The implications of land use on the state and health of a river system in a semi-arid region of South Africa

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Abstract

Ecological State and water quality of the Moreleta, Pienaars and Moretele Rivers is affected by the type of landuse adjacent to the river. Sewage works, agriculture and industry contribute to poorer water quality as indicated by increased nitrate and orthophosphate levels. Ecological category based on macroinvertebrate presence in the river system was not closely linked to the Ecological State. Ecological categories based on macroinvertebrate presence ranged from *Very Poor* to *Fair*. The Ecological State categories ranged from *Poor* to *Natural*. Therefore, the Ecological State scoring system developed by this project team should be used in conjunction with the miniSASS scoring system to give a broader overview of the state of the river system for monitoring and management purposes. The laboratory water quality analyses showed that there were no dangerously high levels of any of the water quality parameters analysed in the river and this was also evident by the presence of the pollution sensitive caddisflies at all except one of the sites. The Ecological State of the river was better within conservation areas. Areas with a *Natural* or *Good* Ecological State have more habitats for fauna and flora and therefore a higher biodiversity. This study highlights the importance of conserving areas of natural ecology along rivers. A recommendation is made for improving the method that non-professionals could use to assist with the monitoring of South African rivers.

Keywords

ecological state, landuse, macroinvertebrates, miniSASS, water quality.

1 Introduction

Fresh water is essential for life on earth. Water is used in all aspects of human life, including agriculture, industry, biodiversity conservation, sanitation and hydration. South Africa is considered to be a water-stressed country as water is scarce, due to the low annual rainfall received.

Fresh water constitutes about 0.01% of global water, and yet it supports about 6% of all described species in the world [1]. Freshwater biodiversity is an invaluable natural resource in terms of human and environmental health, economy, culture, aesthetics, science and education.

The above reasons alone make it critical for freshwater systems to be conserved and managed. In order for rivers to be managed, information such as the quality of their water, their health and ecological state need to be assessed. The impact of humans and the surrounding land-use must be managed continually.

This project investigated the water quality and ecological state in a river system which arises within the city in which the project team members live: Pretoria in South Africa. The upper sections of the river system, the Moreleta and Pienaars Rivers, flow through urban and smallholding farm land. The middle section of the river flows mainly through agricultural land and further along the Moretele River becomes one of the most important floodplain systems in the northern part of South Africa. The river system along the section investigated also has two large dams on it.

Hypothesis: Landuse surrounding a river will affect the water quality and ecological state of the river.

1.1 Landuse and the impact of river water quality

It is commonly known and accepted that river health and water quality is affected by the landuse immediately surrounding a river. The land use dictates how much and which types of effluent and pollutants reach the river. Precipitation run-off and direct effluent pumping are two of the main contributors to river pollution[2]. Run-off pollution occurs when rain flows across the ground and collects contaminants, specifically in cities, industrial areas and on agricultural land. Effluent is pumped directly into rivers from factories in industrial areas adjacent to rivers. Water leaving sewage works is also pumped into rivers. In rural and communal areas there is also the issue of the unhygienic use of rivers for example washing clothes in the rivers.

In urban areas, storm-water carries away a wide variety of contaminants as it runs off rooftops, roads, parking lots, sports fields, construction sites, gardens, and other surfaces in cities and suburbs. The oily sheen on rainwater in roadside gutters storm-water, from grease and vehicle oils is a common example of urban run-off toxins[2.]

On farms or other agricultural sites, the water carries away fertilizers, pesticides, herbicides and fungicides, these would add orthophosphates and nitrates to the water; and sediment from crops and grazing land[2]. Runoff in overgrazed areas carries away sediment and topsoil with the nutrients and other materials from land which no longer has enough living vegetation to hold the soil in place.

There is less unnatural run-off and less pollutants in run-off into rivers in nature reserves and national parks. In these conservation areas, the run-off is normally more controlled due to there being more vegetation to hold the soil in place as well as the lack of fertilizers, pesticides, herbicides.

1.2 Biomonitoring as an accepted method for monitoring river water quality and river health

In South Africa, river water quality monitoring techniques using macroinvertebrates are common. The most successful and accurate technique for identifying water quality in South Africa is *the South African Scoring System* version 5 (SASS5). The SASS5 technique is unique to South Africa and uses the presence of macroinvertebrates- considering over 90 different taxa- to determine the quality of the water and hence the health of a river. It is a low technology, scientifically reliable and robust technique to monitor water quality in rivers and streams[3].

SASS5 has been tested and found to produce the same scores in different seasons and is suitable for use throughout the year, especially in the region in which this project was conducted[4].

The miniSASS, a simplified version of SASS, has been developed so that lay people and school pupils may get involved with biomonitoring of the rivers in their communities. It is based on the SASS5 as it also uses the presence of macroinvertebrates to indicate the river health of an area, but it uses a reduced number of taxa (13 taxa), to allow for simpler identification and understanding. The idea behind the development of miniSASS, is that people will monitor rivers by taking regular miniSASS assessments and download their information onto a specific website, thereby raising an alarm if there are unusual results indicating possible pollutant or toxin release into the river.

<u>Macroinvertebrates</u>

Macroinvertebrates are animals that have no backbone and are visible with the naked eye. They are used to identify water quality for the following reasons[5]:

- Each species has different sensitivities to water quality conditions;
- They are easily collected and identified;
- They are sedentary thereby indicating the area of the pollution; and
- They give an indication of recent events affecting a water quality site.

Macroinvertebrates can be divided into three different categories based on their different sensitivities to water quality conditions and pollution[6]:

1. Highly sensitive to pollution;
2. Semi-tolerant of pollution; and
3. Pollution tolerant.

<u>Highly Sensitive Macroinvertebrates</u>

Highly sensitive macroinvertebrates live in less polluted areas as they require high dissolved oxygen levels, and if these organisms are found in large numbers it indicates that the water is in good condition[6] .

These organisms include:

- Mayflies;
- Riffle beetles (adults);
- Caddisflies (larvae);
- Stoneflies (nymphs);
- Water pennies;
- Gilled snails; and
- Hellgrammites (dobsonfly larvae)

<u>Semi-tolerant Macroinvertebrates</u>

These Macroinvertebrates are somewhat tolerant to the pollution of water, and if they are found in abundance with a wide range of diversity, they indicate that the water is in fair condition[6].

These organisms include:

- Alderflies (larvae);
- Dragonflies and damselflies (nymphs);
- Whirligig beetles (larvae);
- Riffle beetles (larvae);
- Fishflies (larvae);
- Sowbugs;
- Scuds;
- Crayfish;
- Clams; and
- Mussels

<u>Pollution Tolerant Macroinvertebrates</u>

These macroinvertebrates are fully tolerant to water pollution and tend to thrive in poor quality conditions. If they are found in large numbers it indicates that conditions in the river have deteriorated. These organisms have adapted in many ways to withstand such conditions as they use 'snorkels' to reach the surface if the water to access oxygen, and they are less dependent on dissolved oxygen to breathe [6].

These organisms include:

- Black flies (larvae);
- Midge flies (larvae);
- Lunged snails;
- Aquatic worms; and
- Leeches.

The two most accurate indicators of good water quality are Stoneflies and Caddisflies[6] . Both require cold, clean water (usually pristine water quality in the case of the stoneflies) to live in. This makes them excellent bio-indicators of water quality.

2 Study area

The study area includes the main stem of a river system comprising the Moreleta and sections of the Pienaars and Moretele Rivers in South Africa (Figure 1). The Moreleta River has its source very close to where the team members involved in this study reside, in Pretoria, and the Pienaars River has its source just outside Pretoria in an agricultural smallholding area to the North East of the city. Pretoria is in Gauteng Province in South Africa.

