	0.053	0.025	0.003	0.448
Species-environment correlations	0.626	0.67	0.615	0.423	
Cumulative percentage variance					
of species data	19.6	31.4	37	37.8	
of species-environment relation	51.7	82.8	97.5	99.6	
Sum of all eigenvalues					0.448
Sum of all canonical eigenvalues					0.17

Summary of Monte Carlo test

Test of significance of first canonical axis: eigenvalue = 0.088
F-ratio = 17.325
p-value = 0.1160

Test of significance of all canonical axes: Trace = 0.170
F-ratio = 1.887
p-value = 0.0260

The results showed a clear distinction between the two years of sampling. From Figure 5-8, it can be seen that the variation in phytoplankton groups was affected by an increase in flow, dissolved inorganic nitrogen (DIN), dissolved oxygen (DO) and turbidity. The Chlorophyceae and Bacillariophyceae were the most closely associated with these environmental variables and were also the dominant groups during 2017. The Euglenophyceae genera were associated with increasing total organic carbon (TOC) levels and chlorophyll-*a* (Chl-*a*) concentrations found in samples collected during the drought experienced in 2016. The eigenvalues for the first and second axes were 0.088 and 0.053 and explain 51.7% and 31.1% of the variance respectively (Table 5-2). The species-environment correlation was 0.626 for the first axis and 0.67 for the second axis (Table 5-2).

5.3.2 Abundance of algae and cyanobacteria

Chlorophyll-*a* concentrations were lower during 2017 than 2016, with a significant decrease at site 12 (Section 3; Figure 3-14). Other sites that experienced a decrease in chl-*a* concentrations were sites 1-4, 6 and 8 in the Sabie River, site 7 in the Sand River and sites 10 and 11 in the Marite River. Only sites 5 and 9 in the Sabie River experienced an increase in chl-*a* concentrations. The total cell concentration of algae (cells/ml) in the catchment were higher in 2016 (24 802 cells/ml) than in 2017 (2 103 cells/ml). This was mostly due to the high cell concentrations of the Cyanophyceae (9 541 cells/ml) in 2016. The highest cell counts (*Phormidium*) were recorded in October 2016 at site 12 in the Sand River (6 389 cells/ml).

The most abundant group observed in the Sabie River were the Bacillariophyceae, and this was the dominant group in 2016 (Figure 5-9) at all the sampling sites except site 4. During 2016, the Cyanophyceae was the dominant group in the Sand River, and the Chrysophyceae was dominant in the Inyaka Dam. The most abundant group during 2017 (Figure 5-9) was the Bacillariophyceae (1 201 cells/ml), followed by the Chlorophyceae (511 cells/ml). Although cell counts were considerably lower during the 2017 study period, this was mostly due to the counts for *Pandorina* at site 12 of 43 cells/ml in January and 49 cells/ml in October. The Bacillariophyceae was the dominant group during each of the sampling occasions at most sites, except sites 11 and 12. The dominance in algal assemblages changed at site 4 in the Sabie River and at sites 7 and 12 in the Sand River from the cyanobacteria being dominant during 2016 to the Bacillariophyceae being dominant at sites 4 and 7, and the Chlorophyceae being dominant at site 12 during the immediate post-drought period. During the immediate post-drought period, the Cyanophyceae was the dominant group found in the Inyaka Dam (site 11) whereas in 2016, the Chrysophyceae was dominant. *Radiocystis, Aphanocapsa* and *Gloeocapsa* were the most abundant cyanobacterial genera found during the survey, while the genus *Dinobryon* from the class Chrysophyceae was the most abundant type of algae detected in the Inyaka Dam.

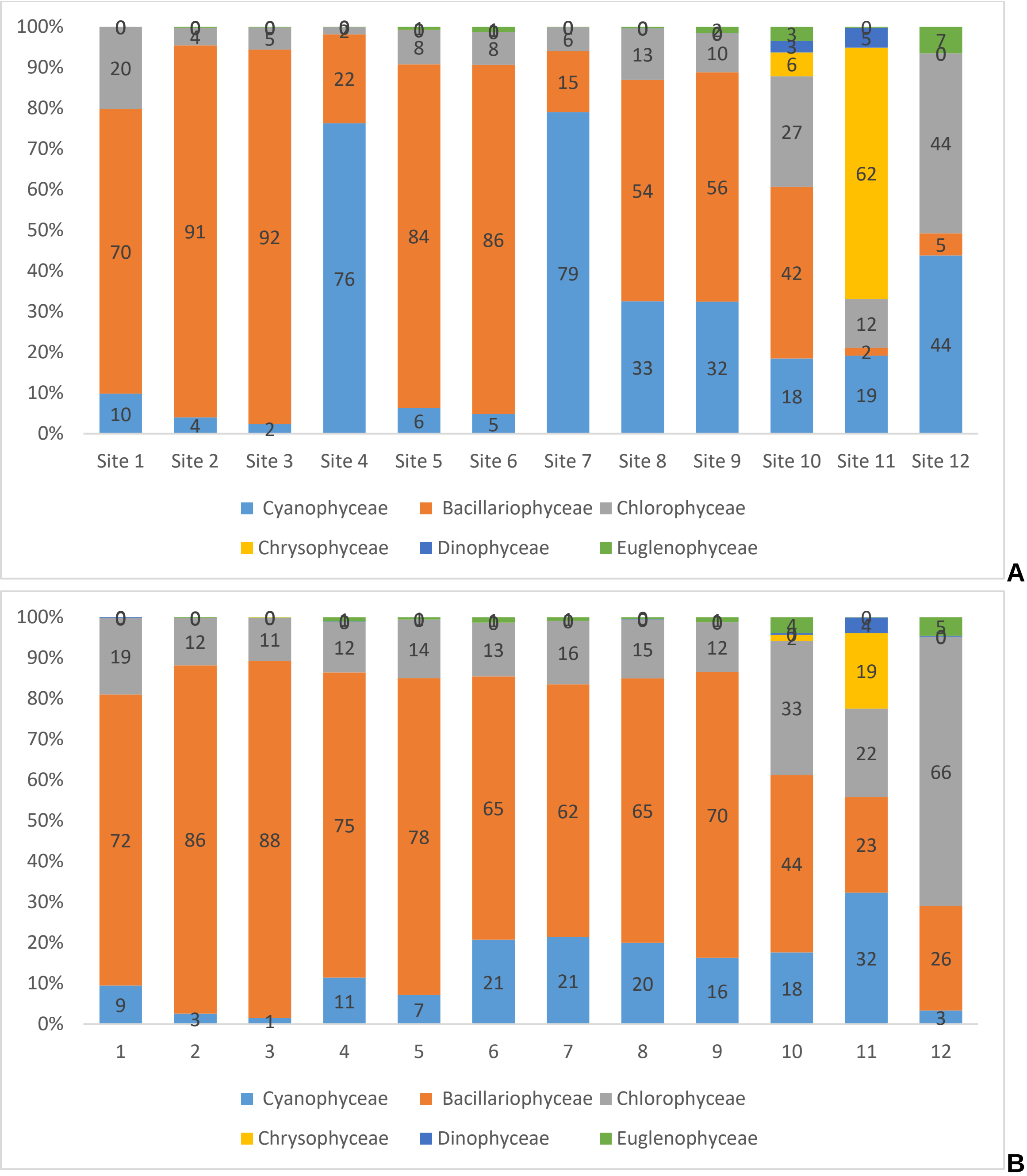


Figure 5-9: Percentage total abundance (cells/ml) of the different algal phyla at each of the sites observed during the four sampling occasions in 2016 (A) and 2017 (B)

5.4 Discussion

It is evident from several studies (Stevenson, 2014; Stevenson *et al.*, 2010; Wehr *et al.*, 2015) that the characterisation of algal assemblages is an important step in indicating changes in environmental conditions that can have an impact on ecosystem health and in determining if the actual algae can cause problems. Identification of environmental and land-use factors that can affect and control phytoplankton assemblages in a particular catchment are important in determining the management strategy and the maintenance of a desired ecosystem state (Peretyatko *et al.*, 2007).

As was the case in this study, the most abundant group of algae in rivers is the Bacillariophyceae. The genera in this group are cosmopolitan and grow well in low flowing, alkaline waters of moderate salinity and low to moderate organic pollution. These are all typical characteristics observed in the Sabie and Sand rivers during this study. The group Bacillariophyceae or diatoms forms the base of the food chain in most aquatic ecosystems, and they have the ability to respond quickly to changing environmental conditions. This means that they are at the interface between abiotic and biotic worlds (Wehr *et al.*, 2015). *Gomphonema* was the most abundant genus found at the majority of sites during this study. Members of the Gomphonemataceae are characterised by their tolerance of different flow conditions (Wehr *et al*., 2015). This characteristic was evident in this study since this group was the most abundant group during both the low-flow conditions (drought of 2016) and the high-flow conditions experienced during the immediate post-drought period of 2017. The year 2016 was characterised by low flow and extreme dry conditions with higher concentrations of nutrients and total organic carbons (TOCs) (see Section 3). Diatom genera such as *Nitzschia* and *Navicula,* which are also indicators of organic enrichment and pollution (Wehr *et al.*, 2015), were found to be more abundant in 2016 than in 2017 during the immediate post-drought period. This is supported by the higher levels of TOC observed during 2016 (see Section 3). The genus *Nitzschia* contains many species that have been identified as pollution-tolerant and have been used as indicators of deteriorated water quality (Whitton *et al.*, 1991; Cholnoky, 1958). Both the genera *Nitzschia* and *Cymbella* were abundant during 2016 and 2017. *Cymbella* is known to be widely distributed in freshwater lakes and streams. Inyaka Dam had very few representatives of the class Bacillariophyceae, with *Navicula* being the most abundant in 2016. In 2017, during higher flow and lower nutrient conditions, this changed to the genera *Gomphonema* and *Cyclotella*. The genus *Cyclotella* is environmentally important and is known to grow in environments that range from oligotrophic to eutrophic (Wehr *et al.*, 2015).

The group Cyanophyceae was the most abundant at site 12 in the Sand River during 2016 with *Phormidium* being the most abundant genus. This genus occurs in both standing and running water and can survive extreme conditions (Wehr *et al*., 2015) with high concentrations of nitrate (>3 mg/l) and high concentrations of phosphorus (Potapova, 2005). *Phormidium* is also known to produce various cyanotoxins such as microcystin and anatoxin-a (Paerl & Otten, 2013). The second-most abundant cyanobacterial genus found during 2016 was *Aphanothece*, which was observed mostly in the Inyaka Dam and at site 12 in the Sand River. However, during 2017, the Inyka Dam (site 11) was dominated by the cyanobacteria *Radiocystis*. This genus is morphologically very similar to the genus *Microcystis* except for the radially oriented cell groupings and has been reported in literature as one of the most abundant cyanobacterial bloom-forming genera found in tropical waters (Paulino *et al*., 2017). Some species are known to produce microcystin and although microcystin concentrations were determined for all the samples during this study, none were above the detection limit of 0.018 µg/l.

As was noted by Caruso *et al*. (2001) and Mosley (2015), a change was observed in dominance in algal assemblages at sites 4, 7 and 12 from typically cyanobacterial-dominated assemblages during drought conditions to conditions dominated by Bacillariophyceae (sites 4 and 7) and Chlorophyceae (site 12) during the immediate post-drought period. *Pandorina, Chlorococcum* and *Scenedesmus* were the most abundant Chlorophyceae genera and occurred in high cell concentrations at site 12. These genera are indicative of nutrient-rich waters (Potapova, 2005) and occur as unicells under these conditions. *Scenedesmus* species are known for their high tolerance of pollution (Potapova, 2005). *Pandorina* also occurs in nutrient-rich waters and functions as an indicator of water pollution and even hypertrophic conditions, as was indicated by the total phosphate levels (Van Ginkel *et al*., 2000) at site 12 (Bellinger & Sigee, 2010).

The group Chrysophyceae was dominant in the Inyaka Dam during 2016, with *Dinobryon* as the most abundant genus. Although this genus usually occurs in low-nutrient lakes and is considered by some authors such as Rawson (2012) as an oligotrophic indicator, it still has the potential to form harmful blooms due to its ability to take up low concentrations of phosphorus (Wehr *et al.*, 2015). According to Wehr *et al*. (2015), drinking water suppliers such as the Inyaka Dam are often affected by tastes and odour events caused by *Dinobryon* blooms. Species of this genus are known to produce volatile organic compounds such as terpenes and terpenoids, oxylipins and other hydrocarbons. Although the Chrysophyceae were no longer dominant in the Inyaka Dam during 2017, *Dinobryon* was still the most abundant genus of this group in the dam.

Euglena was the most abundant genus from the group Euglenophyceae during 2016 and occurred only at site 12 in the Sand River during this time. *Euglena* is generally not found in fast flowing streams and rivers and is indicative of eutrophic water bodies. Some species of this genus can form dense populations in urban wastewater that contains high concentrations of organic compounds (Wehr *et al.*, 2015). The water quality observed (see Section 4) at site 12 in the Sand River is thus ideal for this algal taxon. The representatives of this genus were found in much lower cell concentration during 2017 when high flow conditions were experienced that washed away most of the nutritional components.

