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The Vulnerability of the Shingwedzi River, a Non-Perennial River in a Water Stressed Rural Area of the Limpopo Province, South Africa

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1. Introduction

1.1 Background

The Shingwedzi River drains one of the drier sub-catchments of the South African component of the Limpopo River Catchment which is situated in the north-eastern part of the Limpopo Province of South African (Figure 1). This non-perennial river is a tributary of the Olifants River, or *Rio des Elephantes* as it is known in Mozambique, into which it drains which in turn joins up with the Limpopo River.

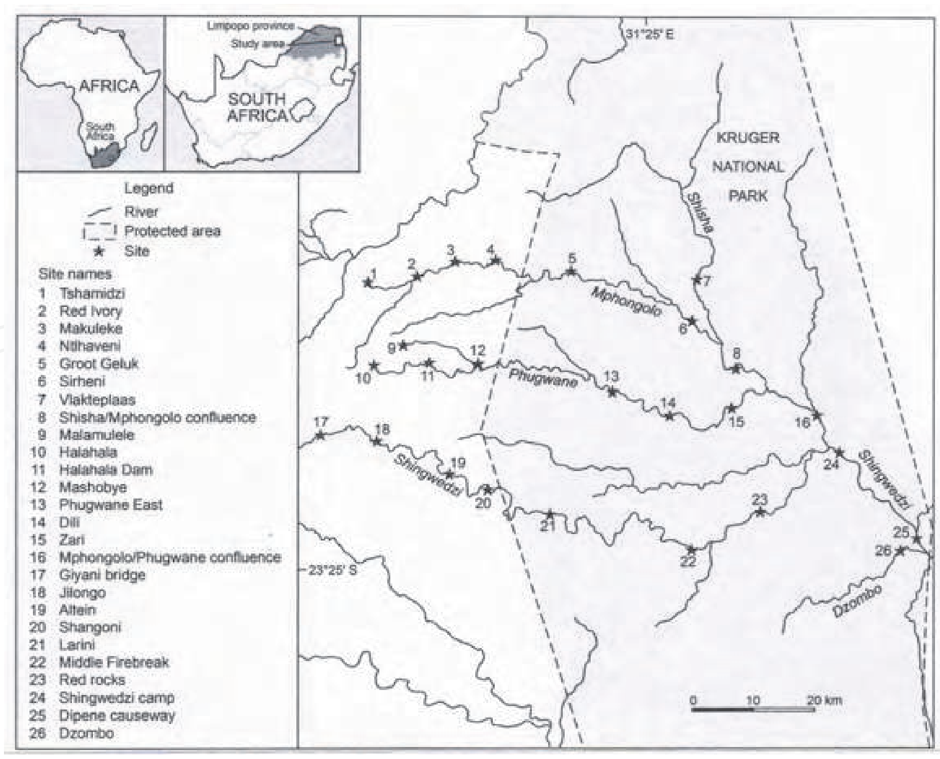

Fig. 1. Map of the study area showing rivers, sampling sites and the boundary of the Kruger National Park, South Africa (Adapted from Fouché and Vlok, 2010).

The Integrated Catchment Management (ICM) approach currently applied in South Africa has resulted in 19 Water Management Areas (WMAs) demarkated within the country's boundaries. The Luvuvhu-Letaba Water Management Area (WMA 02), of which the Shingwedzi River forms part, lies entirely within the Limpopo Province and borders on Zimbabwe and Mozambique (DWAF, 2004a). A unique feature of this WMA is the world renowned nature conservation area, the Kruger National Park (KNP), along its eastern boundary which occupies more than a third of the land area of the WMA. The Shingwedzi River and the two major rivers of the WMA, the Luvuvhu and Groot Letaba Rivers, flow through the KNP into Mozambique. The Luvuvhu River is a direct tributary of the Limpopo River but the Groot Letaba River first flows into the Olifants River before joining the Limpopo River.