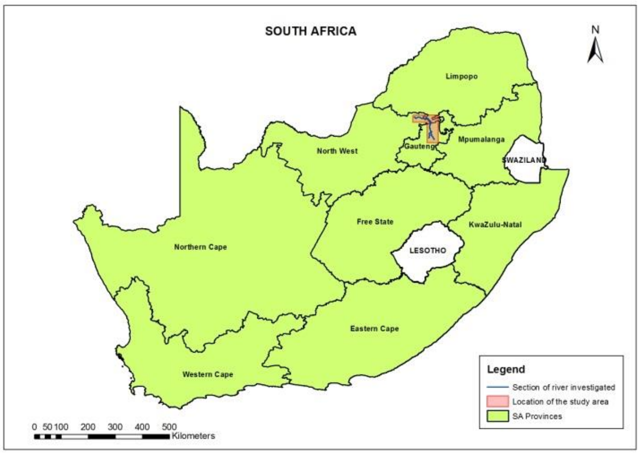

Figure 1: Map of South Africa showing the location of the study area and the section of the rivers investigated.

The source of the Moreleta River is located within an urban area close to the Moreleta Kloof Nature Reserve (Figure 2). This river flows through residential areas of Pretoria, through wetlands, to the Faerie Glen Nature Reserve (Figure 3), also within the residential area. Then it flows through an industrial area in the north of the city, soon after which it joins the Pienaars River (Figure 4). The river then flows through agricultural smallholding areas (Figure 5) then through flat plains where it eventually becomes a floodplain (known as the Moretele floodplain) before entering the Borakalalo National Park (Figure 6). The river then joins the Crocodile River which eventually flows into the Limpopo River which borders the northern part of South Africa. From there the Limpopo River flows through Mozambique and into the Indian Ocean.

In order to investigate the impact of surrounding landuse on river condition and water quality, it was decided to sample the main stems of these three rivers starting at the headwaters and ending in the lower reaches in the Borakalalo National Park. The study area therefore extended through three provinces (Figure 1) from Gauteng, through Limpopo Province to the North West Province and includes approximately 230 km of river.

Figure 2: Moreleta Kloof Nature Reserve in the residential area of Pretoria

Figure 3: Faerie Glen Nature Reserve in the residential area of Pretoria

Figure 4: Downstream of Site 5 along the Pienaars River

Figure 5: Livestock farming along the Pienaars River at Site 5

Figure 6: The project team with a game guard at the Moretele River at Site 6 in Borakalalo National Park

3 Method of Sampling and analysis of the water quality and Ecological State along the Moreleta, Pienaars and Moretele Rivers.

The length of river within the study area was mapped and divided into sections based on ecoregions. These include:

- Western Bankenveld;
- Western Bankenveld (and Highveld);
- Eastern Bankenveld; and
- Bushveld.

The ecoregions that were used, were developed by the Department of Water Affairs, now known as the Department of Water and Sanitation in South Africa[7]. The ecoregions are based on general attributes that are mostly related to the rivers and streams, including:

- Main vegetation types;
- Average annual precipitation;
- Stream frequency;
- Slopes; and
- Mean annual temperature.

The landuse approximately 500m either side of the river was mapped using ArcGIS 10.1. The landuse data was derived from the South African National Biodiversity Institute 2013/2014 land cover dataset[8]. The mapping was done by Wetland Consulting Services Pty. (Ltd.). A representative site from each ecoregion and landuse type was selected. The more detailed landuse categories were grouped based on landuse type to make analysis easier.

The broad landuse types that were considered included:

- Grassland;
- Low shrubland;
- Thicket /Dense bush;
- Woodland/Open bush;
- Wetlands;
- Water;
- Cultivated fields;
- Plantations and woodlots;
- Urban (including residential, commercial and industrial);
- Village;
- Smallholdings;
- Mines and disturbed area; and
- Eroded non-vegetated areas.

The sampling sites were determined, and limited by, safe access to the river as well as the drought conditions experienced during the 2015-2016 rainfall season followed by flooding when the rains returned very late in the summer. Unfortunately a stretch of the river between Site 5 and Site 6 was not able to be sampled because at the time scheduled for the team to sample the river, the river had started flooding and could not be reached. Six sites were sampled by the four team members, during February and March 2016. A brief description of the sites and the land uses affecting the river at the sites are presented below:

The first three sites on the Moreleta River and the site on the upper reaches of the Pienaars River occur within the Western Bankenveld (Figure 7).

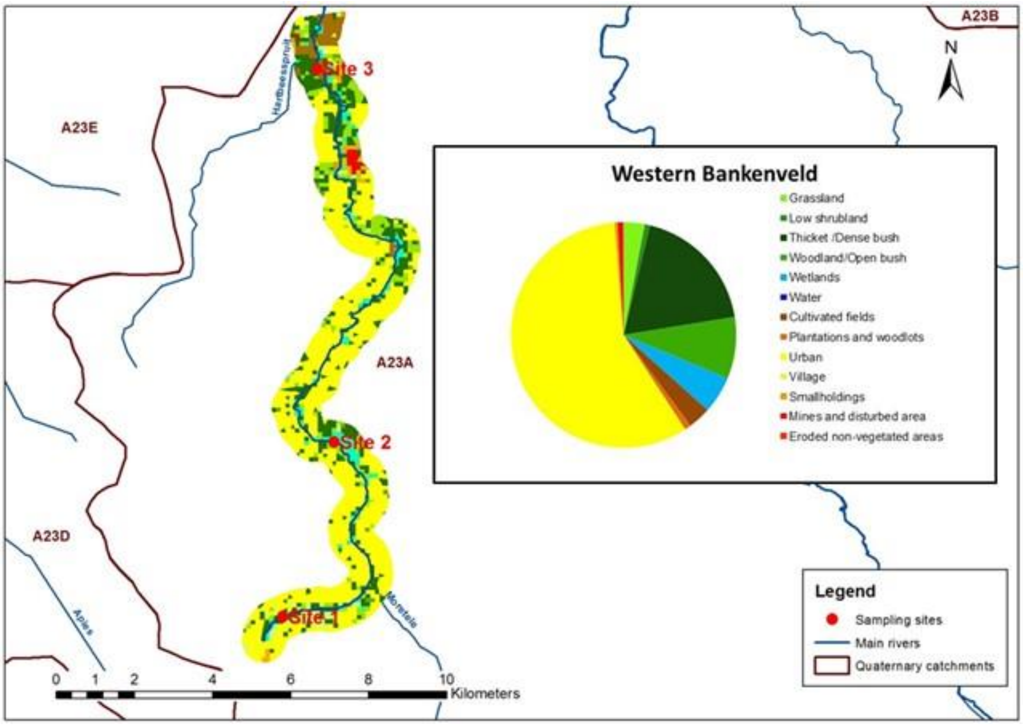

Figure 7: Location of the sampling sites and the surrounding land use of the river reach for the Moreleta River in theWestern Bankenveld Ecoregion

In this region there are lowlands, hills and low mountains. Other general characteristics of the Western Bankenveld Ecoregion are:

- Vegetation: grassland and thorn trees;
- Average annual precipitation: low – medium;
- Slopes vary from flat to fairly steep; and
- Average temperatures: vary from moderate to hot in some areas.

Site 1: Headwaters of the Moreleta River

The main landuses are *urban*, *residential.* The headwaters are within the Moreleta Kloof Nature Reserve (Figure 8) which is managed by the Department of Environmental Management of the local municipality.