Site 10 in the Marite River exhibited the highest diversity regarding the different algal taxa that were identified. However, both the Sabie and Sand rivers demonstrated high diversity, especially during 2017. The highest cell concentrations were observed during 2016, which was most probably due to the longer residence time as a result of low flow velocity that allowed sufficient time for growth and reproduction. Although biomass is an important attribute in environmental assessments because it is related to productivity and nuisance problems, the algal biomass observed during this study was not indicative of nuisance or drinking water production problems. For comparison, the Vaal River receives large volumes of effluent containing nutrients, which support total phytoplankton cell concentrations of up to 1 600 000 cells/ml (Janse van Rensburg, personal communication 25 October 2017). In the present study, only site 12 in the Sand River shows signs of developing a problem with harmful algal blooms.

The taxonomic composition of algae in the case of the Sabie River Catchment is however, as noted by Stevenson (1998), still a powerful tool for assessing the biological and stress conditions in the catchment and for diagnosing the direct and indirect causes of environmental problems. This was emphasised by the CCA, which demonstrated that the water quality had a significant influence on the genera that occurred in the catchment. This was also evident in the water quality analysis and was supported by the high cell concentrations of total coliform bacteria and *Escherichia coli* (*E. coli*) observed at site 12, as discussed in Section 4. The water quality of the Inyaka Dam (site 11) during the dry year can be classed as oligotrophic, and this is supported by the presence of the phytoplankton genus *Dinobryon*. However, due to the ability of *Dinobryon* to produce taste and odour problems, monitoring is emphasised to ensure the production of acceptable drinking water for the community.

5.5 Conclusion

The most abundant group of algae in the Sabie, Sand and Marite rivers, with the exception of the Inyaka Dam and site 12 in the Sand River, is the Bacillariophyceae. The genera in this group are cosmopolitan and grow well in low flowing, alkaline waters of moderate salinity and low to moderate organic pollution. These were typical conditions observed in most of the rivers investigated.

The Inyaka Dam was dominated by one genus (*Dinobryon*) of the Chrysophyceae during the dry conditions, while the Cyanophyceae dominated under the post-drought conditions due to an increase in nutrients. During the low-flow conditions of 2016, the Cyanophyceae dominated at site 12, most probably due to higher nutrient concentrations, higher temperatures and a more stagnant environment as a result of the drought. These conditions changed during 2017, and the Chlorophyceae became the dominant algae. There was 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 2016.

The number of genera observed did not change significantly between the two years, and high cell concentrations and bloom formations were absent. A general increase in the species diversity, richness and evenness was observed during the wetter year (2017). The presence of various genera (from various groups of phytoplankton) indicative of organic pollution confirmed the deteriorating water quality observed at many sites but especially site 12 in the Sand River during the dry year.

Multivariate statistical analyses confirmed that the water quality had a significant influence on the genera that occurred in the catchment during both 2016 and 2017.

6 INFLUENCE OF LAND USE ON WATER QUALITY

6.1 Introduction

Rivers are very vulnerable to land-use activities (Vörösmarty *et al.*, 2010) and the development of settlements that involves an increase in population. The deterioration of river water quality due to over use by human activities has become a major environmental concern (Ding *et al.*, 2016). Monitoring water quality in regard to land-use influences has become a widely accepted method to establish an integrated view of water quality. Several studies (Chen *et al*., 2016; Ding *et al*., 2016; Kändler *et al*., 2017; Xizhi *et al*., 2017) determined land use as a quantitative measure in relation to water-quality indicators, and variables associated with water pollution can be significantly correlated with land uses (Donohue *et al*., 2006; Xizhi *et al*., 2017). According to Donohue *et al*. (2006), the principal legislative tool for evaluating aquatic system integrity has for decades been facilitated internationally through only chemical monitoring. However, within South Africa, a set of guidelines exists that strengthens not only chemical measurements of water quality but also biological, physical and aesthetic measurements for different land uses (DWAF, 1996a). The broad water uses that the South African Water Quality Guidelines (DWAF, 1996a) considers are Domestic, Recreational, Industrial and Agricultural, the latter including Irrigation, Livestock Watering, and Aquaculture and Aquatic Ecosystems.

Van Wyk *et al*. (2001) used historical research initiatives on the Sabie-Sand Catchment to identify gaps left open by monitoring programmes. The authors indicated that sufficient knowledge exists on monitoring and measurement but that research is still needed in regard to information that enhances the knowledge pertaining to the "needs of resource-poor people and the links between land activities and river health" (Van Wyk *et al*., 2001, p354). Therefore, the aim of this section was to investigate how land use influences the water quality of the Sabie, Sand and Marite rivers and the Inyaka Dam during extreme climatic conditions.

6.2 Materials and methods

Statistical analyses were carried out to summarise the characteristics of stream water quality and phytoplankton assemblages and to determine the relationships among the land use activities, water-quality parameters and phytoplankton genera. The data sources of this study were twofold. The first dataset consisted of biological, chemical and physical water-quality parameters. The second data source related to spatial and non-spatial data representing the catchment area above each sampling point. The data analyses that were used to compare both datasets with each other included multivariate statistical analysis.

A non-metric multidimensional scaling (NMDS) of the percentage land use surrounding the rivers influencing each site indicates the similarity (or dissimilarity) of sites based on the land use (Figure 6-1).

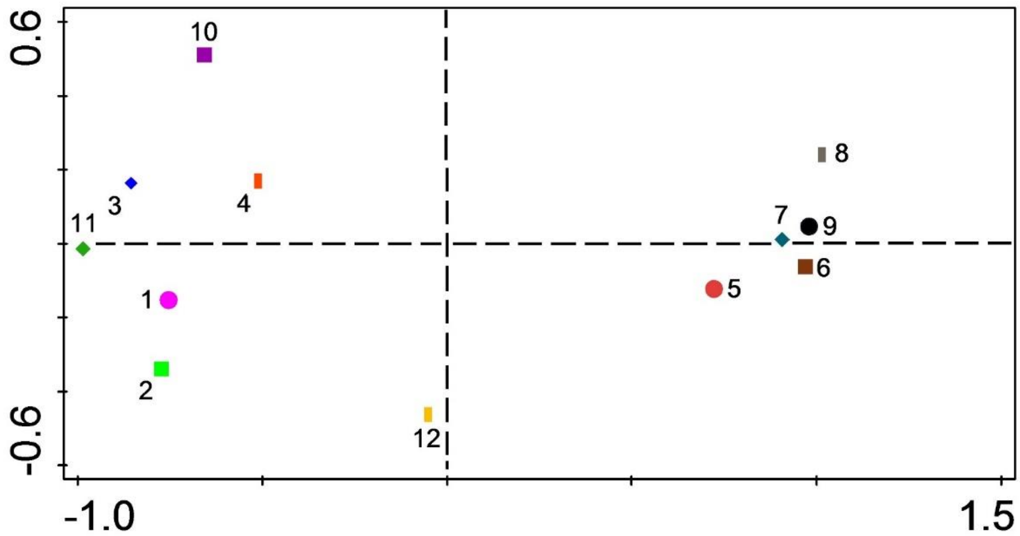
A constrained form of the linear ordination method of principal components analysis (PCA), otherwise known as a redundancy analysis (RDA), was performed using the Canoco 4.5 software program (Ter Braak & Šmilauer, 2002). According to several studies (Ding *et al.,* 2016; Kändler *et al.,* 2017; Zhao *et al.,* 2015), the RDA is a key method used in determining environmental quality and landscape relationships. The RDA method summarises the variation in a set of response variables (e.g. water-quality variables) explained by a set of explanatory variables (e.g. percentage land use of catchment) (Buttigieg & Ramette, 2014).

6.3 Results

6.3.1 Non-metric multidimensional scaling

The NMDS plot indicates similarity/dissimilarity among the sampling sites of the study in regard to land use. The Bray Curtis 2D stress value was 0.02 and the Euclidian distance 2D stress 0.01, indicating a good fit. Clearly grouped 'closer' together are sites 5, 6, 7, 8 and 9, which are located in the Sabie and Sand rivers where they flow through the Kruger National Park (KNP) (Figure 6-1). This grouping shows a clear separation of the conservation areas. Because the Inyaka Dam (site 11) is a still-standing impoundment, it is expected to stand alone since the water parameters of a still-standing impoundment will not experience the same environmental conditions as the water parameters of a flowing river. In addition, the Inyaka Dam (site 11) is surrounded by forestation.

Both sites 10 and 12 are close to communities with varying socio-economic status. They are, however, separate from each other. For example, the Marite River (site 10) has steeper slopes with a higher runoff rate and erosion dongas whereas Thulamahashe, the urban township of the Sand River, is characterised by flatter terrain. Sites 1, 2, 3 and 4 are all grouped to the left quadrangles, which indicate the grouping of sites closer to agricultural and forestry practices with less influence from rural settlements.



Sites shown are 1: Sabie River Headwaters; 2: Sabie River after wastewater treatment; 3: Sabie River before Hazyview; 4: Sabie River after Hoxane Water Treatment Works; 5: Sabie River at Kruger National Park Gate; 6: Sabie River Skukuza; 7: Sand River Kruger National Park; 8: Lower Sabie River after Sabie-Sand confluence; 9: Sabie River bordering Mozambique; 10: Marite River after Inyaka Dam; 11: Inyaka Dam outlet; 12: Sand River Thulamahashe after wastewater treatment plant

Figure 6-1: Non-metric multidimensional scaling ordination plot of the percentage land use surrounding the river in regard to the sampling localities

6.3.2 Redundancy analysis

The first RDA conducted was to determine if the land use (predictor variables) had a significant influence on the water quality (response variables) during a dry year with low flow conditions (2016). The sample localities in the RDA triplot (Figure 6-2) can be seen together with the land-use and water-quality indicators for this analysis. The first axis describes 41.6% of the cumulative percentage variance of the species-environmental relations, and the second axis describes 20.2% thereof (Table 6-1). The Monte Carlo permutation test (499 permutations under reduced model) was used as the test of significance ($p<0.05$) of all canonical axes. For both the test of significance of the first canonical axis and the test of significance of all the canonical axes, the *p*-value representing significance was equal to 1. There was thus no influence of land use on water quality. Although the influence was not significant, the relationship between the predictor and the response variables can still be explored.

The first axis 1 or principal component is strongly associated with sites 1, 5, 6, 7, 8 and 9 and the predictor variables cultivated commercial fields (CuCom) and open bush woodlands (WdlnO). Site 1 is surrounded by forestry plantations and informal urban grass and open bush. It was noticed that all of the conservation sites grouped closely together (sites 6, 7, 8 and 9). Site 9 projected close to the origin, indicating a weak association with all the variables. Sites 5, 6, 7 and 8 have strong positive correlations with the predictor variables grasslands (GrasL), urban informal (Urinf), urban lawns (UrLaw) and urban built-up (UrBuU), the latter representing KNP staff and community housing in Skukuza

The second axis or principal component is strongly associated with sites 2, 3, 4, 10, 11 and 12. The predictor variables water (Water), erosion-bare (EBare) and inland forestry (IndFo) are closely associated with sites 10 and 11 in the Marite River. Site 11, the Inyaka Dam, is strongly associated with turbidity, manganese and iron. The latter two variables could be the main contributing factors to the high turbidity values. Urban influences had strong correlations with sites 2 and 3. Strong positive responses were seen between the water-quality variables magnesium, methyl orange alkalinity (M alkalinity), calcium, magnesium and sulphates in regard to urban lawns (UrLaw), urban built-up (UrBuU) and urban informal (Urinf). The increase in M alkalinity was possibly the result of higher concentrations of magnesium and calcium, which have their main source in the urban sub-catchment from the natural geology of the catchment (DWAF, 1996a). The increase in M alkalinity demonstrated in sub-catchments 2 and 3 is well explained by geology since the two dominant geological rock types in the sub-catchments are dolomite and granite. Dolomite represents a direct source of calcium and magnesium with its chemical formula being $CaMg(CO_3)_2$, and granite is a direct source of cations such as calcium and magnesium (King, 2013). Site 4 has strong positive correlations with the predictor variables cultivated orchards (CuOrc) and urban built-up (UrBuU) and the water-quality variables total dissolved solids (TDS) and total phosphates. Related to these is the response variable dissolved oxygen (DO).

Site 7 in the Sand River and sites 10 and 11 in the Marite River are all strongly associated with increased concentrations of aluminium, as was also evident in Section 4. No land-use activities could be associated with the high levels of aluminium that were measured, but one could speculate that the origin of aluminium is the soil that is washed into the rivers due to erosion, since these three sites closely associate with bare and eroded areas.

Site 12 is strongly associated with high ammonia levels, chlorophyll-a (Chl-a) concentrations and total coliform counts. High concentrations of ammonia and high total organic carbon (TOC) levels usually indicate organic pollution, and this is supported by the high levels of bacteria associated with sewage pollution (see Section 4). Site 12 also correlates strongly with the predictor variables that represent rapidly developing rural circumstances, for example, urban village (UrVil), urban townships (UrTsh), cultivated subsistence (CuSub), mines

(Mines), wetlands (Wetld) and the above-mentioned water-quality parameters (response variables). The positive correlations of these water-quality variables are also discussed in Section 4. This provides further support in regard to the negative effects associated with the lower-income settlements or the urban township/village at site 12.