The Shingwedzi River, which originates near the town of Malamulele (S 23° 00, 680 E 30° 42,416), has a number of tributaries of which the Mphongolo, Phugwane, Shisha and Dzombo (Figure 1) are the most important. The first two originate outside the KNP whilst the entire catchments of the latter two are within the boundaries of the KNP.

The Shingwedzi River Catchment is relatively small, covering an area of *ca* 5300 km^2, and the climate is regarded as hot and dry. In addition to low rainfall, which ranges between 400 and 650 mm a^{-1}, it also has a high mean annual evaporation rate of *ca* 1700 mm a^{-1}, resulting in a low annual run-off (Table 1) which, typical to South Africa, displays a historically high degree of variability as is illustrated by the data records of the Shisha River, one of the major Shingwedzi River tributaries (Figure 2). The catchment forms part of the summer rainfall region of South Africa and it typified by dry winters. Average temperatures range between 2,4°C in winter to 40,8°C in summer and the area is mostly frost free.

Sub-catchment	Natural MAR	Ecological Reserve
Luvuvhu	520	105
Shingwedzi	90	14
Groot Letaba	382	72
Klein Letaba	151	20
Total	**1053**	**241**

Table 1. The mean annual runoff (MAR) and recommended Ecological Reserve (million m^3 a^{-1}) of the sub-catchments in the Luvuvhu-Letaba Water Management Area in South Africa (Adapted from DWAF, 2004a, 2004b).

The topography of sub-catchment is characterised by plains with a low to moderate relief in the east, giving rise to open hills, while low mountains with high relief are present towards the west (Midgley *et al.,* 1994). Based on the geology, three regions can be distinguished. The first region consists of the upper reach of the Shingwedzi River and actually includes only a small section of river. The second region lies mostly to the west of the KNP boundary and the third region contains the lower reaches of the Shingwedzi River and is predominantly inside the KNP. The first region consists mainly of basalts of the Letaba Formation (Lebombo Group, Karoo Supergroup). The second region consists of potassium-poor quartz-feldspar of the Goudplaats Gneiss Basement, with some Letaba basalts (Karoo

Supergroup). The third region is made up mainly of Goudplaats Gneiss and Makhuttswi Gneiss with a small contribution from ultramafic metavolcanics and metasediments of the Giyani Greenstone Belt (Swazian Erathem). The erodibilty of soils throughout the whole sub-catchment is high and according to Midgley *et al.* (1994) soil depths are moderate to deep in the east, where acid and intermediate intrusives occur and sandy loam soils dominate whereas it is moderate to deep in the west, with its basic/mafic lavas, where the soils are clayey. In the north and south of the sub-catchment small patches of intercalated assemblages of compact sedimentary and extrusive rocks appear.

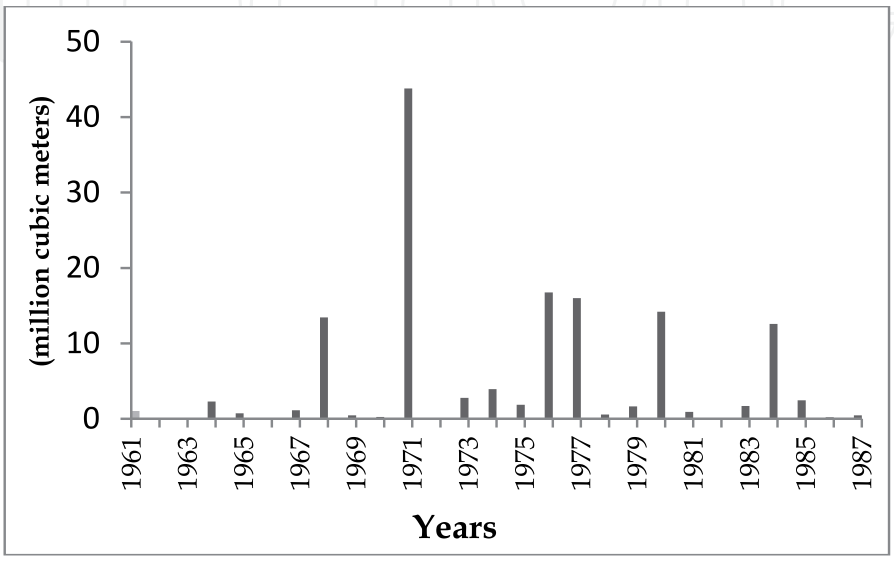

Fig. 2. The Mean Annual Runoff recorded between 1961 and 1987 on the Shisha River, a tributary of the Shingwedzi River, South Africa (Midgley *et al.*, 1994).