Figure 8: Sampling in the Moreleta River in Moreleta Kloof Nature Reserve.

Site 2: Moreleta River

The main landuses are *urban*, *residential*. The water flows through wetlands before entering the Faerie Glen Nature Reserve (Figure 9), also managed by the municipality.

Figure 9: Sampling in the Moreleta River in the Faerie Glen Nature Reserve.

Site 3: Moreleta River north of the city

Urban and industrial. The water flows through more residential areas and then an industrial area and disturbed areas before reaching the sampling site. The site is within a camping resort and is very disturbed (Figure 10).

Figure 10: Sampling in the Moreleta River downstream of the industrial area. Note the open water and overhanging vegetation biotypes being sampled.

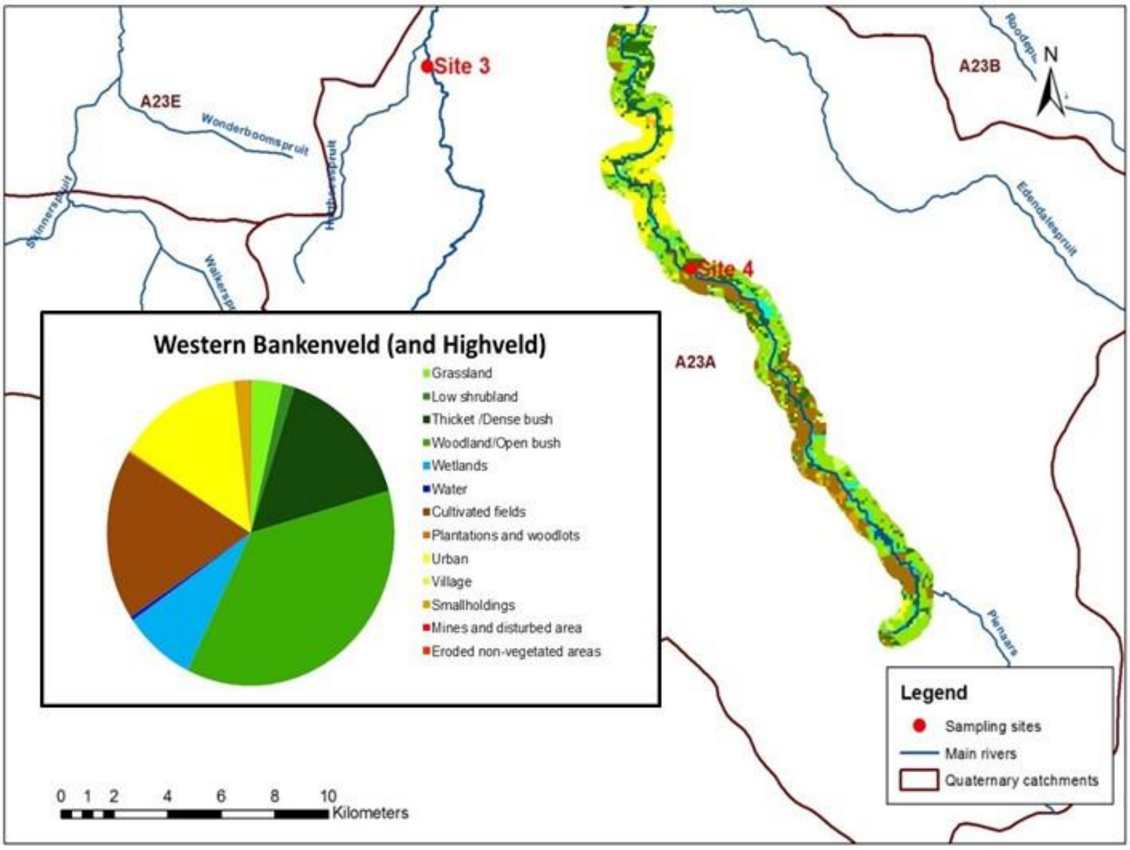

Figure 11: Location of the sampling site and the surrounding land use of the river reach for the upper Pienaars River in the Western Bankenveld (and Highveld) Ecoregions

Site 4: Upper reaches of the Pienaars River

On the outskirts of the city. The water flows through small holdings of cultivated land and natural and exotic vegetation (Figure 12).

Figure 12: Sampling in the Pienaars River

Site 5 occurs within the Eastern Bankenveld ecoregion (Figure 13). This region has hills and mountains. The general characteristics are:

- Vegetation: either grassland or mixed bushveld (grasses with thorn trees and broadleaf trees);
- Average annual precipitation: medium to relatively high;
- Slopes: gentle to flat; and
- Average temperatures: mostly moderate.

Site 5: Pienaars River

This site (Figure 14) is located downstream of where the Moreleta River and the Pienaars River join. The water flows through smallholdings (Moreleta River), natural vegetation (Pienaars River) and then enters the large, Roodeplaat Dam. After the dam, there is a sewage works adjacent to the river. The site occurs within communal land where there is agriculture and livestock farming.

Figure 14: Sampling on the Pienaars River downstream of the Roodeplaat Dam and sewage works.

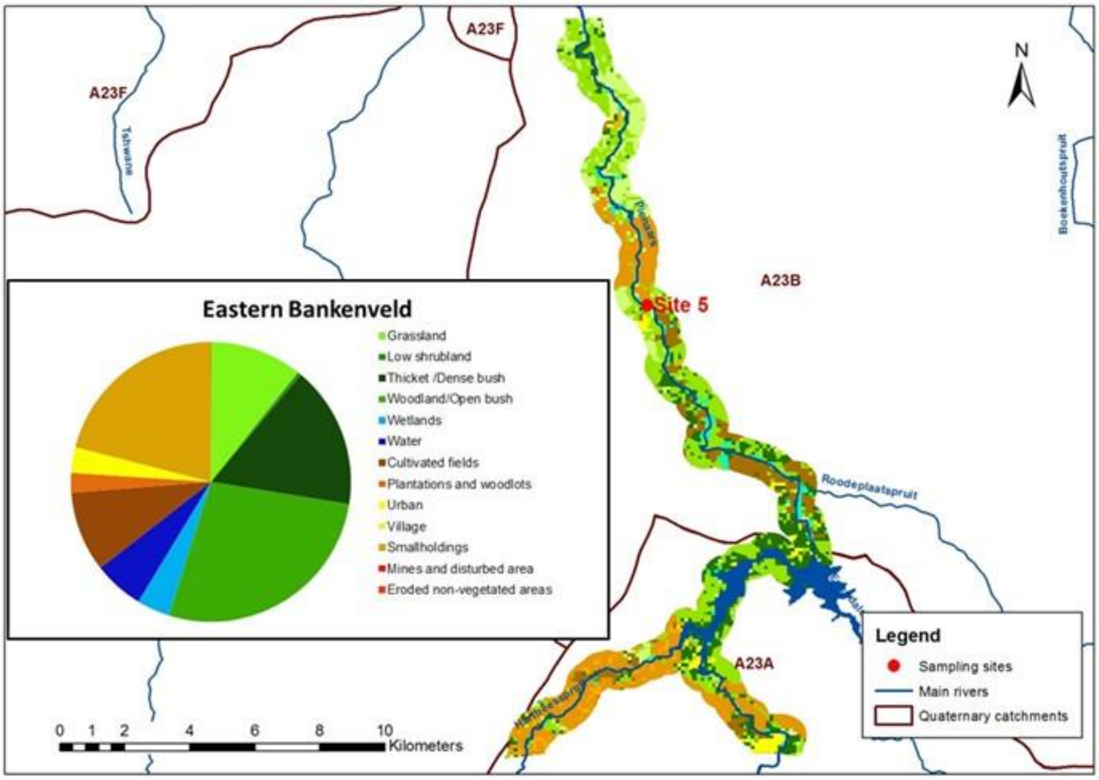

Figure 13: Location of the sampling site and the surrounding landuse of the river reach for the Moreleta and Pienaars Rivers in the Eastern Bankenveld Ecoregion

Site 6 occurs in the Bushveld Basin ecoregion (Figure 15). This region consists mainly of flat plains. Other general characteristics are

- Vegetation: grasses with mixed broadleaf trees and thorn trees;
- Average annual precipitation is medium – low;
- Slopes: gentle – flat; and
- Average temperatures: generally high.