Figure 6-2 below presents a triplot of the RDA ordination that demonstrates the influence of land-use percentages (predictor values) on the mean measured water-quality parameters (response values) at the 12 different sampling sites for the Sabie-Sand Catchment during the dry period of 2016.

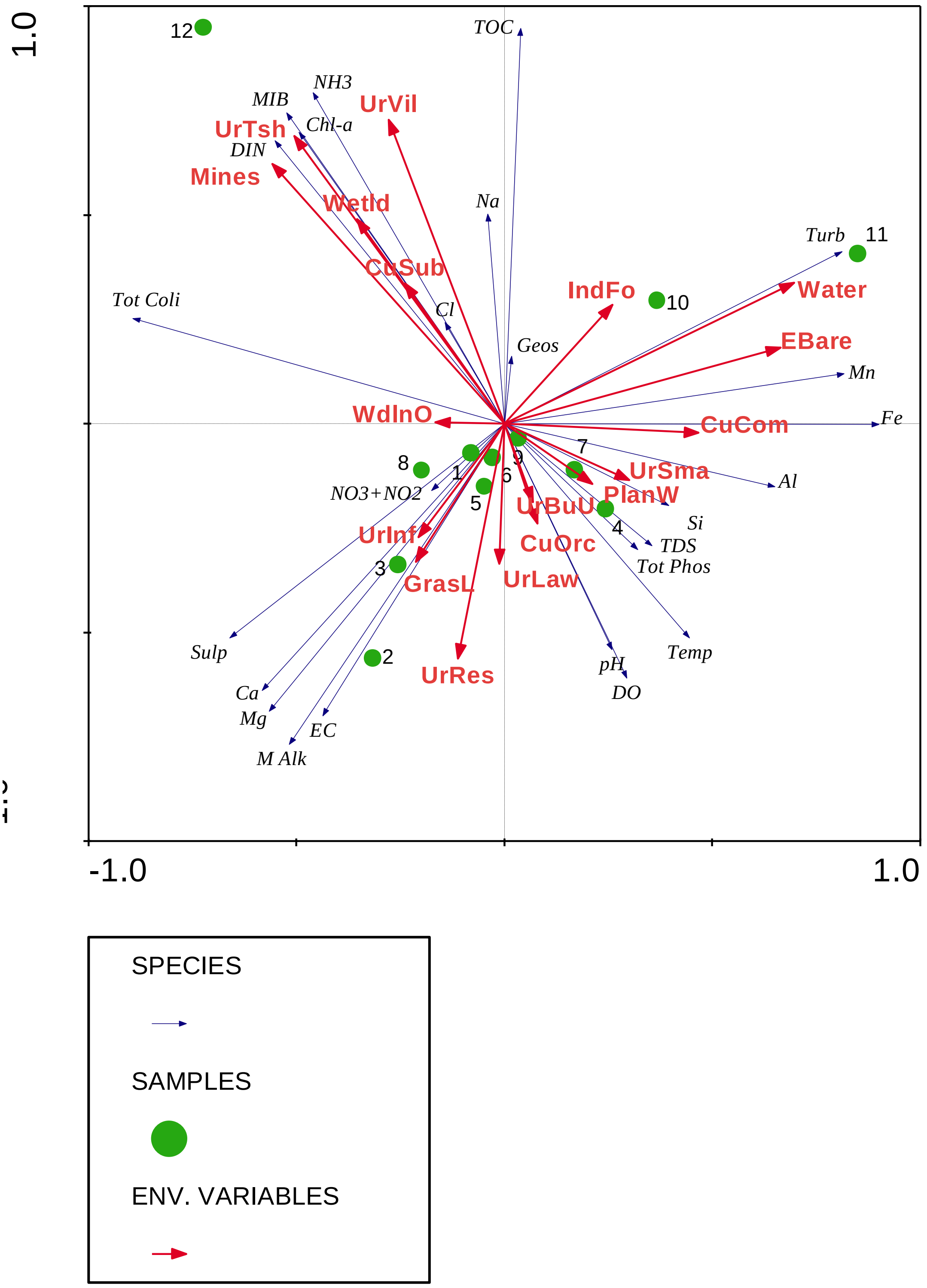


Figure 6-2: Triplot of the redundancy analysis ordination for the dry period of 2016

Table 6-1: Eigen values and species-environment relations of the redundancy analysis

Axes	**1**	**2**	**3**	**4**	**Total inertia**
Eigenvalues	0.416	0.202	0.182	0.090	1.00
Species-environment correlations	1.000	1.000	1.000	1.000	
Cumulative percentage variance					
of species data	41.6	61.8	80.1	89.1	
of species-environment relation	41.6	61.8	80.1	89.1	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					1.000

Summary of Monte Carlo test
Test of significance of first canonical axis: eigenvalue = 0.416
F-ratio = 0.000
p-value = 1.0000
Test of significance of all canonical axes: Trace = 1.000
F-ratio = 0.000
p-value = 1.0000
(499 permutations under reduced model)

The second RDA was conducted to determine if the land use (predictor variables) had a significant influence on the water quality (response variables) during a high rainfall year with high flow conditions (2017). The sample localities in the RDA triplot (Figure 6-3) can be seen together with the land-use and water-quality indicators for this analysis. The first axis describes 83.9% of the cumulative percentage variance of species-environmental relations, and the second axis describes 10.5% thereof (Table 6-2). The Monte Carlo permutation test (499 permutations under reduced model) was used as the test of significance ($p<0.05$) of all canonical axes. For both the test of significance of the first canonical axis and the test of significance of all the canonical axes, the *p*-value representing significance was equal to 1. There was thus no influence of land use on water quality. In the triplot, it can be seen that most of the sites grouped together and projected close to the origin, indicating a weak association with all the variables, except for sites 1, 11 and 12.

The first axis or principal component is strongly associated with sites 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12, with sites 2-9 associated with the urban predictor variables on the one end of the scale and sites 10-12 still closely influenced by the predictor variables previously described, namely water (Water) (site 11), mines (Mines), urban townships (UrTsh) and urban villages (UrVil) (site 12) on the other end of the scale. Total coliforms and aluminium had the highest correlation with the first component. Total coliforms once again closely related to site 12 and urban villages (UrVil), while increases in the average values of aluminium and iron were closely related to sites 2 and 3. The second axis or principal component is strongly associated with site 1 and with the predictor variables plantation/woodlots (PlanW) and cultivated commercial fields (CuCom) and the water-quality variable 2-Methylisoborneol (2-MIB). As discussed earlier in sections 4 and 5, site 1 experienced an increase in both Chl-a concentrations and total coliforms during the immediate post-drought period. Both these variables represent the presence of organisms that could contribute to the significant increase in taste and odour compound 2-MIB.

Table 6-2: Eigen values and species-environment relations of the redundancy analysis

Axes	**1**	**2**	**3**	**4**	**Total inertia**
Eigenvalues	0.839	0.105	0.048	0.005	1.00
Species-environment correlations	1.000	1.000	1.000	1.000	
Cumulative percentage variance					
of species data	83.9	94.4	99.2	99.7	
of species-environment relation	83.9	94.4	99.2	99.7	
Sum of all eigenvalues					1.000
Sum of all canonical eigenvalues					1.000

Summary of Monte Carlo test
Test of significance of first canonical axis: eigenvalue = 0.839
F-ratio = 0.000
p-value = 1.0000
Test of significance of all canonical axes: Trace = 1.000
F-ratio = 0.000
p-value = 1.0000
(499 permutations under reduced model)

Figure 6-3 below presents a triplot of the RDA ordination that demonstrates the influence of land-use percentages (predictor values) on the mean measured water-quality parameters (response values) at the 12 different sampling sites for the Sabie-Sand Catchment during the immediate post-drought period of 2017.

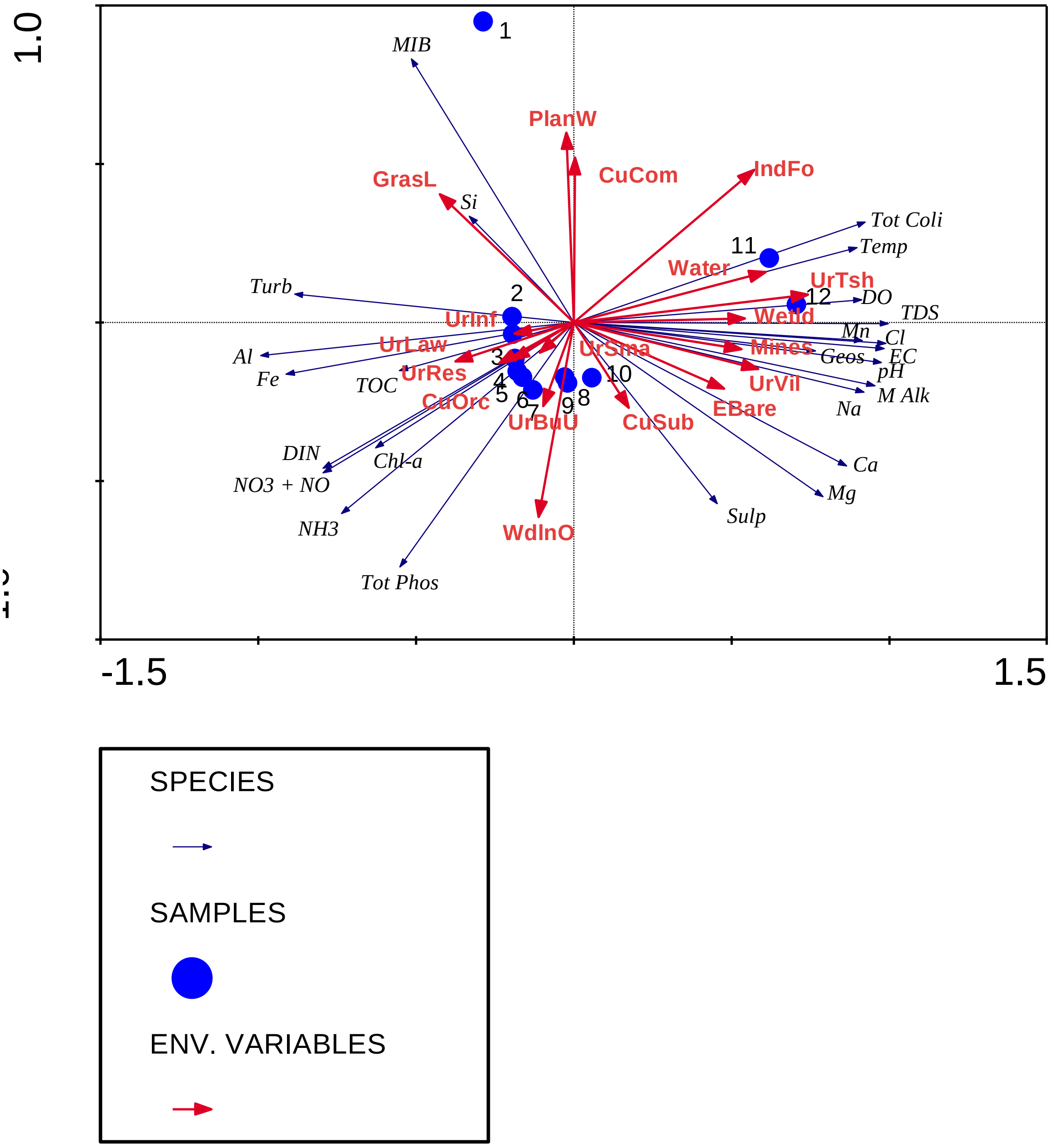


Figure 6-3: Triplot of the redundancy analysis ordination for the immediate post-drought period of 2017

6.4 Discussion

The water quality in the Sabie-Sand Catchment is relatively good (except at site 12) and shows only minimal effects of deterioration even during extreme climate conditions. Except for site 12, land use has thus far not had a significant influence on the water quality. The results showed that rural land-use indicators and most of the environmental stress indictors of water quality positively correlated with site 12. In terms of organic enrichment indicated by TOC, ammonia concentrations and total coliforms, the rural influence and more specifically, the pollution due to a non-functional wastewater treatment plant (WWTP) at site 12 had a negative influence on the water quality, especially during low flow conditions.

Plantations/woodlots (PlanW) influenced the water quality less than urbanisation. In terms of ‘lack’ of nutrient enrichment from dissolved inorganic nitrogen (DIN) and the degree of electrical conductivity (EC), forest plantations and cultivated commercial fields had a positive effect on water quality (Figure 6-2) during the low rainfall year (2016) with the resulting low baseflows of the upland area in this specific catchment. This type of positive effect was also seen by Xizhi *et al.* (2017). The authors describe an improvement in water quality relating to an increase in forested areas as a result of the increase in forest undergrowth. Undergrowth serves as a buffer for soil erosion during rainstorm runoff and can also reduce nutrient inflow by serving as an adsorption medium (Xizhi *et al.*, 2017).