The vegetation in the sub-catchment is diverse and Mucina & Rutherford (2006) recognise the distinct vegetation units listed in Table 2 in the sub-catchment. Based on the vegetation and climate the whole sub-catchment is regarded to fall within one region which can generally be referred to as Lowveld or which is referred to by Kleynhans *et al.,* (2007b) as the Bushveld Basin Ecoregion.

Vegetation Units	Dominant woody vegetation
Cathedral Mopane Bushveld	*Colophospermum mopane*
Mopane Basalt Shrubland	*Combretum* sp / *Colophospermum mopane*
Tsende Mopaneveld	*Colophospermum mopane / Acacia nigrescens/Combretum sp*
Lowveld Rugged Mopaneveld	*Colophospermum mopane*
Mopane Gabbro Shrubland	*Colophospermum mopane*
Makuleke Sandy Bushveld	*Pterocarpus rotundifolius / Combretum collinum*
Nwambyia-Pumbe Sandy Bushveld	*Combretum apiculatum*
Granite Lowveld	Mixed *Combretum / Terminalia sericea*

Table 2. The vegetation units recognised in the Shingwedzi catchment (Mucina & Rutherford, 2006).

With regard to development the sub-catchment differs from the rest of the WMA where economic activity is characterized by irrigation, afforestation, tourism and commercial and informal farming. Most of the areas outside the KNP are dominated by rural settlements, informal farming and very little industrial development. Midgley *et al*. (1984) reported that the land listed for formal irrigation covers an estimated 2,9 km^2. Small scale mining operations, of which the majority is defunct, are dotted through the landscape. Under natural conditions the quality of the surface water is good but water of high mineral content occurs in some of the drier parts (DWAF 2004b). Bacteriological pollution of the surface water is a result of run-off from cattle pens and rural villages with insufficient sanitation infrastructure and services. The water resources within the WMA are nearly fully utilized resulting in limited options for further resource development. Reconciliation of water availability and requirements, based on data of the year 2005 (Table 3) show that requirements, with the exception of the Luvuvhu and Shingwedzi River sub-catchments, exceeded the available resources (DWAF 2004a, 2004b). The zero balance in the Shingwedzi sub-catchment is reason for concern because not only is water use regarded as "neglible" (DWAF 2004b) but the available amount of water is based primarily on groundwater resources. The concern is strengthened by the statement that the "over-exploitation of groundwater in the sub-catchment is not sustainable whilst there is insufficient knowledge on the long-term sustainable yield from groundwater and the interdependencies with surface water" (DWAF 2004b). It should further be borne in mind that the reconcilliation, and in particular the requirements, was based on an estimated population of 135 000 people (DWAF 2004a) in the sub-catchment at that time. If the trend in population growth in this region is similar to the rest of South Africa it would be correct to surmise that the Shingwedzi River and its tributaries could come under severe pressure as the need for more water will increase in the near future. Based on the above it is important to take cognisance of the fact that if the increased water requirements for human needs are met using surface water it could become difficult to meet the ecological reserve (Table 1). These deficits could lead to a failure in supplying an adequate amount of water of appropriate quality to address the ecological requirements of the KNP and the honouring of international obligations to Mozambique. Both of these aspects are key considerations in the South African National Water Resources Strategy (NWRS) (DWAF 2004b).