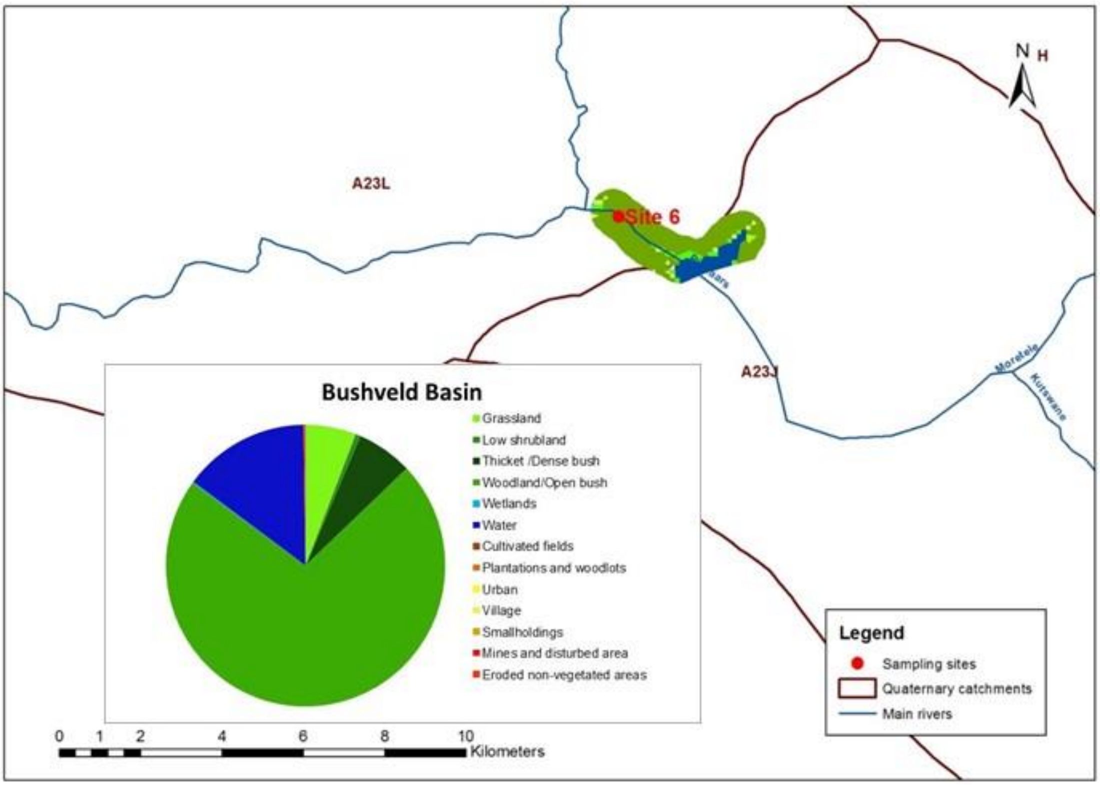

Figure 15: Location of the sampling site and the surrounding landuse of the river reach for the Moretele River in the Bushveld Basin Ecoregion.

Site 6: Moretele River

This site is located within the Borakalalo National Park (Figure 16) just after the river flows through the Klipvoor Dam. Before the dam, the water flows through agricultural land after extensive floodplain wetlands.

Figure 16: Sampling the Moretele River in the Borakalalo National Park.

At each site the following sampling was done:

3.1 MiniSASS analysis

A miniSASS analysis to determine the water quality based on macroinvertebrate presence. The scoring table is presented in Table 1. Two different categories of rivers are distinguished by the miniSASS scoring system, based on whether the substrate is rocky or sandy. All the sites that were sampled were classified as rocky, although other substrates including sand were present. Based on Table 1, the weight that each macroinvertebrate taxon carries is shown in the pie chart in Figure 17. The higher the score/weight, the more sensitive the macroinvertebrate is to poor water quality. Therefore, the higher the average score of the site, the better the water quality or ecological condition of the river water. As can be seen in Figure 17, stoneflies carry the highest weight.

Table1: MiniSASS scoring table.

Invertebrate Group	**Sensitivity Score**
Flat worms	3
Worms	2
Leeches	2
Crabs or shrimps	6
Stoneflies	17
Minnow mayflies	5
Other mayflies	11
Damselflies	4
Dragonflies	6
Bugs or beetles	5
Caddisflies	9
True flies	2
Snails	4
TOTAL SCORE	
Number of Groups	
Average score (miniSASS Score)	

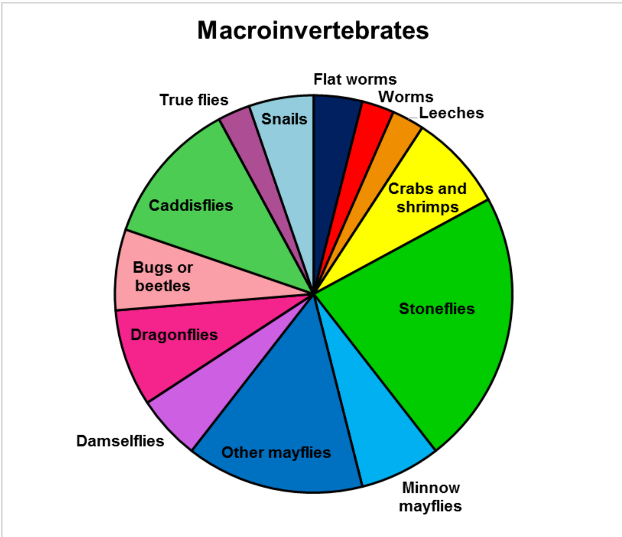

Figure 17. Macroinvertebrate taxa score

Sampling involved two team members catching invertebrates in the river using large nets. They walked against the current and disturbed the rocks and sand with their feet to flush out the invertebrates. The nets were also swept among vegetation along the edges of the river. Sampling was done for 5 minutes. During that time, the different biotypes (for example open water and overhanging vegetation) were sampled. The two other team members collected the invertebrates on and under the rocks in the river. After 5 minutes the contents of the net and the invertebrates found on the rocks were placed into trays for identification (Figures 18 and 19).

Figure 18: Macroinvertebrates in the tray for identification and recording.

Figure 19: Identifying the macroinvertebrates collected at a sampling site.

3.2 Ecological State assessment

Ecological State was scored according to a scoring system that was developed by the project team. The scoring system was based on factors that influence or would be influenced by, the ecological state of the river, other than the living instream macroinvertebrates. Factors such as instream vegetation; riparian vegetation; erosivity and observed fauna were scored – the more types of instream vegetation, the more possible habitats for organisms including fish, crabs and other aquatic animals and water birds and the higher the biodiversity. The presence of indigenous trees in the riparian zone was rated much more heavily than exotic trees, since exotic plants reduce the habitats available for indigenous fauna and out compete indigenous plants. Not only were living organisms that were observed scored, but also the evidence of these organisms, for example otter dung found at one of the sites was an important observation, since these animals are rare and their presence could not be overlooked. The factors included in this scoring system are presented in Table 2.