The low association of the Sabie River sites (sites 6, 8 and 9) and site 7 in the Sand River with the location of the sites within conservation areas suggests a positive influence on water quality from this land use/tenure class. This was especially evident in the decrease in the water-quality parameters of concern at sites 7-12, which showed that there was an improvement due to conservational practices within the Sand River.

It was further established that although urbanisation and the surrounding land uses had a negative effect on the water quality of the Sand River, they had less influence on the quality of the Marite and Sabie rivers. This is important because 6% of the land use for sub-catchment 10 is classified as urban village. The sites in the Marite River (sites 10 and 11) had strong correlations with the slope class 3 (see Section 3). These sites are situated near an urban village and all provide evidence of high runoff. This was confirmed by the erosion-bare ground associated with these sites during both 2016 and 2017. High turbidity, manganese, iron and aluminium concentrations further confirmed this strong correlation with erosion.

6.5 Conclusion

Water has distinct purposes from a human perspective. Water is a prerequisite for life and also carries economic importance (Postel, 2000; Roux, 1999). As water users, the challenge is, therefore, to balance economic and social growth in terms of agriculture, industries, dam and borehole construction, channelisation, etc. with ecological well-being (Belcher, 2004; Postel, 2000). Land use on its own is a dynamic factor that can either contribute to the deterioration and instability of a water system or in rare cases, contribute to water quality enhancement. The main aim of this study was to assess the association between land use and water quality in the Sabie-Sand Catchment. The secondary aim was to assess whether or not the expansion of rural settlements has negatively influenced the water quality.

This study showed how river health is negatively affected in underdeveloped catchments with low elevations and confirmed the link of lower elevations and increased development with the resulting degradation of river health. The largest negative influence on water quality within the catchment was the rural township and the associated influences in sub-catchment 12. This is confirmed by the findings of the Ecostatus Report on the Sabie-Sand River Catchment (Roux *et al*., 2017). The negative influence of land use on water quality was shown by the non-compliance of water-quality parameters such as bacterial and nutrient concentrations with the urban village settlement and its ineffective infrastructure (e.g. the WWTP).

A need exists to enhance the knowledge pertaining to the "needs of resource-poor people and the links between land activities and river health" (Van Wyk *et al.*, 2001, p354). Since the present study has identified the links to land activities that have the most influence on water quality, further research needs to be defined in a way for remediation towards the needs of resource-poor people.

Support should be given to this urban settlement in the form of an adequate water supply and sanitation facilities, starting with the known WWTP point polluter. Solutions to adequate maintenance and monitoring should be found to ensure effluent that conforms to national water quality guidelines and complies with the determined RQOs.

7 GENERAL CONCLUSION

Climate change will probably increase the frequency of change between low river flows and high river flows, thus affecting both water quality and quantity. Although the impacts on water quantity are well known, the impacts on quality are not. Through this study investigating water quality during a drought and during the immediate post-drought period, the effects of both low and high river flows were determined. The findings of the study are consistent with findings from many other studies.

Most of the variables measured during this study complied with the target water quality range (TWQR) and RQOs as prescribed by the South African Water Quality Guidelines (DWAF, 1996a, 1996b, South Africa, 2016). There were, however, variables that did not comply with the TWQR, regardless of the climatic and hydrological conditions that governed. Total coliforms and the concentrations of *Escherichia coli* (*E. coli*), ammonia, aluminium and chloride did not comply during 2016 and 2017.

This study also showed the adverse effects of both the drought and the immediate post-drought conditions. Low flow conditions during the drought period were associated with higher values for electrical conductivity (EC), which implies higher salinity. The higher temperatures and the higher nutrient (total phosphates) and chlorophyll-*a* (chl-*a*) concentrations supported higher algal cell numbers was observed at most sites, resulted in an increase in the trophic level of the waterbody. An increase in the concentrations of total coliforms and *E. coli* and metals such as aluminium and iron together with an increase in nutrients (nitrate-nitrite) and turbidity was observed during the immediate post-drought period. Variable effects were observed for dissolved oxygen (DO), total dissolved solids (TDS) and chl-*a*. However, many of these effects were dependent on the characteristics of the sampling site and its sub-catchment.

Although the algal cell concentrations decreased significantly under the immediate post-drought conditions, the composition of these assemblages increased in diversity during 2017. In addition, the genera observed were indicative of high water quality with low nutrient concentrations but also confirmed the organic pollution evident from the bacterial counts.

River water quality is modified by activities and processes taking place both in the water and in the surrounding landscape within its catchment area. These activities and processes include geomorphic processes, riparian and vegetation changes, climate variation and anthropogenic land uses (Brierley, 2010). The influence of land-use patterns was most evident at site 12. The adverse effects of urban villages were compounded by the drought conditions, resulting in extremely high levels of *Escherichia coli* (*E. coli*) and total coliforms, increased nutrient concentrations and cyanobacterial cell concentrations and thus eutrophication of the water body. The woodland-open bush of the conservation tenure class had a remedial effect on the water quality, which was only influenced by the geology of the surrounding area during high rainfall and runoff.

The continual compliance of most of the water-quality parameters to the set TWQR and RQOs during extreme climatic conditions indicates the resilience of the Sabie-Sand Catchment. The natural assimilative capacity is the ability of the water resource to 'cleanse' itself of waste and toxins. Without protection against anthropogenic interactions, this natural assimilative attribute will decline, resulting in negative changes in the river system (Strydom *et al.*, 2006). This was also confirmed by the decline in the ecostatus shown by Roux *et al*. (2017). It is, therefore, very important to assess and evaluate the mitigating processes continually to maintain river health as far as possible, before prolonged effects render the river systems completely useless for human and ecosystem functions. Protection strategies and enhanced knowledge are critical. The importance thus lies in understanding the interactions and the effects thereof for the efficient management of water resources, land uses and aquatic ecosystem health. The long-term effects of successive droughts occurring over multiple years or decades with longer durations as a result of climate change may be much more severe, and this requires further research and modelling.

It is important to attain knowledge of the natural resources around us. Hydrology, aquatic science and other disciplines that are related to water and the use thereof already demonstrate a tremendous amount of expanding background knowledge. The challenge is to implement and improve this knowledge to ensure the continuous sustainable use of water. By monitoring variations in the water quality and water quantity, sustainable management of water resources and control of pollution are possible (Chen *et al.*, 2012). Through conducting water-quality assessments, which Meybeck *et al.* (1996) refer to as the chemical, physical and biological evaluations of water, together with water quality monitoring, which is the collection of relevant information, we are a step closer to achieving this sustainable use.

REFERENCES

APHA (2013). Standard Methods for the Examination of Water and Wastewater. 22nd ed. American Public Health Association, Washington D.C.

Ashton, P.J., Earle, A., Malzbender, D., Moloi, M.B.H., Patrick, M.J. and Turton A.R. (2006). A Compilation of All the International Freshwater Agreements Entered into by South Africa with Other States. WRC Report No. 1515/1/06.

Ayres, P. (2012). Continuous riparian vegetation change following a large, infrequent flood along the Sabie River, Kruger National Park. Potchefstroom: NWU. (Dissertation – M.Sc.).

Baker, A. (2003). Land use and water quality. *Hydrological Processes*, 17:2499-2501.

Balance, A., Hill, L., Roux, D., Silberbauer, M., Strydom, W.F. (2001). State of the Rivers Report. Crocodile, Sabie-Sand and Olifants River Systems. WRC Report No.: TT 147/01.

Belcher, A. (2004). The Ecological Reserve and River Health Monitoring: A Practical Approach in Water Resource Management. Proceedings of the 2004 Water Institute of Southern Africa (WISA) Biennial Conference, Cape Town, South Africa, 2-6 May. Produced by: Document Transformation Technologies Organised by Event Dynamics ISBN: 1-920-01728-3. p. 248-253.

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

Bengis, R., Govender, D., Lane, E., Myburgh, J., Oberholster, P. and Buss, P. (2016). Eco-epidemiological and pathological features of wildlife mortality events related to cyanobacterial bio-intoxication in the Kruger National Park, South Africa. Journal of the South African Veterinary Association 87(1): 1391-1395.

Beumer, J. & Mallory, S. (2014). Water Requirements and Availability Reconciliation Strategy for the Mbombela Municipal Area. South Africa. Department of Water Affairs. Report Nr.: PWMA 05/X22/00/2012/6.

Bolgovicsa, A., Várbíróbb, G., Ácsc, E., Trábertc, E., Tihamér Kiss, K., Pozderkaa, V., Görgényia, J., Bodab, P., Lukácsb, B-A., Lászlód, Z.N., Abonyic, A., Borics, G. (2017). Phytoplankton of rhithral rivers: Its origin, diversity and possible use for quality-assessment. Ecological Indicators 81: 587-596

Borics, G., Varbiro, G., Grigorszky, I., Krasznai, E., Szabo, S. and Tihamer Kiss, K. (2007). Large Rivers Vol. 17, No. 3-4 Arch. Hydrobiology Supplement: 161/3-4: 465-486,

Boulton, A.J. (1999). An overview of river health assessment: philosophies, practice, problems, and prognosis. *Freshwater Biology*, 41:469-479.

Brierley, G. P. (2010). Landscape memory: the imprint of the past on contemporary landscape forms and processes. *Area*, 42:76-85. 105

Burgoyne, P.M. (1995). Phytosociology of the north-eastern Transvaal high mountain grasslands. Pretoria: UP. (Dissertation – M.Sc.). p.212.

Buttigieg, P.L. & Ramette, A. (2014). A Guide to Statistical Analysis in Microbial Ecology: a community-focused, living review of multivariate data analyses. FEMS Microbiology Ecology, 90(3):543-550. https://mb3is.megx.net/gustame/constrained-analyses/rda Date of Access: 1 Sept. 2017.

Caruso, B.S. (2001). Regional river flow, water quality, aquatic ecological impacts and recovery from drought. Hydrological Science Journal 46: 677-699.

Census. (2011). Census 2011 Community Profile Databases. https://census2011.adrianfrith.com/place/877069 Date of Access: 17 Nov. 2017

Chambers, P., DeKimpe, C., Foster, N., Goss, M., Miller, J. & Prepas, E. (2001). Agricultural and Forestry Land Use Impacts. (*In* Environment Canada. Threats to Sources of Drinking Water and Aquatic Ecosystems Health in Canada: National Water Research Report Series No.1. Canada: National Library of Canada Cataloguing). (In Publication). p. 69.

Chen, Q., Mei, K., Dahlgren, R.A., Wang, T., Gong, J., & Zhang, M. (2016). Impacts of land use and population density on seasonal surface water quality using a modified geographically weighted regression. *Science of the Total Environment,* 572:450-466.

Chen, Q., Wu, W., Blanckaert, K., Ma, J., Huang, G. (2012). Optimization of water quality monitoring network in a large river by combining measurements, a numerical model and matter-element analyses. *Journal of Environmental Management*, 110:116-124.

Cholnoky, B.J. (1958). Hydrobiologische untersuchungen in Transvaal II. Selbstreinigung im Jukskei-Crocodile Flusssystem. *Hydrobiologia*, 11 (3-4): 205-266.

Coetzer, K.L., Erasmus, B.F., Witkowski, E.T. and Bachoo, A.K. (2010). Land-cover change in the Kruger to Canyons Biosphere Reserve (1993-2006): A first step towards creating a conservation plan for the subregion. *South African Journal of Science*, 106(221):1-10. 106

Cousins, T., Dlamini, V., Smits S. & Maluleke, N. (n.d.). Planning for a Multiple Use System Approach at Local Level: experiences from Bushbuckridge, South Africa. http://award.org.za/wp-content/uploads/sites/2/2014/03/Planning-for-a-Multiple-Use-System-Approach-at-Local-Level.pdf Date of access: 24 May 2016.

Dallas, H.F. & Day, J.A. (2004). The Effect of Water Quality Variables on Aquatic Ecosystems: A Review. WRC Report No: TT 224/04.

DEA. The Department of Environmental Affairs. (2016). EGIS – Environmental Geographic Information Systems. https://egis.environment.gov.za/gis_data_downloads Date of access: 1 February 2016.

Dell Inc. (2016). Dell Statistica (data analysis software system), version 13. software.dell.com.

Di Gregorio, A & Jansen, L.J.M. (2000). Land Cover Classification System (LCCS): Classification Concepts and User Manual. Food & Agriculture Organization. http://www.fao.org/docrep/003/x0596e/X0596e00.htm#P-1_0 Date of access 27 Sept. 2017.

Ding, J., Jiang, Y., Liu, Q., Hou, Z., Liao, J., Fu, L. & Peng, Q. (2016). Influences of the land use pattern on water quality in low-order streams of the Dongjiang River basin, China: A multi-scale analysis. *Science of the Total Environment*, 551-552:205-216.

Donohue, I., McGarrigle, M. L. & Mills, P. (2006). Linking catchment characteristics and water chemistry with the ecological status of Irish rivers. *Water Research*, 40:91-98.

DWAF. Department of Water Affairs and Forestry (2004). National Water Resource Strategy. 1st ed. Department of Water Affairs and Forestry, Pretoria. p57-58.