Sub-catchment	**Local yield**	**Local requirement**	**Balance**
Luvuvhu	147	98	**49**
Shingwedzi	3	3	**0**
Groot Letaba	159	196	**(37)**
Klein Letaba	32	37	**(5)**

Table 3. Reconciliation of the water availability and requirements for the year 2005 (million m^3 a^{-1}) of selected sub-catchments in the Luvuvhu-Letaba Water Management Area, South Africa. Figures in brackets are negative (Adapted from DWAF 2004b).

Although it is often stated that no major dams occur in the Shingwedzi River system (DWAF, 2004b; Midgley *et al*, 1994) it should be noted that the Makuleke Dam (S 22° 52,046 E 30° 54,377) has been constructed in the Mphongolo River, while there are dams in the upper catchment, near the town of Malamulele, and in main the stem of Shingwedzi River.

In the latter case there is the Kanniedood Dam near the Shingwedzi Rest Camp and the Sirheni Dam near a rest camp with the same name, in the KNP. Although no or little water extraction is done at these impoundments, the impact that they have on the flow regime and connectivity of the system can not be ignored.

As far as the water quality perspectives are concerned it is stated (DWAF 2004b) that phosphate, which result from diffuse sources such as the run-off from agriculture and informal domestic wastewater, is regarded as the only parameter that is adversely affected by activities in the sub-catchment. In addition point sources of pollution, that include mining effluents and treated sewage effluents, could have negative impacts on other water quality parameters.

According to Kleynhans and Louw (2007) EcoClassification is a term used in South Africa for "the ecological classification process for river ecosystems and refers to the determination and categorisation of the Present Ecological State (PES) as well as the health or integrity of various biophysical attributes of rivers relative to the natural or close to the natural reference condition". The purpose of the EcoClassification process is to gain insight and understanding into the causes and sources of the deviation of the PES of biophysical attributes from the reference condition. In South Africa the EcoClassification process forms an integral part of a number of methods such as Ecological Reserve and Environmental Flow Requirement determinations. The methodology is also applied in the national River Health Programme (RHP) where it is used to establish biological response as an indicator of ecosystem health and only assesses cause and effect relationships in general terms.

A number of indices that form part of a suite of tools, originating to a large extent from those developed for use in the RHP, has been adapted for use in the EcoClassification process where it is used to determine the Ecological Category (EC) of a river or reach of a river. The indices, each *inter alia* characterised by a strict protocol, were developed following a Multi Criteria Decision Making Approach (MCDA) (Kleynhans & Louw, 2007) and include the driver asssessment indices (the Hydrological Driver Asessment Index, the Geomorphology Driver Assessment Index and the Physico-chemical Driver Assessment Index) and the biotic response indices (the Fish Response Assessment Index, the Macro Invertebrate Response Assessment Index and the Riparian Vegetation Response Assessment Index).

Kleynhans (2007) refers to the Fish Response Assessment Index (FRAI) as "an assessment index based on the environmental intolerances and preferences of the reference fish assemblage and the response of the constituent species of the assemblage to particular groups of environmental determinants or drivers". The Vegetation Response Assessment Index (VEGRAI) is "designed for the qualitative assessment of the response of riparian vegetation to impacts in such a way that that qualitative ratings translate into quantitative and defensible results "(Kleynhans *et al.*, 2007b). Thirion (2007) describes the Macro Invertebrate Response Assessment Index (MIRAI) as an index that "is used to determine the invertebrate EC by integrating the ecological requirements of the invertebrate taxa in a community or assemblage and their response to modified habitat conditions". A second macro-invertebrate based index, the South African Scoring System (SASS) which in actual fact is the forerunner of MIRAI, was developed as an indicator of water quality. According to Thirion (2007) it has become clear that SASS also gives a general indication of the present state of the invertebrate community but it does not have a particularly strong cause-effect basis.