Table 2. The scoring system used for determining the Ecological State of the river

Ecological State factor	Feature	Score	Feature	Score	Feature	Score	Feature	Score	Feature	Score	Maximum possible score
Instream vegetation	Submerged	1	Floating	1	Reeds	1	Grasses	1	Sedges	1	5
Riparian cover	Dense	3	Sparse	1	None	-2					3
Riparian vegetation	Indigenous	3	Exotic	-2	None	0					3
Bank slope	Gentle	3	Medium	2	Steep	1					3
Bank erosivity	Low	3	Medium	2	High	-1					3
Fauna	Water birds	1	Frogs	1	Butterflies	1	Dragonflies	1	Shore-flies & bees	1	5
Evidence of other fauna	Aquatic mammals	2	Land mammal	1	Reptiles	1	Molluscs	1			5
Litter	Large amount	-3	Small amount	-1	none	0					0
Turbidity/ water clarity	Clear	3	Murky	-1							3
Maximum possible score											**30**

The overall ecological categories based on miniSASS and Ecological State are presented in Table 3.

Table 3. Category scores used for determining the Ecological category (condition)

mini SASS CategoryScore	Ecological State Score	Ecological category (Condition)
> 7.2	20 - 30	Natural
6.2 - 7.2	15 - 20	Good
5.7 - 6.1	11 - 15	Fair
5.3 - 5.6	6 - 10	Poor
< 5.3	< 5	Very Poor

3.3 Water sampling

A water sample was taken at each site for laboratory analyses for various parameters, Total Dissolved Solids, pH, nitrate and orthophosohate levels as well as various other elements including iron, magnesium and zinc. These analyses were done, and sponsored by, WaterLab Pty. (Ltd.).

Data analysis

The Ecological Category based on macroinvertebrate presence was calculated using Table 1 and shown for each sampling site. The Ecological State of the river was calculated at each sampling site using Table 2 and compared to the Ecological Category derived from the macroinvertebrate assessment. These were in turn compared to the water quality determined from the laboratory water quality analyses at each sampling site. The results were interpreted and used to determine the influence of the dominant surrounding and upstream land use (derived from the buffer zone analyses in Figures 7, 11, 13 and 15) at each river sampling site.

4 Results

4.1 MiniSASS and Ecological State

MiniSASS and Ecological State results for sites 1-6 are shown on the Ecoregion maps below (Figures 20-22).

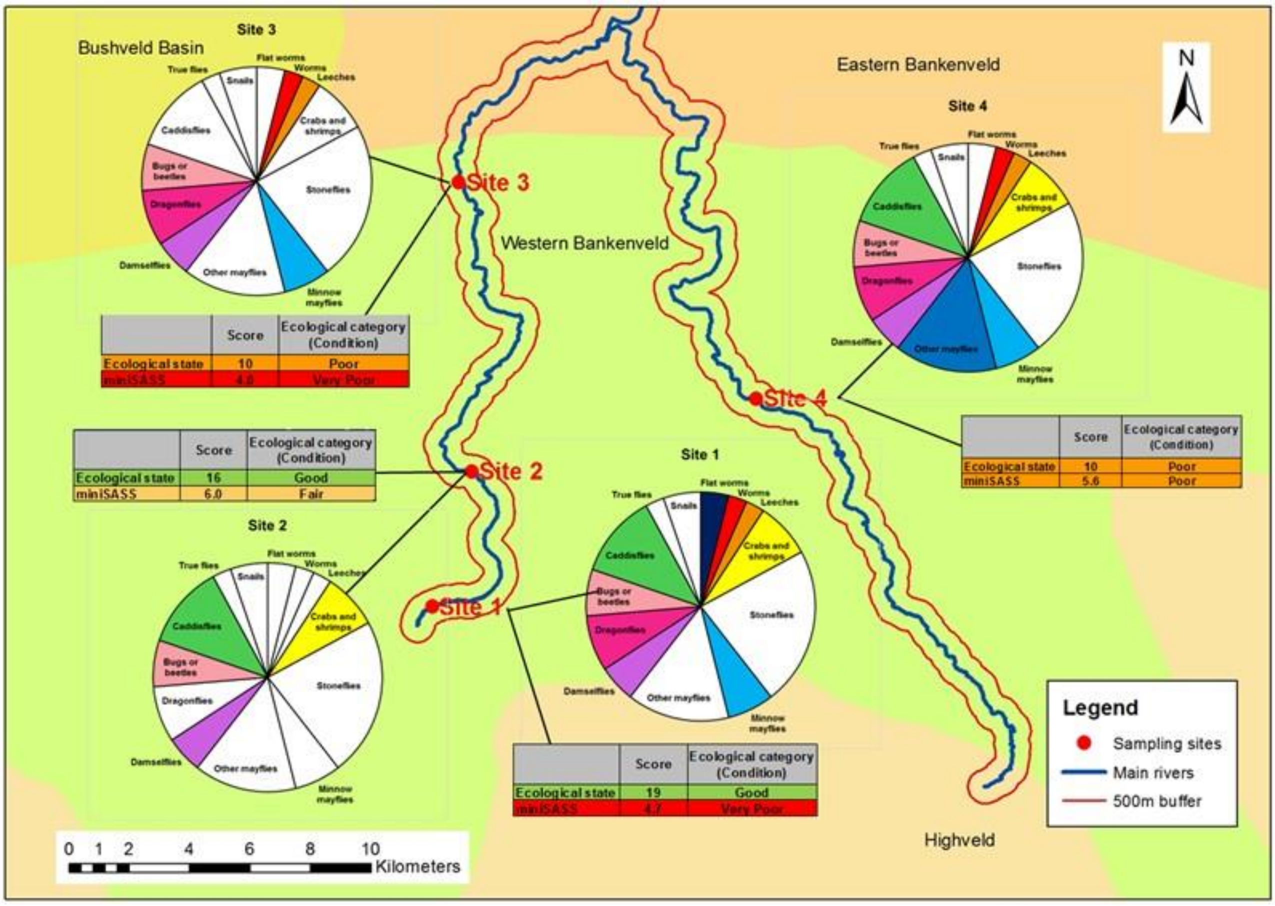

Figure 20: Results of the miniSASS and Ecological State of Sites 1-3 on the Moreleta River and Site 4 on the Pienaars River.