DWAF. Department of Water Affairs and Forestry. (1996a). SOUTH AFRICAN WATER QUALITY GUIDELINES 2nd Ed. Volume 7: Aquatic ecosystems.

DWAF. Department of Water Affairs and Forestry. (1996b). SOUTH AFRICAN WATER QUALITY GUIDELINES 2nd Ed. Volume 8: Field guide.

DWAF. Department of Water Affairs and Forestry. (2004). Internal Strategic Perspectives: Inkomati Water Management Area – Version 1. Tlou & Matji (Pty) Ltd. DWAF Report No.: P WMA 05/000/00/0303.

DWS. Department of Water and Sanitation. (2017a). Hydrological Services – Surface Water (Data, Dams, Floods and Flows). http://www.dwa.gov.za/Hydrology/Verified/hymain.aspx Date of access: 26 May 2017.

DWS. Department of Water and Sanitation. (2017b0. Resource Quality Information Services – Water quality data exploration tool: layers. Supporting data for use in Google Earth http://www.dwa.gov.za/iwqs/wms/data/000key2data.asp Date of access: 1 February 2016.

Dye, P.J. (1996). Climate, forest and streamflow relationships in South African afforested catchments. *The Commonwealth Forestry Review*, 75(1):31-38. 108

Ecological Reserve within the context of Integrated Water Resources Management in the catchments of the Lowveld. WRC Report No.: TT 477/10. p1-170.

Eslamian S. & Eslamian F.A. (20170. Handbook of Drought and Water Scarcity: Environmental Impacts and Analysis of Drought and Water Scarcity. eBook, CRC Press.

Esri, (2015). ArcGIS Desktop: ArcMap Release 10.4. Redlands, CA: Environmental Systems Research Institute.

Esri. (20160. ArcGIS for Desktop. ArcMap – Surface toolset concepts: How Slope works. http://desktop.arcgis.com/en/arcmap/10.3/tools/spatial-analyst-toolbox/how-slope-works.htm Date of access: 11 Sept. 2017.

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

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

Ferrier, R. & Edwards, A. (2002). Sustainability of Scottish water quality in the early 21st century. *The Science of the Total Environment,* 294:57-71.

Fisher, A. (2000). Preliminary findings from the mid-Atlantic regional assessment. *Climate Research,* 14(3):261-269.

Foley, J.A., De Fries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N. & Snyder, P.K. (20050. Global Consequences of Land Use. Review Article. *Science*, 309:570-574.

Food and Agriculture Organization of the United Nations (FAO) (2002). Land Tenure Studies. Chapter 3. Land tenure and rural development. p.7.

GeoSience (2003). South Africa. 1996. Department of Environmental Affairs and Forestry. Geology layer. Council for GeoScience, M. Roos. Pretoria. http://www.geoscience.org.za/index.php/publication/ Date of access: 2003. 109

Geoterra Image (South Africa) (2015). 2013-2014 South African National Land-Cover Dataset. DEA/CARDNO SCPF002: Implementation of Land-Use Maps for South Africa. Project Specific Data User Report and MetaData.

Gertenbach. W.P. (1983). Landscapes of the Kruger National Park. *Koedoe*, 26(1):9-121.

GlobalMapper. (2016). http://www.bluemarblegeo.com/products/global-mapper-download.php Date of access: 1 February 2016.

GoogleEarthPro (2015). Satellite imagery from various satellites and providers: Landsat / Copernicus; Digital Globe and CNES / Airbus https://www.google.com/earth/download/gep/agree.html Date of access: 1 February.

Hair, J.F., Jr., Black, W.C., Babin, B.J. & Anderson, R.E. (2009). Multivariate data analysis. 7th ed. Upper Saddle River, NJ: Pearson Prentice Hall. p. 116-120.

Harding, W.R. and Paxton, B. (2001). Cyanobacteria in South Africa: A review. *WRC Report.* No. TT 153/01.

Harker, B., Lebedin, J., Goss, M.J. Madramootoo, C., Neilsen, B.P & Van der Gulik, T. (2004). Land-Use Practices and Changes – Agriculture. (*In* Brannen, L. and Bielak, A.T., *eds*., Environment Canada. Threats to Water Availability in Canada: NWRI Scientific Assessment Series 110

Heritage, G.L. & Van Niekerk, A.W. (1995). Drought conditions and Sediment transport in the Sabie River. *Koedoe*, 38(2):1-9.

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

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

Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press. p. 173-210). https://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch3s3-4-3.html Date of Access: 22 March 2017.

Janse van Vuuren, S., Taylor, J.C., Gerber, A. and 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.

Jarvis, A., Reuter, H.I., Nelson, A. & Guevara, E. (2008). Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database (http://srtm.csi.cgiar.org). Downloaded via Global Mapper: http://www.bluemarblegeo.com/products/global-mapper-download.php Date of access: 1 February 2016.

Jewitt, G.P., Weeks, D., Heritage, G., Görgens, A.H. & O'Keeffe, J.H. (1997). The ecological significance of floods in the Sabie River, South Africa: A simulation exercise. In: Proceedings of the 3rd International Conference on River Flood Hydraulics, 5-7 November 1997. University of Stellenbosch: Stellenbosch.

Jiang J., He X. & Cane D.E. (2007). Biosynthesis of the earthy odorant geosmin by a bifunctional *Streptomyces coelicolor* enzyme. Natural Chemical Biology 3(11): 711-715

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

Johnson, M.R., Anhaeusser, C.R., & Thomas, R.J. (2006). The geology of South Africa. Pretoria, Council for Geoscience.

Kändler, M., Blechinger, K., Seidler, C., Pavlů, V., Šanda, M., Dostál, T., Krása, J., Vitvar, T., Štich, M. (2017). Impact of land use on water quality in the upper Nisa catchment in the Czech Republic and in Germany. *Science of the Total Environment,* 586:1316-1325.

Karr, J.R. & Chu, E.W. (1997). Biological Monitoring and Assessment: Using Multimetric Indexes Effectively. EPA 235-R97-001. University of Washington: Seattle. p1-138.

Khadse, G.K, Patni, P.M and Labhasetwar, P.K. (2015). Removal of iron and manganese from drinking water supply. *Sustainable Water Resource Management*, 1:157-165.

Kimble, G.H., Cooks, J. & Ferreira, C.E. (2014). Veld – Grasslands, Africa. (*In* Encyclopaedia Britannica, inc. https://www.britannica.com/science/veld Date of access: 11 Nov. 2017).

King, H.M. (2013). A sedimentary rock similar to limestone. Also known as "dolostone" and "dolomite rock." https://geology.com/rocks/dolomite.shtml Date of access: 3 May 2018.

Komárek, J. and Anagnostidis, K. (20050. Cyanoprokaryota: Oscillatoriales. In Büdel B., G.G., Krienitz L., Schagerl M. (Ed.). Freshwater Flora of Central Europe, Part 2: 758. Jena: Spektrum Akademischer Verlag.

Kumagai, M., Ishikawa, K. & Chunmeng, J. (2002). Dynamics and biogeochemical significance of the physical environment in Lake Biwa. *Lakes and Reservoirs: Research Management*, 7:345-348.

Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., Döll, P., Kabat, P., Jiménez, B., Miller, K.A., Oki, T., Sen, Z. & Shiklomanov, I.A. (2007). Freshwater resources and their management. (*In* Parry, M.L., Canziani, O.F., Palutikof, J.P., Van der Linden, P.J. & Hanson, C.E., *eds*., Climate Change 2007: 112

Kusangaya, S., Warburton, M.L., Archer van Garderen, E. & Jewitt, G.P.W. (20130. Impacts of climate change on water resources in southern Africa: A review. *Physics and Chemistry of the Earth,* 67-69:47-54.

Lamberti, G.A. (1996). The role of periphyton in benthic food webs. In: Stevenson, R.J., Bothwell, M., Lowe, R.L. (Eds.), Algal Ecology: Freshwater Benthic Ecosystems. Academic Press, San Diego, California, USA, pp. 533-572.

Land Type Survey Staff (2002). Land type survey of South Africa: Modal profiles. ARC – Institute for Soil, Climate, and Water, Pretoria, South Africa.

Larned, S.T., Scarsbrook, M.R., Snelder, T.H., Norton, N.J. & Biggs, B.J. (2004). Water quality in low-elevation streams and rivers of New Zealand: recent state and trends in contrasting land-cover classes. *New Zealand Journal of Marine and Freshwater Research*, 38:347-366.

Lee, M.T. & White, D.C. (1992). Applications of GIS databases and water quality modeling for agricultural nonpoint source pollution control. WRC Research Report No. 214.

Lepš, J. & Šmilauer, P. (2003). Multivariate Analysis of Ecological Data Using CANOCO. 1st ed. Cambridge: Cambridge University Press.

Li, T., Li, S., Liang, C., Bush, R.T., Xiong, L. & Jiang, Y. (2018). A comparative assessment of Australia's Lower Lakes water quality under extreme drought and post-drought conditions using multivariate statistical techniques Journal of Cleaner Production 190: 1e11

Mallory, S., Deacon, A., Huggins, G., Kotze, P., Louw, D., Mackenzie, J., Scherman, P. & Van Jaarsveld, P. (20130. The determination of water resource classes and associated resource quality objectives in the Inkomati Water Management Area: Status quo assessment, IUA and biophysical node delineation and identification. South Africa. Department of Water Affairs. Report Nr: RDM/WMA05/00/CON/CLA/0213.

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.

Masango, M.G, Myburgh, J.G., Labuschagne, L., Govender, D., Bengis, R.G and Naicker, D. (2010). Assessment of M*icrocystis* bloom toxicity associated with wildlife mortality in the Kruger National Park, South Africa. Journal of Wildlife Diseases, 46(1):95-102.

Matondo, J.I., Peter, G. & Msibi, K.M. (2005). Managing water under climate change for peace and prosperity in Swaziland. *Physics and Chemistry of the Earth,* 30:943-949.

Matthews, W.S. (19910. Phytosociology of the North-eastern Mountain Sourveld. Pretoria: UP. (Dissertation – M.Sc.).

Matthews, W.S., Bredenkamp, G.J. & van Rooyen, N. (1991). The grassland-associated vegetation of the Black Reef Quartzite and associated large rocky outcrops in the north-eastern mountain sourveld of the Transvaal escarpment. *South African Journal of Botany*, 57(3):143-150.

Mayer, B., Shanley, J.B., Bailey, S.W., & Mitchell, M.J. (2010). Identifying sources of stream water sulfate after a summer drought in the Sleepers River sub-catchment (Vermont, USA) using hydrological, chemical, and isotopic techniques. Appl. Geochem. 25 (5), 747-754.

Mei, K., Liao, L., Zhu, Y., Lu, P., Wang, Z., Dahlgren, R.A. and Zhang, M. (2014). Evaluation of spatial-temporal variations and trends in surface water quality across a rural-suburban-urban interface. Environmental Science Pollution Research 21:8036-8051

Meybeck, M., Kimstach, V. & Helmer, R. (1996). Strategies for water quality assessment. (*In* Chapman, D., ed. Water Quality Assessments: A Guide to Use of Biota, Sediments and Water in Environmental Monitoring. 2nd ed. Cambridge: University Press p.1-34). http://www.who.int/water_sanitation_health/resourcesquality/wqachapter2.pdf Date of access: 31 Oct. 2017. 114

Middleton, B.J & Bailey, A.K. (2005). Water Resources of South Africa 2005-Study. (WR2005). South African Water Research Commission. WRC Report No.: TT381/08.

Mosley, L.M. (2015). Drought impacts on the water quality of freshwater systems; review and integration. Earth-Science Reviews 140: 203-214

Mosley, L.M., Zammit, B., Jolley, A., & Barnett, L. (2014). Acidification of lake water due to drought. J. Hydrol. 511, 484-493.

Moulton, R.J. & Cuthbert, D.R. (2000). Cumulative Impacts/Risk Assessment of Water Removal or Loss from the Great Lakes – St. Lawrence River System. *Canadian Water Resources Journal*, 25:181-208.

Mucina, L. and Rutherford, M. C. (20060. The vegetation of South Africa, Lesotho and Swaziland. South African National Biodiversity Institute, Pretoria. *Strelitzia*, 19(3):31-50.

Mucina, L., Rutherford, M.C., Powrie, L.W., Rebelo, A.G., Camp, K.G.T., Lötter, M.C., Hoare, D.B., Boucher, C., Bredenkamp, G.J., Vlok, J.H.J., Euston-Brown, D.I.W., Jurgens, N., Du Preez, P.J., Le Roux, A., Schmiedel, U., Scott-Shaw, C.R., van Rooyen, N., Dobson, L., Palmer, A.R., Geldenhuys, C.J., Lloyd, J.W., van der Merwe, B., Bezuidenhout, H., Siebert, F., Siebert, S.J., Goodman, P.S., Winter, P.J.D., Helme, N., Smit, J.H.L, Desmet, P.G. Pfab, M., Mckenzie, B., Scholes, R.J., Manning, J.C., van Wyk, E., Zambatis, N., Lechmere-oertel, R.G. Eckhardt, H.C., Lubbinge, J.W., Matthews, W.S., Mcdonald, D.J., Smit, W.J., Bennet, R.G., Jonas, Z., Lombard, A.T., De Frey, W., Robesson, R., Oellermann, C., Grobler, A., van Niekerk, A., van der Merwe, & J.H. van der Merwe. (2006). Grassland Biome. p. 349-436. (In: L., Mucina and M.C., Rutherford. The vegetation of South Africa, Lesotho and Swaziland.) *Strelitzia*, 19:748-790.