Physico-chemical monitoring has traditionally been the backbone of water quality monitoring in many countries including South Africa (DWAF, 1986). These results are however representative of conditions at the instant of sampling and do not provide information about the effects of these changes on biological communities and in particular do not provide an insight into historic conditions. The use of diatoms to assess conditions in the aquatic environment has a long history and diatom indices have been developed for various impacts such as salinity, pH, oxygen requirement, nitrogen metabolism, the trophic state which includes inorganic nitrogen and phosphorus concentrations, saprobity or organic enrichment reflected by biological oxygen demand and desiccation (Fouché & Vlok 2009). These indices are based on the fact that diatoms are sensitive to, and appear to have a consistent tolerance to a wide range of environmental parameters. Diatoms have extensively been studied in South African river systems (Schoeman, 1982; Passy *et al.*, 1997; Hardy *et al.*, 2004; Taylor *et al., 2007a*) and efforts have been made to relate diatom to water quality (Archibald, 1972). Benthic diatom assemblages, being sessile, are exposed to water quality changes at a site over a period of time (Breen, 1998). Initially the approach used for prediction of ecological conditions using diatoms was focused on the abundance of ecologically known taxa but this was refined to indicator-based environmental predictions (Watanabe *et al.*, 1988) where diatom taxa that are tolerant to pollution will always be present in high numbers (Birks *et al.*, 1990). As a result an "indicator value" is always included in an index in order to provide greater weight to those taxa which are good indicators of particular environment conditions.

1.2 Rationale for the study

Although it feeds into the KNP, which is often regarded as the flagship conservation area of South Africa, the Shingwedzi sub-catchment has been neglegted probably due to the fact that "for practical purposes no sustainable yield is derived from surface flow and water use is neglible"(DWAF 2004b). Even though the ecosystem health of a substantive number in South African Rivers have been determined in recent years, the Shingwedzi River has not been part of the effort of the national River Health Programme (RHP) (Strydom *et al.*, 2006). To an extent this is contradictory to the importance of a river that lies within a water-scarce area. In addition a survey of the literature (Gaigher, 1969; Pienaar, 1978; Russell, 1997; Olivier, 2003) showed that a paucity of data existed with regard to fish and this lack of knowledge was in particular severe with regard to areas outside the borders of the KNP.

As part of the project it was hypothesised that the ecological status of the Shingwedzi River is under pressure due to impacts on the drivers and that this is reflected by negative changes in the biological responses which include the fish and riparian vegetation.

2. Materials and methods

2.1 Site selection and surveys

Prospective sites, that were regarded as representative of the different river reaches, were selected using 1:50 000 maps of the area during a desktop study. This was followed by an aerial survey designed not only to investigate the suitability of the sites for monitoring but to detect and locate point and non-point sources of pollution and other anthropogenic impacts on the river. The selection of the sites were then adjusted to include the downstream effects of potential pollution sources such as de-commisioned mines, villages, sewage treatment works and areas of large-scale farming activities. Following the aerial survey all the identified sites were "ground-truthed"during a pilot survey after which the best suited sites were selected for the survey. Each site was surveyed twice, with one survey during summer and the other during winter which also in effect represents the high flow and low flow seasons respectively.

At each site the protocol of the Geomorphological Index (Rowntree *et al.,* 2000) was followed and aspects such as the bank stability, the habitat diversity, erosion and the habitat cover assessed. The gradient of a river segment between consecutive sites was calculated using the recorded altitude of the sites and the distance between the sites. These gradients were used to deduct the zone class and longitudinal zones for each segment and then a "long profile" (Rowntree & Wadeson, 1999) for the Mphongolo, Phugwane and Shingwedzi rivers were drawn.

2.2 Impacts

During the aerial surveys impacts were identified and their location recorded using a handheld GPS. Limited video footage and photographs were captured to illustrate sources of pollution, habitat modifications and other land uses that had a negative impact on the environment. These impacts were then verified and rated during the surveys. The impacts at the survey sites were also noted and recorded. While traveling between sites during the surveys additional impacts were noted and recorded.

2.3 *In situ* determinations and water samples

At each site the pH, dissolved oxygen, electrical conductivity, total dissolved substances and temperature was determined *in situ* with handheld Eutech meters. Sub-surface water samples were collected in acid treated bottles, placed on ice and transported to the laboratory for the determination of nutrient content and total suspended solids.