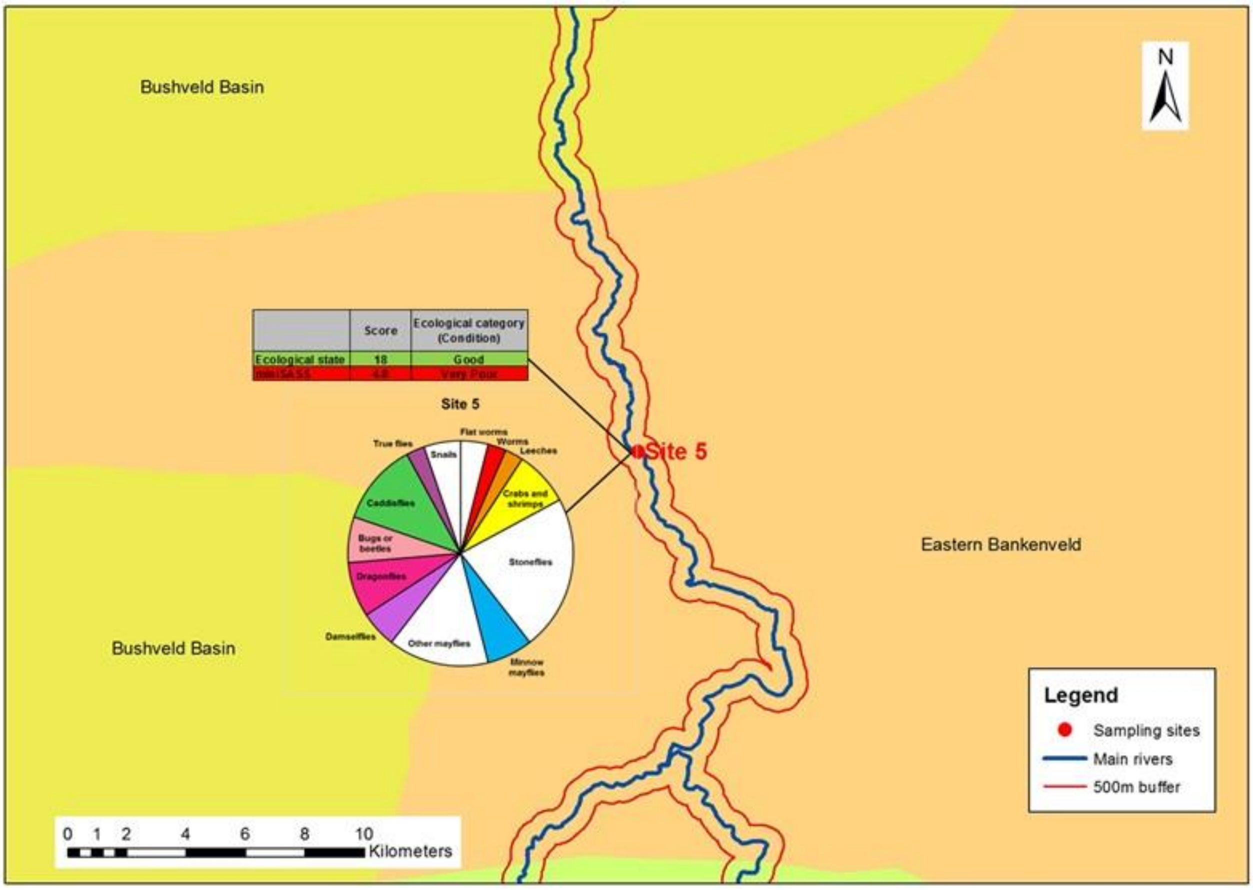

Figure 21: Results of the miniSASS and Ecological State of Site 5 on the Pienaars River

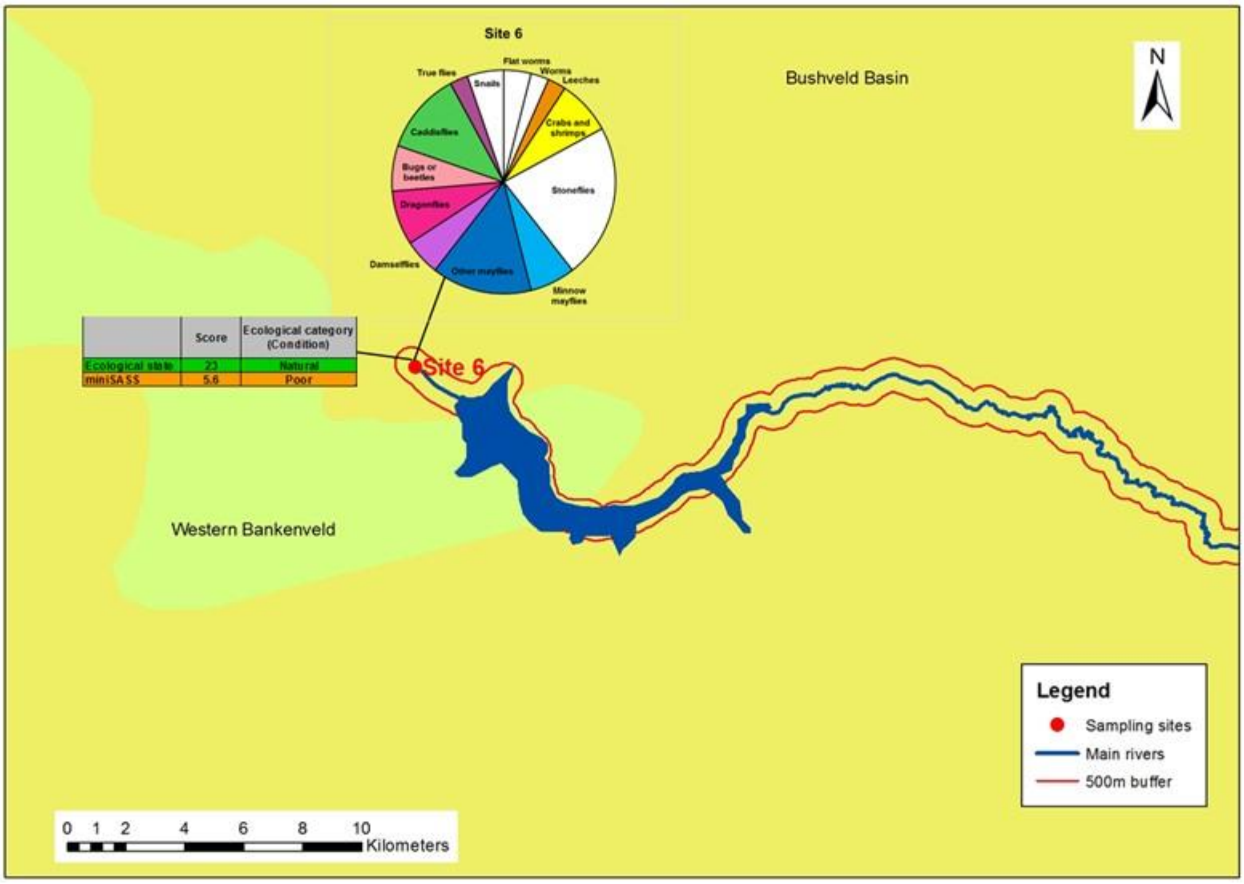

Figure 22: Results of the miniSASS and Ecological State of Site 6 on the Moretele River in Borakalo National Park

4.2 General water quality results

General water quality results (from the laboratory analyses) are presented in Figures 23-28. The Total Dissolved Solids (TDS) increased along the length of the river (Figure 23).

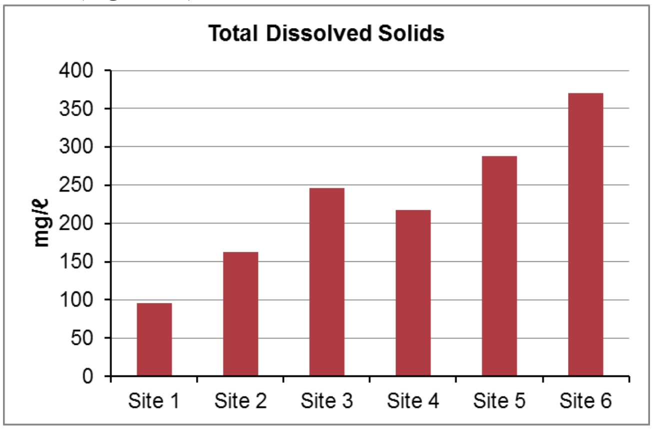

Figure 23: Total Dissolved Solids in water sampled at each site.