Munzhedzi, S. & Mgquba S.K. (2013). Climate Change and the Water Sector. Climate and Impact Factsheet Series, Factsheet 3 of 7. www.sanbi.org/sites/default/files/documents/documents/ltas-factsheetclimate-change-and-water-sector2013.pdf Date of access: 20 Oct. 2017.

Nanson, G.C. & Gibling, M. (20040. Anabranching and Anastomosing River. Encyclopedia of Geomorphology: Vol. 1, 1A-I London: Routledge. Taylor & Francis e-Library, 2006. 115

Norman, N. & Whitfield, G. (2006). Geological Journeys. *A traveller's guide to South Africa's rocks and landforms*. Cape Town, CT: Struik Nature. p. 10-320.

O'Keeffe, J.H. (19850. The Conservation Status of the Sabie and Groot Letaba Rivers Within the Kruger National Park. IFWS Special Report No. 85/2. Rhodes University: Grahamstown. (South African Water History Archival Repository – C0424, Pretoria).

O'Keeffe, J.H., Weeks, D.C., Fourie, A. & Davies, B.R. (1996). A pre-impoundment study of the Sabie-sand river system, Mpumalanga with special reference to predicted impacts on the Kruger National Park. Volume Three: The effects of proposed impoundments and management recommendations. p1-106.

Olds, B.P., Peterson, B.C., Koupal, K.D., Farnsworth-Hoback, K.M., Schoenebeck, C.W., & Hoback, W.W. (2011). Water quality parameters of a Nebraska reservoir differ between drought and normal conditions. Lake Reservoir Manage. 27, 229-234.

Paerl, H.W. and Otten, T.G. (2013). Harmful Cyanobacterial Blooms: Causes, Consequences, and Controls. Microbial Ecology 65: 995-1010.

Patz, J.A. (2001). Public Health Risk Assessment Linked to Climatic and Ecological Change. *Human and Ecological Risk Assessment: An International Journal,* 7(5):1317-1327.

Paulino, M.G., Tavaresa, D., Bieczynski, F., Pedrão, P.G., Souza, N.E.S., Sakuraguia, M.M, Luquet, C.M., Terezanc, A.P., Fernandes, J.B., Gianid, A., & Fernandes, M.N. (2017). Crude extract of cyanobacteria (*Radiocystis fernandoi*, strain R28) induces liver impairments in fish. Aquatic Toxicology 182: 91-101

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

Peretyatko, A., Teissier, S. and Symoens, J.J. (2007). Phytoplankton biomass and environmental factors over a gradient of clear to turbid peri-urban ponds. Aquatic Conservation. Marine and Freshwater Ecosystems, 17: 584-601.

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

Pollard, S. & Walker, P. (2000). Catchment management, water supply and sanitation in the Sand River Catchment, South Africa: Description and Issues. WHIRL Project Working Paper 1. UK Department for International Development (DFID). Project R7804. NRI, Chatham: UK. p1-18.

Pollard, S. and Du Toit, D. (2011). The Shared River Initiative Phase I. Towards the sustainability of freshwater systems in South Africa: An exploration of factors that enable or constrain meeting the Ecological Reserve within the context of Integrated Water Resources Management in the catchments of the lowveld. WRC Report No.: TT 477/10.

Pollard, S., Mallory, S., Riddell, E. and Sawunyama, T. (2011). Towards improving the assessment and implementation of the Reserve: Real-time assessment and implementation of the Ecological Reserve. Final report WRC project K8/881/2.

Postel, S.L. (2000). Entering an Era of Water Scarcity: The Challenges Ahead. *Ecological Applications,* 10(4):941-948.

Potapova, M. (20050. Relationships of soft-bodied algae to water quality and habitat characteristics in U.S. Rivers: Analysis of the National Water – Quality Assessment (NAWQA) Program data set. Report No. 05-08The Academy of Natural Sciences

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

Quinn, G.P. and Keough, M.J. (2001). Experimental Design and Data Analysis for Biologists. Chapter 17 – Principal components and corresponding analysis. 1st ed. NJ: Cambridge University Press.

Rawson, D.S. (2012). Algal Indicators of Trophic Lake Types (1956). Limnology and Oceanography 1(1):18-25. URL: http://www.aslo.org Accessed: August 2018.

Resources Inventory Committee (RIC) (2017). British Columbia Ministry of Environment – Lands and Parks. Guidelines for Interpreting Water Quality Data. https://www.for.gov.bc.ca/hts/risc/pubs/aquatic/interp/interp-01.htm#2-7 Date of access: 26 Oct. 2017.

Romano, M.P. (1963). Hydrology of the Sabie River. South African Journal of Science: 119-125.

Rountree, M.W., Rogers, K.H. & Heritage, G.L. (20000. 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. (DOI: 10.1080/03736245.2000.9713711). 117

Roux, D.J. (1999). Design of a National Programme for Monitoring and Assessing the Health of Aquatic Ecosystems, with Specific Reference to the South African River Health Programme. *Environmental Science Forum*, 96:13-32.

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 accessed May 2016.

Roux, F., Diedericks, G., Kleynhans, C.J., Thirion, C., Hoffmann, A.C. and Selepe, M. (2017). Ecostatus of the Sabie-Sand River catchment, Inkomati River system phase II (2016). IUCMA

Rutherford, M. C., Mucina, L. & Powrie, L. W. (2006). Biomes and Bioregions of Southern Africa. The vegetation of South Africa, Lesotho and Swaziland. *Strelitzia*, 19(3):31-50.

SANSA (2015). FUNDISA disk – SPOT 6/7 mosaic and multispectral data via the North-West University Geo- and spatial department mapping facility.

Schindler, D.W. (2001). The cumulative effects of climate warming and other human stresses on Canadian freshwaters in the new millennium. *Canadian Journal of Fisheries and Aquatic Sciences*, 58:18-29.

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.

Smit, I. (2017). After the drought: What is the future for Kruger's waterholes? http://www.wildcard.co.za/drought-future-krugers-waterholes (Accessed July 2018)

Smits, S., Pollard, S., Du Toit, D., Butterworth, J. and Moriarty, P. (2004). Modelling scenarios for water resources management in the Sand River Catchment, South Africa. WHIRL Project Working Paper 8 (DRAFT). https://scholar.google.co.za/scholar?hl=en&q=Modelling+scenarios+for+water+resources+management+in+the+Sand+River+Catchment%2C+South+Africa&btnG=&as_sdt=1%2C5&as_sdtp= Date of access: 24 May 2016.

Soil Classification Working Group (SCWG) (1991). Soil classification – a taxonomic system for South Africa. Memoirs on the Agricultural Natural Resources of South Africa No. 15. Pretoria.

South Africa (2003). (Resource Quality Services). PDF files of South African land cover from the CSIR ARC national 1:250 000 land cover data set segmented by secondary drainage region X3.

South Africa (2008). Department of Water Affairs and Forestry. DWAF hydrology. http://www.drdlr.gov.za/ Date of Access: 1 Jul. 2016.

South Africa (2013). Spatial Planning and Land Use Management Act 2013 (Act No. 16 of 2013). (Notice 36730). *Government gazette*, 578:2, 5 Aug.

South Africa (2016). National Water Act, 1998 (Act no. 36 of 1998): Classes of water resources and resource quality objectives for the catchments of the Inkomati. (Government notice no. 1616). *GOVERNMENT GAZETTE*, 40531(618), 30 Dec. 2016.

South Africa (2016). National Water Act, 1998 (Act no. 36 of 1998): Classes of water resources and resource quality objectives for the catchments of the Inkomati. (Government notice no. 1616). *GOVERNMENT GAZETTE*, 40531(618), 30 Dec. 2016.

Srinivasan R. & Sorial G.A. (2011) Treatment of taste and odor causing compounds 2-methylisoborneol and geosmin in drinking water: A critical review. Science Direct 23 (1) 1-13.

Stets, E.G., Kelly V.J. & Crawford, C.G. (2014). Long-term trends in alkalinity in large rivers of the conterminous US in relation to acidification, agriculture, and hydrologic modification Science of the Total Environment (488-489): 280-289.

Stevenson, R.J. (1998). Diatom indicators of stream and wetland stressors in a risk management framework. Environmental Monitoring and Assessment. 51: 107-118.

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

Stevenson, R.J., Pan, Y., and Van Dam, H. (2010). Assessing ecological conditions in rivers and streams with diatoms. In: Smol, J.P., Stoermer, E.F. (Eds.), The Diatoms: Applications to the Environmental and Earth Sciences, second ed. Cambridge University Press, Cambridge, UK, pp. 57-85.

Strydom, W.F., Hill, L. and Eloff, E. (2006). The National Aquatic Ecosystem Health Monitoring Programme (River Health Programme) Achievements of the River Health Programme 1994-2004: A national perspective on the ecological health of selected South African rivers. Report contributors: The Department of Water Affairs and Forestry; The Department of Environmental Affairs and Tourism; Water Research Commission (WRC) and CSIR. Report No. ISBN: 0-620-36168-9.

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

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

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.

Ter Braak, C.J. & Šmilauer, P.N. (2002). *CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5)*. Ithaca, NY: Microcomputer Power, 500 pp. 119

Tlou, T. (2011). Bushbuckridge Local Municipality: First order Reconciliation Strategy for the Inyaka Regional Water Supply Scheme Area. Department of Water Affairs. Contract: WP 9712. p2-27.

USGS. (2015). Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global. https://lta.cr.usgs.gov/SRTM1Arc Date of access 21 Aug. 2017.

Utermöhl, H. (19580. Zur Vervollkommung der quantitativen Phytoplankton Methodik. *Mitteilungen Internationale Vereinigung für Theoretische und Angewandte Limnologie*, 9(1):1-38.

Van der Hoven. C., Ubomba-Jaswa, E., van der Merwe, B., Loubser, M., Abia, A.L. (2017). The impact of various land uses on the microbial and physicochemical quality of surface water bodies in developing countries: Prioritisation of water resource management areas. Environmental *Nanotechnology, Monitoring and Management*, 8:280-289.

Van Ginkel, C.E., Hohls, B.C., Belcher, A., Vermaak, E. and Gerber, A. (2000). Assessment of the Trophic Status Project Main Report. Report number N/0000/00/DEQ/1799 of the Institute for Water Quality Studies, Department of Water Affairs. Pretoria, 314pp

Van Vliet, M.T.H., & Zwolsman, J.J.G. (2008). Impact of summer droughts on the water quality of the Meuse River. Journal of Hydrology 353: 1-17.

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. *South African Journal of Science*, 97:349-356.

Venter, F., Scholes, R. & Eckhardt, H. (20030. The abiotic template and its associated vegetation pattern. (In: Du Toit JT, Rogers KH, Biggs H, *eds*., *The Kruger Experience*: Ecology and management of savanna heterogeneity). Washington DC: Island Press, 2003. p. 83-117.

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R. (2010). Global threats to human water security and river biodiversity. *Nature*, 467, 555-561.

Vrebos, D., Beauchard, O. & Meire, P. (2017). The impact of land use and spatial mediated processes on the water quality in a river system. *Science of the Total Environment*, 601-602:365-373. 120

Wade, A.J., Whitehead, P.G., Hornberger, G. M. & Snook, D.L. (2002). On modelling the flow controls on macrophyte and epiphyte dynamics in a lowland permeable catchment: the River Kennet, southern England. The *Science of the Total Environment*, 282:375-393.

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

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

Wells, J. (1992). A Pre-Impoundment Study of the Biological Diversity of the Benthic Macro-Invertebrate Fauna of the Sabie-Sand River System. Cape Town: UCT. (Thesis – M.Sc.).

Wetherald, R.T. & Manabe, S. (2002). Simulation of hydrologic changes associated with global warming. *Journal of Geophysical Research*, 107(D19, 4379):1-15.

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

White K. (2004). Encyclopaedia of Geomorphology: PEDIMENT. Vol.1, 1A-I London: Routledge. Taylor & Francis e-Library, 2006.

Whitton, B. A., Rott, E. and Friedrich, G. (1991). Use of algae for monitoring rivers: proceedings of an international symposium held at the Landesamt fur Wasser und Abfall Nordhein-Westfalen, Dusseldorf, Germany, 26-28 May 1991, E. Rott, Innsbruck

Whitworth, K.L., Baldwin, D.S., & Kerr, J.L. (2012). Drought, floods and water quality: drivers of a severe hypoxic blackwater event in a major river system (the southern Murray-Darling Basin, Australia). Journal of Hydrology. 450-451: 190-198.