2.4 Biological indices

The status of the riparian vegetation was determined by applying the protocol of the Vegetation Response Assessment Index (VEGRAI) (Kleynhans *et al*., 2007b) and selected aspects of the Riparian Vegetation Index (Kemper, 2001). At all the sites a minimum length of 100m of the riparian zone on both the right and left hand river banks were surveyed. The decision whether species in the woody component could be regarded as riparian was based on the findings of van Wyk & van Wyk (1997), Grant and Thomas (2000, 2001) and Schmidt *et al*. (2007).

At each site, where water was present, the relevant macro-invertebrate biotopes were identified and the macro-invertebrates sampled at hand of the protocol used for the South African Scoring System (SASS ver.5) (Dickens & Graham, 2005) and MIRAI (Thirion, 2007). According to the SASS 5 scoring system a sensitivity value with regard of their tolerance towards organic pollution in the water is allocated of the families. These sensitivity scores range between 15 for the sensitive group which includes the Oligoneuridae and Prosopistomatidae, to 1 for the least sensitive group which includes the Muscidae and Culicidae. In this study an arbitrary cut-off point at 8 was taken as the separation between sensitive and non-sensitive. Due to the fact that that SASS was developed as an indicator of water quality it was decided calculate the SASS scores which could then be related to the recorded *in situ* and determined water quality parameters.

With regard to the Fish Response Assessment Index (FRAI) each site was photographed, the biotopes or flow-depth classes (Kleynhans, 2007) identified, demarcated and a sketch map drawn. Overhanging vegetation and undercut banks were identified, their extent estimated and scored. In fast-deep and fast-shallow biotopes the fish were electro-narcotized and collected with scoop nets. Where possible, due to the presence of crocodiles and snags, a small seine net was used in the slow-deep and slow–shallow biotopes. Where this was not possible fish were sampled with a cast net. In small pools, backwaters and in particular where sampling had to be done under and amongst vegetation a pole-seine net was used. All the specimens collected were identified using the key from Skelton (2001). The data collected was used to populate the FRAI model and calculate the scores. To calculate the FRAI scores it is imperative that the reference state (RS) of the river be established (Kleynhans, 2007; Kleynhans & Louw, 2007). In this study the RS was established at the hand of available historic data or derived from similar neighbouring rivers in the same ecoregion (Kleynhans, 2007). The Frequency of Occurrence (FROC) ratings of the expected fish species was obtained from Kleynhans *et al.* (2007a).

Diatom sampling, at the sites where water occurred, and preservation was done at hand of the methods of Taylor *et al.* (2007a). Following sample preparation diatoms were microscopically identified using the key provided by Taylor *et al.* (2007b) and the data was then used to populate the following indices: the Specific Pollution Sensitivity Index or SPI, the Biological Diatom Index or BDI (Lenoir & Coste, 1996) and the Trophic Diatom Index or TDI (Kelly & Whitton, 1995). In addition the Water Quality Index (WQI) (Bate *et al.*, 2004), which is a scale to estimate water quality using measured water quality parameters, was calculated.

3. Results

3.1 The selected sites and sampling frequency

A total of twenty six sites were selected in the river system both in- and outside the boundaries of the KNP (Figures 1 and Table 4). The site in the Tshamidzi River, a tributary of the Mphongolo River, was selected as the highest upstream point in the sub-catchment of the respective river systems and represented what could be regarded as a "least impacted" site. The sites in the Shisha and Dzombo rivers, sites 7 and 26 respectively, were selected to represent two smaller tributaries that originate within the boundaries of the KNP and could therefore be regarded as the least impacted rivers within the Shingwedzi River system. Figure 3 shows that although the Shingwedzi sub-catchment falls within one ecoregion (Ecoregion 3 or Bushveld Basin) three level 2 subregions (3.02, 3.03 and 3.05) could be identified and Table 5 shows the distribution of the sites within these ecoregions and supplies a brief description of each sub-region. While the sites inside the KNP were surveyed in June 2007 (winter, low flow) and March 2008 (summer, high flow) the sites outside were surveyed in May 2007 (winter, low flow) and February 2008 (summer, high flow).