All iron levels were below 0.09mg/l and were highest at Site 4, followed by Site 1 and Site 2. They were negligible at all other sites (Figure 24).

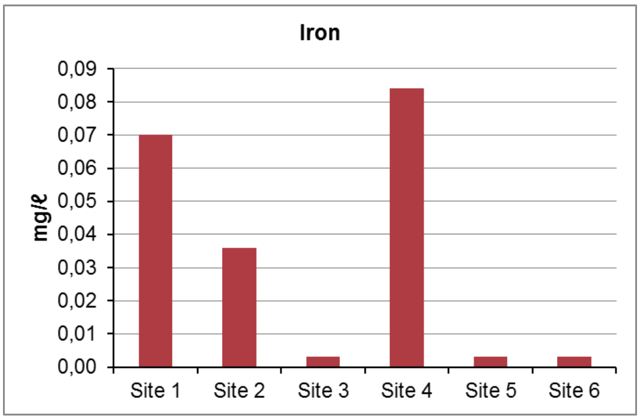

Figure 24. Iron concentration in the water sampled at each site.

Magnesium (Figure 25) and zinc (Figure 26) levels were highest at Site 4 relative to all the other sites.

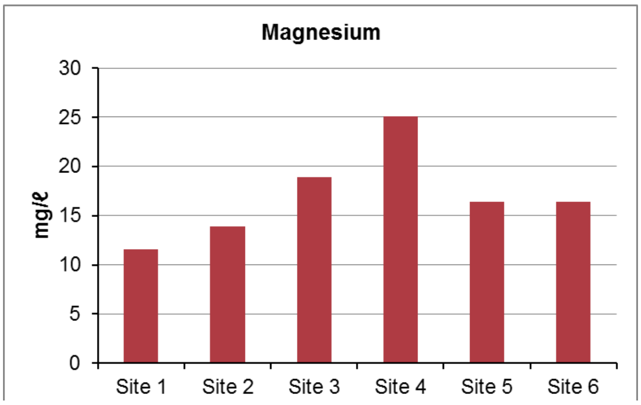

Figure 25: Magnesium concentration in the water sampled at each site.

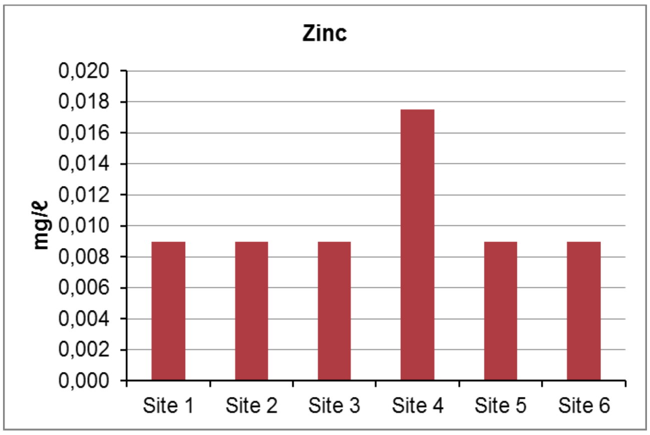

Figure 26: Zinc concentration in the water sampled at each site.

Nitrate levels were the highest at Site 5 after the sewage works and then at Site 3 immediately after the urban and industrial area (Figure 27).

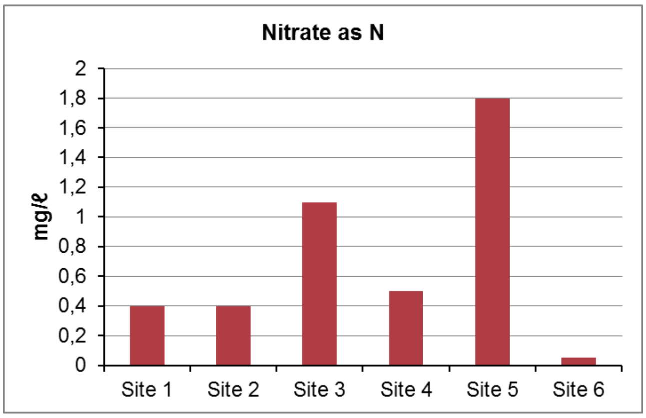

Figure 27. Nitrate concentration in the water sampled at each site.

Orthophosphate levels were negligible at all the sites except the last two on the Pieneers (Site 5) and Moretele (Site 6) Rivers after the agricultural lands and sewage works (Figure 28).

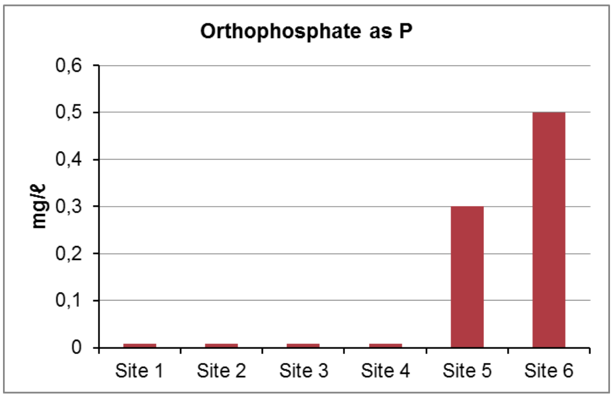

Figure 28. Orthophosphate content in the water sampled at each site.

The pH values ranged from 7.4 to 7.7 at Sites 1, 2, 3 and 5, while at Site 4 the pH was 8.3 and at Site 6 it was 9.3.

5 Discussion

The results show that the surrounding land use does affect water quality. At Sites 1 and 2, the headwater reaches of the Moreleta River, the Ecological State is *Good*. This is probably because the sites are within conservation areas. However, the water quality, based on macroinvertebrate presence, was *Very Poor* at Site 1 and improved to *Fair* at Site 2. At Site 1, the macroinvertebrate taxa present could be affected by stormwater from surrounding houses and roads which might include oils from motor cars, soaps and even pool chemicals from backwashing of swimming pools. There are also higher iron levels in the water at Site 1 than at Site 2, and the source of this could be the minerals in the rocks of the catchment areas of this site. There is less iron in the water at Site 2 and a better miniSASS score, showing that the water quality was better, probably because the water flows through wetlands before reaching Faerie Glen Nature Reserve. This happens despite it still being in an urban area. This highlights the importance of maintaining natural corridors even in urban environments, especially where there are wetlands along the rivers.

At Site 3 the Ecological State is also *Poor* and this is because the bank erosivity was high and there was a large amount of litter and other human impacts at the site. The water quality based on macroinvertebrate presence is *Very Poor*. This is attributed to the water flowing through more urban areas including an industrial site before reaching Site 3. The nitrate levels were high at this site compared to other sites, possibly due to the influence from the industrial area where pollutants may be entering the river.

At the headwater reach of the Pienaars River, Site 4, the Ecological State of the river is *Poor* because it is very disturbed with many exotic plant species in the riparian area. The water quality, based on macroinvertebrate presence, is *Poor*. Water quality analysis showed high iron levels compared to all other the sites, except Site 1. The iron, magnesium and zinc levels are also higher at this site than all the other sites. This could possibly be affecting the macroinvertebrates in the river. Another reason could be that this site was sampled just after the rains and the river had just started flowing not giving the macroinvertebrate community time to recover, following the drought. At the time of sampling the water was murky and this would affect the macroinvertebrates. This is supported by the general water quality analysis which indicated that, apart from the slightly higher iron, magnesium and zinc levels, the river water was relatively clean at the time of sampling.