Wilbanks, T.J., P. Romero Lankao, M. Bao, F. Berkhout, S. Cairncross, J.-P. Ceron, M. Kapshe, R. Muir-Wood & R. Zapata-Marti. (2007). Industry, settlement and society. (*In* Parry, M.L., Canziani, O.F., Palutikof, J.P., Van der Linden, P.J. & Hanson, C.E., *eds*., Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press. p. 357-390). 121

Woodhouse, P. (1995). Water Rights and Rural Restructuring in South Africa: A Case Study from Eastern Transvaal. *Water Resources Development,* 11(4):527-544.

WR 1990. Water Resources of South Africa, 1990 study. Simplified geology. (Source Unknown). www.sanbi.org/sites/default/files/documents/documents/ltas-factsheetclimate-change-and-water-sector2013.pdf Date of access: 16 Nov. 2017.

WR. 2012. Water Resources of South Africa, 2012 study. http://www.waterresourceswr2012.co.za Date of access: 16 Nov. 2017.

Wu, N., Schmalz, B. and Fohrer, N. (2011). Distribution of phytoplankton in a German lowland river in relation to environmental factors. Journal of Plankton Research 33 (5): 807-820

Xizhi, L., Jing, H., Peiqing, X., Pan, Z. & Jiaoxuehui. (2017). Correlation Analysis Between the Water Quality and Land Use Composition in Chaobai River Basin. *Nature Environment and Pollution Technology*, 16(1):307-314.

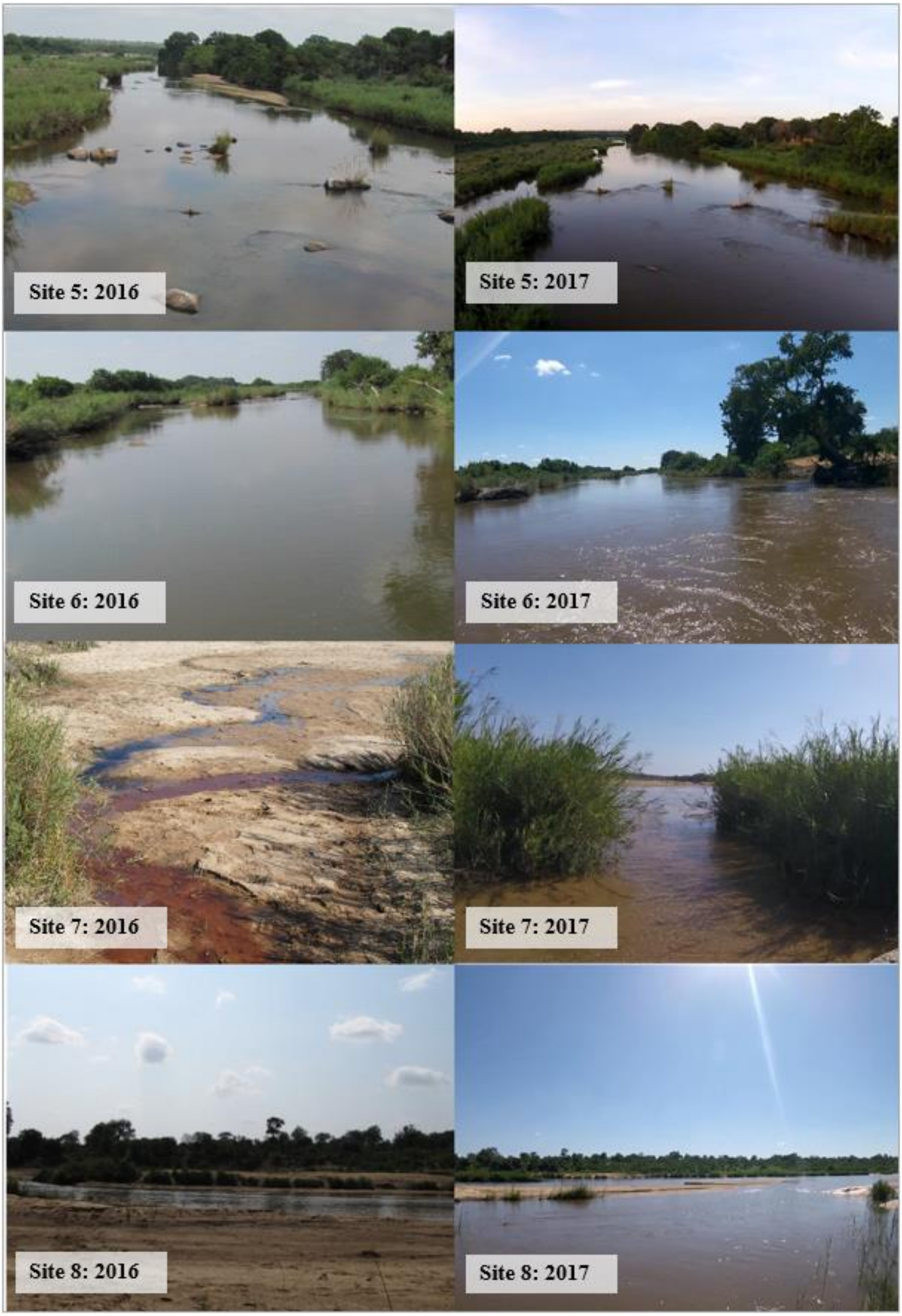
Yan, N.D., Keller, W., Scully, N.M., Lean, D.R.S., & Dillon, P.J. (1996). Increased UV-B penetration in a lake owing to drought induced acidification. Nature 381, 141-143.

Yu, S., Xu, Z., Wu, W. & Zuo, D. (2016). Effect of land use types on stream water quality under seasonal variation and topographic characteristics in the Wei River basin, China. *Ecological Indicators*, 60:202-212.

Zhao, J., Lin, L., Yang, K., Liu, Q. & Qian, G. (2015). Influences of land use on water quality in a reticular river network area: A case study in Shanghai, China. *Landscape and Urban Planning*, 137:20-29.

APPENDICES

Appendix A


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

Appendix B

Table B-1. The *p-values* of the comparisons of the Kruskall Wallis ANOVA

Variable	**Multiple Comparisons p values (2-tailed).** Independent (grouping) variable: Year Kruskal-Wallis test: H ((1-12), n= 8)											
Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Alkalinity	0.7660	0.2454	0.0591	0.3094	0.4678	0.1489	0.5637	1,000	0.7237	0.8831	0.0284	0.1489
Aluminium	1.0000	0.0384	0.0180	0.2482	0.3807	0.3865	0.2454	0.2482	0.2888	0.6631	0.0833	0.0421
Ammonia	0.1266	0.1266	0.1266	0.1266	0.1266	0.1266	0.1266	0.1266	0.1797	0.1266	0.0172	0.0814
Calcium	0.7728	0.0778	0.0284	0.7728	0.3865	0.5614	0.5637	0.8845	0.7213	0.7728	0.1465	0.1913
Chloride	0.5637	0.2425	0.1913	0.0202	0.1913	0.1489	0.3836	0.0209	0.0771	0.0209	0.1489	0.3865
Chl-*a*	0.1306	0.3211	0.0472	0.1306	0.5385	0.1664	0.3749	1,000	0.2710	0.5385	0.1489	0.0202
DOC	0.0833	0.2482	0.1489	0.4678	0.2367	0.5637	0.4678	0.1886	0.0308	1,000	0.0814	0.0433
DO	0.2482	0.2482	0.5637	0.3865	0.3865	0.6631	0.5637	0.1102	0.4795	0.3865	1,000	0.2482
E. coli	0.1489	0.0284	0.0833	0.0202	0.5637	0.5637	0.4795	0.5614	0.4795	0.0814	0.1391	0.2482
EC	0.0209	0.0209	0.0591	0.0209	0.5637	0.0209	0.0209	0.7728	0.4795	0.7728	0.0209	0.0833
Geosmin	0.6552	0.1102	0.0209	0.0833	0.5637	0.7728	0.3749	0.2482	0.0771	0.7728	0.1489	0.3865
Hardness	0.7674	0.0575	0.0202	0.6631	0.6631	0.3094	0.1059	0.3094	0.4795	0.7728	0.3529	0.1102
Iron	0.7728	0.0209	0.0575	0.5637	0.0833	0.3094	0.7728	0.2482	0.7213	0.0202	0.3865	0.0209
Magnesium	0.8501	0.0209	0.0433	0.5590	0.6631	0.1913	0.0284	0.1102	0.1084	0.6552	0.1859	0.0833
Manganese	1.0000	0.0202	1,000	0.8845	0.3173	0.5083	0.3173	1,000	0.1859	0.5439	0.4568	0.3173

Variable	Multiple Comparisons p values (2-tailed). Independent (grouping) variable: Year Kruskal-Wallis test: H ((1-12), n= 8)											
Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
2-MIB	0.1306	0.3173	0.3173	1,000	1,000	1,000	1,000	1,000	1,000	0.3173	0.3173	0.8501
Nitrate + Nitrite	0.0472	0.7715	0.3865	0.3065	0.0814	0.1081	0.1306	0.2817	0.7137	0.2454	0.0472	0.4678
Inorganic nitrogen	0.1367	0.7715	0.1489	0.3065	0.1489	0.3865	0.5357	0.5541	0.8584	0.3865	1,000	0.0209
pH	0.1102	0.7728	0.8845	0.7728	0.7728	0.1489	0.2482	0.2482	0.0339	0.2482	0.2482	0.5637
Silica	0.2454	0.2482	0.5590	0.6612	0.3865	1,000	0.7715	0.5637	0.4795	0.2482	0.7728	0.6631
Sodium	1.0000	0.0275	0.0408	0.1441	0.3865	0.0591	0.3865	0.5637	1,000	0.7728	0.0209	0.0575
Sulphate	0.0472	0.5590	0.7715	0.1465	0.7728	0.5637	1,000	0.5637	0.2888	0.0759	0.0472	0.5637
Total coliforms	0.4795	0.0339	0.2888	0.1573	0.0666	0.0339	0.0641	0.4795	0.2752	0.7237	0.1573	0.4795
TDS	0.2482	0.1489	0.1102	0.1102	0.7728	0.7728	0.1441	0.5637	1,000	0.2482	0.0433	0.7728
Total KN	0.3562	0.2784	0.5083	0.3211	0.0139	0.0180	0.0256	0.0139	0.0262	0.0741	0.0530	0.0384
TOC	0.1913	0.2482	0.4678	0.6631	0.1489	0.2482	0.8845	0.6631	0.2888	0.1081	0.7674	0.2482
Total Phosphates	0.4624	0.6592	0.6592	0.8817	0.7645	0.7615	0.6171	0.6171	0.1859	0.6171	0.7518	0.3211
Turbidity	0.3836	0.1489	0.0433	0.1102	0.6631	0.0433	0.3865	0.0433	0.0771	0.1913	0.3836	0.0833

The *p-values* that are significant are in red.

Appendix C

Table C-1: List of all the genera found during the first year of sampling (2016) at the different sampling sites (1-12)

	Site	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Cyanophyceae													
Anabaena	Ana	0	0	0	0	0	0	1	0	1	0	0	0
Aphanothece	Apha	0	1	1	1	0	0	1	1	1	1	1	1
Arthrospira	Art	0	0	1	1	0	0	1	1	0	0	0	0
Chroococcus	Chro	0	0	0	0	0	0	1	0	0	1	1	1
Geitlerinema	Gei	0	1	0	0	1	0	0	1	0	0	0	0
Johannesbaptista	Joh	0	1	0	0	0	0	1	0	0	0	0	0
Komvovoron	Komv	1	0	1	0	0	1	1	1	0	1	0	0
Leptolyngbya	Lep	0	0	0	0	0	1	0	0	0	0	0	0
Merismopedia	Mer	0	0	0	1	1	1	1	1	0	1	1	1
Oscillatoria	Osc	0	1	0	1	0	0	1	0	0	0	0	1
Phormidium	Pho	0	0	0	1	1	0	1	1	1	0	0	1
Pseudanabaena	Pse	0	0	0	0	0	0	1	1	1	1	0	0
Snowella	Sno	0	0	0	0	0	0	0	0	1	0	0	0
Spirulina	Spi	0	0	0	1	0	0	0	0	0	0	0	0
Total genera		1	4	3	6	3	3	10	7	5	5	3	5

	Site	1	2	3	4	5	6	7	8	9	10	11	12
Chlorophyceae													
Actinastrum	Act	0	0	0	0	0	0	0	1	0	0	0	0
Acutodesmus	Acu	0	0	0	1	0	1	0	1	1	1	0	1
Ankistrodesmus	Ank	0	0	0	0	0	0	1	0	0	1	1	0
Chlamydomonas	Chlam	0	0	0	0	1	1	0	1	0	1	1	1
Chlorella	Chlor	0	0	0	0	0	0	1	1	0	1	1	1
Chlorococcum	Chloro	0	0	0	1	0	0	0	0	0	0	1	1
Closterium	Clos	0	0	1	0	0	0	1	0	0	1	0	1
Coelastrum	Coe	0	0	0	0	0	0	1	0	0	0	0	1
Crucigenia	Cru	0	0	0	0	0	0	0	0	0	1	0	0
Crucigeniella	Cruc	0	0	0	1	0	0	0	0	0	0	0	0
Desmodesmus	Des	0	0	0	1	1	1	0	1	0	1	0	1
Elakatothrix	Ela	0	0	0	0	0	0	0	0	0	0	1	0
Eudorina	Eud	0	0	0	0	0	0	0	1	0	0	0	0
Microspora	Micr	0	1	0	0	1	0	0	0	0	0	0	0
Monoraphidium	Mon	1	1	1	0	0	0	1	0	0	1	1	0
Mougeotia	Mou	0	0	0	0	0	0	1	0	0	0	1	0
Nephrocytium	Nep	0	0	0	0	0	0	0	0	0	1	0	0
Oedogonium	Oed	0	0	1	1	0	0	0	0	1	0	0	0