3.2 River zonation and long profiles

The long profiles of the three rivers (Figure 6), created by plotting the altitudes of the sites, are all very similar and no sharp decrease in altitude in any of the rivers was observed. Although the altitudes at which all three rivers originate are similar the origin of the Mphongolo at Tshamidzi is at the lowest altitude.

The calculated gradients between sites and the resultant zone class according to Rowntree & Wadeson (1999) for the three rivers are shown in Table 6. Based on these classes the whole of the Mphongolo River and the whole of the Shingwedzi River, with the exception of the section between Jilongo and Altein, can be classified as "lower foothill" (Table 7). Although the gradient of the section between Jilongo and Altein causes it to be classified as a "lowland river" it should be noted that the calculated gradient is very close to the lower end of the gradient of "lower foothill". With the exception of the section between Halahala and Mashobye, which is classified as "upper foothill" the Phugwane River is classified as "lower foothill". Lower foothill zones are described by Rowntree & Wadeson (1999) as zones i) with a mixed bed alluvial channel dominated by sand and gravel, ii) where locally there may be bedrock controls, iii) where reach types typically include pool-riffle or pool-rapid and iv) where sand bars are common in pools. According to these authors "pools form a significantly greater component than rapids or riffles and flood plains are often present in these river zones".

Site no	Site name	River	Coordinates	Site no	Site name	River	Coordinates
1	Tshamidzi	Mphongolo (Tshamidzi)	22° 53.565 30° 46.180	14	Dili	Phugwane	23° 01.905 31° 07.851
2	Red Ivory	Mphongolo	22° 52.388 30° 49.065	15	Zari	Phugwane	23° 04.115 31° 13.517
3	Makuleke	Mphongolo	22° 51.699 30° 55.629	16	Mphongolo Phugwane confluence	Phugwane	23° 01.146 31° 19.283
4	Ntlhaveni	Mphongolo	22° 52.846 30° 57.489	17	Giyani Bridge	Shingwedzi	23° 04.383 30° 40.537
5	Groot Geluk	Mphongolo	22° 52.783 31° 02.613	18	Jilongo	Shingwedzi	23° 07.455 30° 50.764
6	Sirheni	Mphongolo	22° 57.859 31° 15.098	19	Altein	Shingwedzi	23° 08.234 30° 54.071
7	Vlakteplaas	Shisha	22° 52.165 31° 13.450	20	Shangoni	Shingwedzi	23° 10.623 30° 56.234
8	Mphongolo/ Shisha confluence	Mphongolo	22° 58.344 31° 15.191	21	Larini	Shingwedzi	23° 12.610 31° 05.460
9	Malamulele	Phugwane	23° 00.680 30° 42.416	22	Middle firebreak	Shingwedzi	23° 12.538 31° 13.935
10	Halahala	Phugwane	23° 03.538 30° 47.021	23	Red Rocks	Shingwedzi	23° 10.321 31° 18.419
11	Halahala Dam	Phugwane	23° 03.464 30° 47.474	24	Shingwedzi	Shingwedzi	23° 06.433 31° 26.255
12	Mashobye	Phugwane	22° 59.965 30° 52.849	25	Dipene	Shingwedzi	23° 23.191 31° 33.224
13	Phugwane East	Phugwane	22° 59.996 31° 01.927	26	Dzombo	Dzombo	23° 13.306 31° 33.110

Table 4. The site numbers, names and position of the sites surveyed in the Shingwedzi River sub-catchment, South Africa.