The main difference between Site 4 and Sites 1 and 2 is less urban influence, with Site 4 being in an area of more natural vegetation but also more agriculture from smallholdings. Despite the higher percentage of agriculture along the river, nitrates and orthophosphates were similar to Sites 1 and 2 and low relative to Sites 3 and 5. This suggests that agriculture may not be having a big influence on the river at Site 4.

After the two rivers converge the water flows into a dam and then past sewage works before reaching Site 5.

At Site 5 the Ecological State is *Good*. The site is away from urban areas and is surrounded mostly by natural vegetation and the riparian area is mostly natural. The main landuse upstream of this site is agriculture. Even although the site is used by livestock for drinking and grazing (see Figure 5), the river banks were not eroded at the site and this contributes to the *Good* Ecological State score. The water quality based on macroinvertebrate presence was *Very Poor*. This could be because of the poorer general water quality which included high levels of nitrate and orthophosphates compared to all the other sites upstream. The increase of these two levels could be due to the increase in smallholdings and agriculture along the river together with the influence of water that is released from the sewage works upstream. Both agriculture and sewage water would add to nitrate and orthophosphate levels.

The Ecological State is *Natural* at Site 6. The site is in a game reserve and surrounded by natural vegetation and the riparian area is natural. The main landuse around this site is wildlife grazing. There was some evidence of paths and trampling in the riparian area mainly due to buffalo crossing the river on a regular basis, but this was considered natural. Many water birds were seen to be using this site. Large numbers of dragonflies, bees and other flying insects were recorded in the aquatic vegetation on the edge of the river.

The water quality based on macroinvertebrate presence was *Poor*. This could be because of the poorer general water quality which included high levels of orthophosphates compared to all the other sites upstream. Again, the increase in orthophosphates could be due to the increase in agriculture along the river together with the influence of effluent released from the sewage works upstream. The nitrate levels were lower at Site 6 than upstream at Site 5. This is interesting because it is expected that the nitrates would increase with the orthophosphates. The lower nitrate levels could be due to the abundant aquatic plants in the dam, immediately upstream of Site 6, taking up the nitrates and lowering the levels downstream.

Stoneflies and caddisflies are excellent bio-indicators of water quality. Stoneflies need pristine water and caddisflies need clean water in which to live[6]. It is interesting to note that no stoneflies were found at any of the sites. This immediately suggests that none of the water is completely clean. However, caddisflies were found at all the sites, except Site 3. This suggests that the water quality of all the sites is not too poor, except at Site 3 which is located just after the urban and industrial area, with no dilution effect from the Pienaars River yet, as at Site 5.

The TDS increased along the length of the river. This trend in the levels is expected, as the water collects the solids as it flows along over different geology and as run-off flows into the river. Apart from the natural source of dissolved solids, this river collects water and its dissolved solids from all the landuses adjacent to it, including agricultural lands, industry and treated sewage water.

Surface water pH values typically range from 4-11[9]. The pH values of the water at Sites 1-5 are relatively neutral and are within the typical range for fresh waters[9]. The higher pH value at Site 6 may be as a result of high rates of photosynthesis in the large dam immediately upstream of the site. High rates of carbon dioxide uptake during photosynthesis increase the pH values[9]. This seems to support the sudden large decrease in the concentration of nitrate at Site 6 which may be as a result of the uptake of nitrate in the upstream dam, possibly by the plants and as a result of eutrophication in the dam.

6 Conclusion

Ecological State and Category as well as river water quality as determined during this study appear to be affected by the type of landuse adjacent to the river. However certain sectors within a landuse category may be playing a larger role in determining the water quality than others. For example, sewage works and the release of treated sewage water from the urban areas, as well as possible pollution from industrial areas linked to the urban areas, may be more important contributors to water quality changes than other factors within the urban environment. This is supported by the finding that general water quality was poorer as indicted by the higher nitrate and orthophosphate levels downstream of industrial areas sewage works respectively. Agriculture and particularly commercial agriculture may also be contributing to the poorer water quality as indicted by water quality and ecological analyses undertaken. In this particular river system, it is likely the combination of urban and agricultural landuses upstream that contributes to the overall deterioration in water quality downstream. a relat

Another conclusion drawn from this study is that, Ecological Category as determined by macroinvertebrate presence in the river system, was not closely linked to the Ecological State measured. At each site sampled, the Ecological State scored higher than the Ecological Category based on macroinvertebrates. The poorer Ecological Categories based on macroinvertebrates recorded may be a result of the extreme drought conditions that South Africa had been experiencing at the time of sampling. This may have impacted on the abundance of the invertebrates and hence resulted in fewer key indicator taxa being caught during sampling. It follows that the better the natural ecological state of the river, the more habitat that is available for invertebrates to take refuge in during the drought and the more quickly the macroinvertebrate diversity will return after the rains return. It would be beneficial to conduct the same sampling at the same sites during a high rainfall summer season to compare the results and determine whether the diversity of macroinvertebrates is higher with more water availability and when the rivers are more frequently flushed or whether the increased run-off from the adjacent land would increase toxin levels and therefore decrease the water quality.

This study also showed that the Ecological State is always better within conservation areas. Since areas with a *Natural* or *Good* Ecological State have more habitats/more healthy habitats, for fauna, they therefore have a higher biodiversity. This indicates the importance of conserving areas of natural ecology along rivers. Maintaining natural or undeveloped ecological corridors along a river will help to protect the river to some extent from changes in the landuse along the river and in the catchment. While this is not an answer to maintaining good water quality in the river, protecting natural buffers (corridors) nevertheless will help to improve water quality and provide additional habitat for river-related fauna. Maintaining the condition of the ecological buffer will also depend on other measures that are implemented in the catchment such as stormwater management measures. Such management measures will not only help to improve water quality in the river but also help to protect the system from changes in flow which may arise from changes in landuse along the river and in its catchment. What is clear from this study is that the ecological condition of a river is dependent on how the land use changes along the river and how factors that may influence water quality and flow in the river relating to the landuse, are managed. In this case, better management of agricultural and sewage inflows into the river would likely make a large contribution to improving water quality.

In addition to the above, it is evident that general water quality along a river may be improved by protecting wetlands along the river. Maintaining wetland habitat within ecological corridors along the river should also form part of a river management strategy.

6.1 Recommendations

Along all rivers that flow through urban, industrial and agricultural areas, there should be natural buffer zones along the river to ensure the conservation of the riparian habitat and wetlands, thereby helping to protect the Ecological State and the biodiversity of the river system, and improve water quality.

The water quality of rivers should be constantly monitored so that any pollution of the river can be quickly noted, reported and rectified. This monitoring would take many people and cost a lot of money. Therefore, as was initially intended when the miniSASS was developed, lay people should become involved in the monitoring. The public is not generally aware of this initiative and an extensive awareness campaign should be undertaken to make people aware of the importance of river monitoring and conservation and how they can become involved and contribute to the management and conservation of their local rivers. Government agencies that are responsible for managing the rivers and associated habitats should encourage schools, environmental groups and other groups of lay people, through incentive schemes and competitions, to do the monitoring, using the miniSASS method together with the Ecological State scoring system developed by this project team. Both scoring systems are easy for non-professionals to use effectively. However, in order to ensure uniformity of their applications, short training courses could be run for interested groups, where concepts such as erosivity and turbidity are explained. This would also pave the way for improvement in the scoring system and allow for the comparison of results over time. The results of this monitoring could be used by communities to police the users of the rivers and ensure the conservation and continued health of their local rivers systems. This is particularly important in regions like southern Africa where water, and particularly clean water, is such a scarce resource.

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