	Site	1	2	3	4	5	6	7	8	9	10	11	12
Oocystis	Ooc	0	0	0	0	0	0	0	0	0	1	0	0
Pandorina	Pan	0	0	0	0	0	0	1	1	0	0	0	1
Pediastrum	Ped	0	0	0	0	0	0	0	1	0	1	0	0
Scenedesmus	Sce	0	0	0	1	1	1	1	1	1	1	1	1
Schroederia	Schr	1	1	1	0	0	0	0	1	0	1	0	0
Spirogyra	Spiro	0	0	0	0	0	0	0	1	0	0	0	0
Staurastrum	Stau	0	0	0	0	0	0	0	0	0	1	1	0
Stigeoclonium	Stig	0	0	0	0	1	0	0	0	0	0	0	0
Tetraedron	Tet	0	0	0	0	0	0	0	0	0	0	1	1
Tetrastrum	Tetr	0	0	0	0	0	0	0	0	0	0	1	0
Treubaria	Treu	0	1	1	0	0	0	0	0	0	0	0	0
Total genera		2	4	5	6	5	4	8	11	3	14	11	10
Bacillariophyceae													
Achnanthes	Ach	1	1	1	1	1	1	1	1	1	1	0	1
Achnanthidium	Achn	1	1	1	1	1	1	0	1	1	1	0	1
Caloneis	Cal	0	0	0	0	0	0	0	1	0	0	0	0
Capartogramma	Cap	0	0	0	0	0	1	0	0	0	0	0	0
Cocconeis	Coc	1	1	1	1	1	1	0	1	1	1	0	0

	Site	1	2	3	4	5	6	7	8	9	10	11	12
Craticula	Cra	0	0	0	0	0	0	0	0	0	0	0	1
Cyclotella	Cyc	0	0	1	0	1	0	1	1	1	1	1	1
Cymatopleura	Cym	0	1	0	1	0	0	0	0	0	0	0	0
Cymbella	Cymb	1	1	1	1	1	1	1	1	1	1	0	1
Diatoma	Diat	0	1	1	0	0	0	0	0	0	0	0	0
Diploneis	Dip	0	0	1	0	0	0	1	1	1	0	0	0
Encyonopsis	Enc	0	1	1	1	0	1	0	1	0	1	0	0
Eunotia	Eun	1	0	0	0	0	0	0	0	0	0	0	0
Fragilaria	Fra	0	1	1	1	1	1	1	1	0	1	0	0
Geissleria	Gei	0	0	0	0	0	1	1	1	1	0	0	1
Gomphonema	Gom	0	1	1	1	1	1	1	1	1	1	1	1
Gyrosigma	Gyr	0	1	1	1	1	1	1	1	1	0	0	1
Hippodonta	Hipp	0	1	1	0	0	0	0	0	0	0	0	0
Melosira	Mel	0	1	1	1	1	0	0	0	1	0	0	1
Navicula	Nav	0	1	1	1	1	1	1	1	1	1	1	1
Nitzschia	Nit	0	1	1	1	1	1	1	1	1	1	1	1
Plagiotropis	Plag	0	0	0	0	0	0	0	0	0	0	0	1
Rhoicosphenia	Rho	0	1	1	0	0	0	0	0	0	0	0	0
Rhopalodia	Rhop	0	0	0	0	0	0	1	0	0	0	0	0

	Site	1	2	3	4	5	6	7	8	9	10	11	12
Sellophora	Sel	0	1	1	0	1	1	0	1	1	1	0	1
Surirella	Sur	0	0	0	1	0	1	0	1	1	0	0	0
Synedra	Syn	0	1	1	1	1	1	1	1	0	0	0	0
Total genera		5	17	18	14	13	15	12	17	14	11	4	13
Chrysophyceae													
Dinobryon	Din	0	0	0	0	0	0	0	0	0	1	1	0
Total genera		0	0	0	0	0	0	0	0	0	1	1	0
Dinophyceae													
Peridinopsis	Per	0	0	0	0	0	0	0	0	0	1	1	0
Peridinium	Peri	0	0	0	0	0	0	0	0	0	1	1	0
Total genera		0	0	0	0	0	0	0	0	0	2	2	0
Euglenaphyceae													
Euglena	Eug	0	0	0	0	0	0	0	0	1	1	0	1
Phacus	Phac	0	0	0	0	0	0	0	0	0	0	0	1
Tracelomonas	Trac	0	0	0	0	0	1	1	1	0	1	1	1
Total genera		0	0	0	0	0	1	1	1	1	2	1	3

	Site	1	2	3	4	5	6	7	8	9	10	11	12
Total genera for site		8	25	26	26	21	23	31	36	23	35	22	31

Table C-2 List of all the genera found during the second year of sampling (2017) at the different sampling sites (1-12).

Cyanophyceae	**Site**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Anabaena	Ana	0	0	0	0	0	0	1	0	0	0	0	0
Aphanocapsa	Aph	0	0	0	0	1	1	1	1	1	0	1	1
Aphanothece	Apha	0	0	0	0	0	0	0	0	1	0	0	0
Arthrospira	Art	0	0	0	0	1	0	0	0	1	0	0	0
Chroococcus	Chro	0	0	0	0	0	1	1	0	0	0	1	0
Cylindrospermopsis	Cyl	0	0	0	1	0	1	1	0	0	0	0	0
Gloeocapsa	Glo	0	0	0	0	0	0	0	0	0	0	1	0
Johannesbaptista	Joh	0	1	0	0	0	0	0	0	0	0	0	0
Komvovoron	Komv	0	0	1	0	1	1	1	1	1	1	0	0
Leptolyngbya	Lep	0	0	0	1	0	0	0	0	0	0	0	0
Merismopedia	Mer	1	0	0	1	0	0	1	1	1	1	0	1
Oscillatoria	Osc	0	0	0	1	0	0	1	0	0	0	0	1
Phormidium	Pho	0	0	0	0	0	1	1	1	1	1	0	0
Radiocystis	Rad	0	0	0	0	0	0	0	0	0	0	1	0
Synechocystis	Synec	0	0	0	0	0	1	0	0	0	1	1	0
Total genera		1	1	1	4	3	6	8	4	6	4	5	3
Chlorophyceae													

Cyanophyceae	**Site**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Actinastrum	Act	0	0	0	0	1	0	0	0	0	0	1	0
Acutodesmus	Acu	0	0	0	1	0	0	1	1	0	1	1	1
Ankistrodesmus	Ank	0	0	0	0	0	0	0	0	0	0	1	0
Chlamydomonas	Chlam	0	0	0	1	1	1	1	1	1	1	1	1
Chlorella	Chlor	0	0	0	1	1	0	0	1	1	1	1	1
Chlorococcum	Chloro	0	0	0	0	0	0	0	0	0	1	1	1
Coelastrum	Coe	0	0	0	0	0	0	1	0	0	0	0	0
Cosmarium	Cos	0	0	0	0	0	0	0	0	0	1	0	0
Crucigenia	Cru	0	0	0	0	0	1	0	0	0	1	1	0
Crucigeniella	Cruc	0	0	0	1	1	1	1	0	0	0	1	0
Desmodesmus	Des	0	0	0	1	0	1	1	1	1	1	1	1
Dictosphaerium	Dict	0	0	1	1	0	1	1	1	0	0	1	1
Elakatothrix	Ela	0	0	0	0	0	0	0	0	0	1	1	0
Eudorina	Eud	0	0	0	0	0	0	0	1	0	0	0	1
Kirchneriella	Kir	0	0	0	0	0	0	0	0	0	1	0	0
Monoraphidium	Mon	0	1	1	1	0	1	1	1	0	1	1	1
Nephrocytium	Neph	0	0	0	0	0	0	0	0	0	0	1	0
Oedogonium	Oed	0	1	0	1	0	0	0	1	0	0	0	0
Oocystis	Ooc	0	1	1	0	1	0	0	0	0	0	0	1

Cyanophyceae	Site	1	2	3	4	5	6	7	8	9	10	11	12
Pandorina	Pan	1	0	0	1	1	1	1	1	1	1	0	1
Pediastrum	Ped	0	0	0	1	0	0	1	1	0	1	0	1
Scenedesmus	Sce	0	0	1	1	1	1	1	1	1	1	1	1
Schroederia	Schr	1	1	1	1	0	0	0	0	0	0	0	0
Spirogyra	Spiro	0	0	0	0	0	0	1	0	0	0	0	1
Staurastrum	Stau	0	0	0	0	0	0	0	0	0	0	1	0
Stigeoclonium	Stig	1	0	0	0	0	0	0	0	0	0	0	0
Tetrastrum	Tetr	0	0	0	0	0	1	0	1	0	1	1	1
Treubaria	Treu	0	1	1	1	0	0	0	0	0	0	0	0
Ulothrix	Ulo	0	0	1	0	0	0	0	0	0	0	0	0
Total genera		4	5	7	13	7	9	10	12	5	14	16	14
Bacillariophyceae													
Achnanthes	Ach	1	1	1	1	1	1	1	1	1	1	0	1
Achnanthidium	Achn	1	1	1	1	1	1	1	1	1	1	0	1
Caloneis	Cal	0	0	0	0	0	0	0	0	0	0	0	1
Capartogramma	Cap	0	0	1	0	0	0	0	0	1	0	0	1
Cocconeis	Coc	1	1	1	1	1	1	1	1	1	1	0	1
Cyclotella	Cyc	0	0	0	1	1	1	1	1	0	1	1	1

Cyanophyceae	Site	1	2	3	4	5	6	7	8	9	10	11	12
Cymatopleura	Cym	0	0	0	1	0	0	0	0	0	1	1	0
Cymbella	Cymb	0	1	1	1	1	1	1	1	1	1	0	1
Diatoma	Diat	0	0	0	0	0	0	0	1	0	0	0	0
Diploneis	Dip	0	0	0	0	0	0	1	1	0	0	0	0
Encyonopsis	Enc	0	1	1	1	1	1	1	1	1	1	0	1
Eunotia	Eun	1	0	0	0	0	0	0	0	0	1	0	1
Fragilaria	Fra	0	1	1	1	1	1	1	1	0	1	0	1
Frustulia	Fru	1	0	0	0	0	0	1	0	0	0	0	0
Geissleria	Gei	0	0	0	0	0	0	0	0	0	0	0	1
Gomphonema	Gom	1	1	1	1	1	1	1	1	1	1	1	1
Gyrosigma	Gyr	0	0	1	1	1	1	1	1	1	1	0	1
Hantzschia	Han	0	0	0	0	0	0	1	1	0	0	0	0
Melosira	Mel	1	1	1	1	1	1	1	1	0	0	0	1
Navicula	Nav	1	1	1	1	1	1	1	1	1	1	1	1
Nitzschia	Nit	0	1	1	1	1	1	1	1	1	1	1	1
Pinnularia	Pin	0	0	1	0	1	0	1	1	0	0	0	1
Plagiotropis	Plag	0	0	0	0	0	0	1	1	1	0	1	1
Planothidium	Plan	1	0	0	0	0	0	0	0	0	0	0	0
Rhoicosphenia	Rho	0	1	1	0	0	0	0	0	0	0	0	0

Cyanophyceae	Site	1	2	3	4	5	6	7	8	9	10	11	12
Sellophora	Sel	0	0	0	0	1	1	1	0	0	0	0	1
Surirella	Sur	0	0	0	0	1	1	1	1	1	0	0	0
Synedra	Syn	0	1	1	1	1	1	0	1	1	1	0	0
Urosolenia	Uro	0	0	0	0	0	0	0	0	0	0	1	0
Total genera		9	12	15	14	16	15	19	19	13	14	6	19
Chrysophyceae													
Dinobryon	Din	0	0	0	0	0	0	0	0	0	1	1	0
Total genera		0	0	0	0	0	0	0	0	0	1	1	0
Dinophyceae													
Peridinopsis	Per	0	0	0	0	0	0	0	0	0	0	1	1
Peridinium	Peri	0	0	0	0	0	0	0	0	0	0	1	0
Total genera		0	0	0	0	0	0	0	0	0	0	2	1
Euglenophyceae													
Euglena	Eug	0	0	0	0	0	0	1	0	0	1	0	1
Strombomonas	Stro	0	0	0	0	0	0	0	0	0	0	0	1
Tracelomonas	Trac	0	0	0	1	0	1	1	0	1	1	0	1

Cyanophyceae	Site	1	2	3	4	5	6	7	8	9	10	11	12
Total genera		0	0	0	1	0	1	2	0	1	2	0	3
Total genera for site		14	18	23	32	26	31	39	35	25	35	30	40