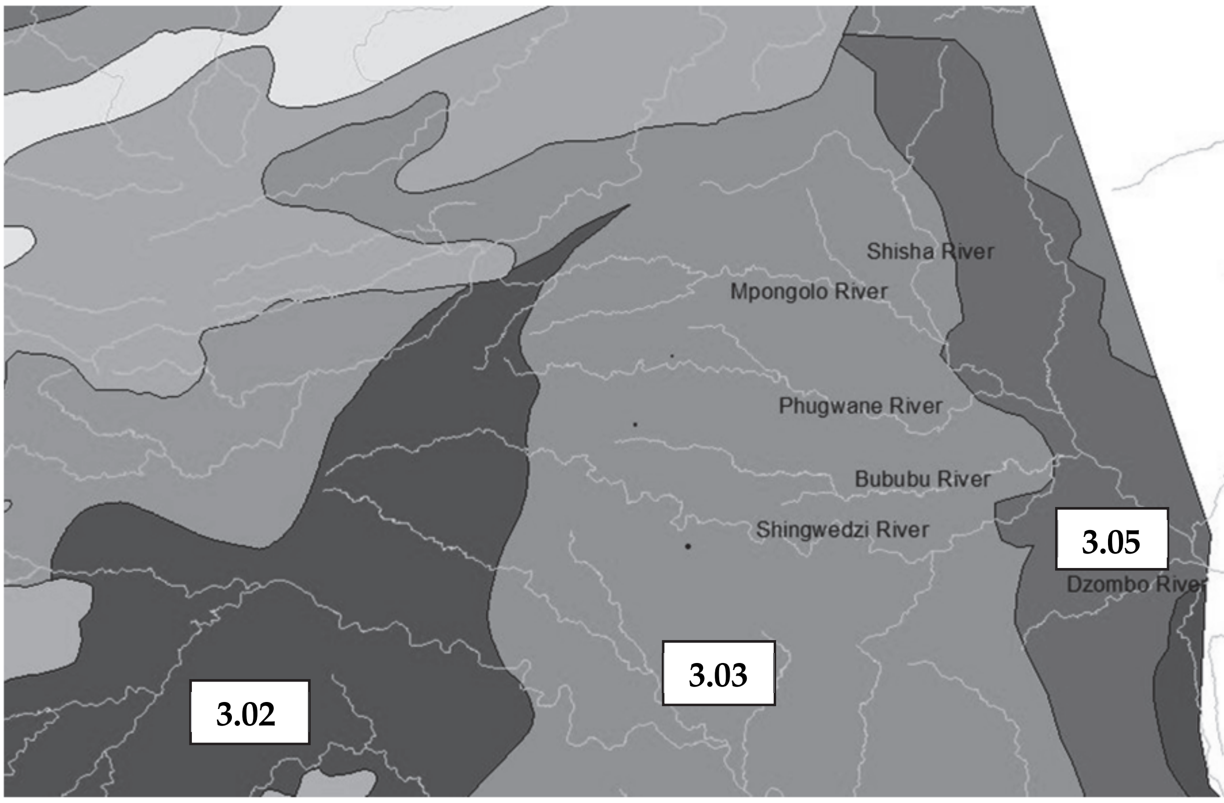

Fig. 3. Map of the study area and the location within the three level 2 Ecoregions of the rivers in the Shingwedzi River sub-catchment, South Africa (Adapted from Kleynhans & Hill, 1999).

Level 2 ecoregion	Ecoregion description	River/Tributary	Sites	Reaches used for FRAI calcultions
3.02	Mixed Lowveld bushveld	Mphongolo and Tshamidzi	1,2	**I**
3.03	Mopane Bushveld	Mphongolo and Shisha	3, 4,5, 6, 7 and 8	**II**
3.03	Mopane Bushveld	Phugwane	9,10, 11,12, 13, 14, 15 and 16	**III**
3.03	Mopane Bushveld	Shingwedzi and Shisha	17, 18, 19, 20, 21, 22 and 23,	**IV**
3.05	Lebombo Arid Mountain Bushveld	Shingwedzi	24, 25 and 26	**V**

Table 5. The distribution of the sampling sites within the level 2 ecoregions (Kleynhans *et al.*, 2007b) identified in the Shingwedzi River sub-catchment, South Africa.

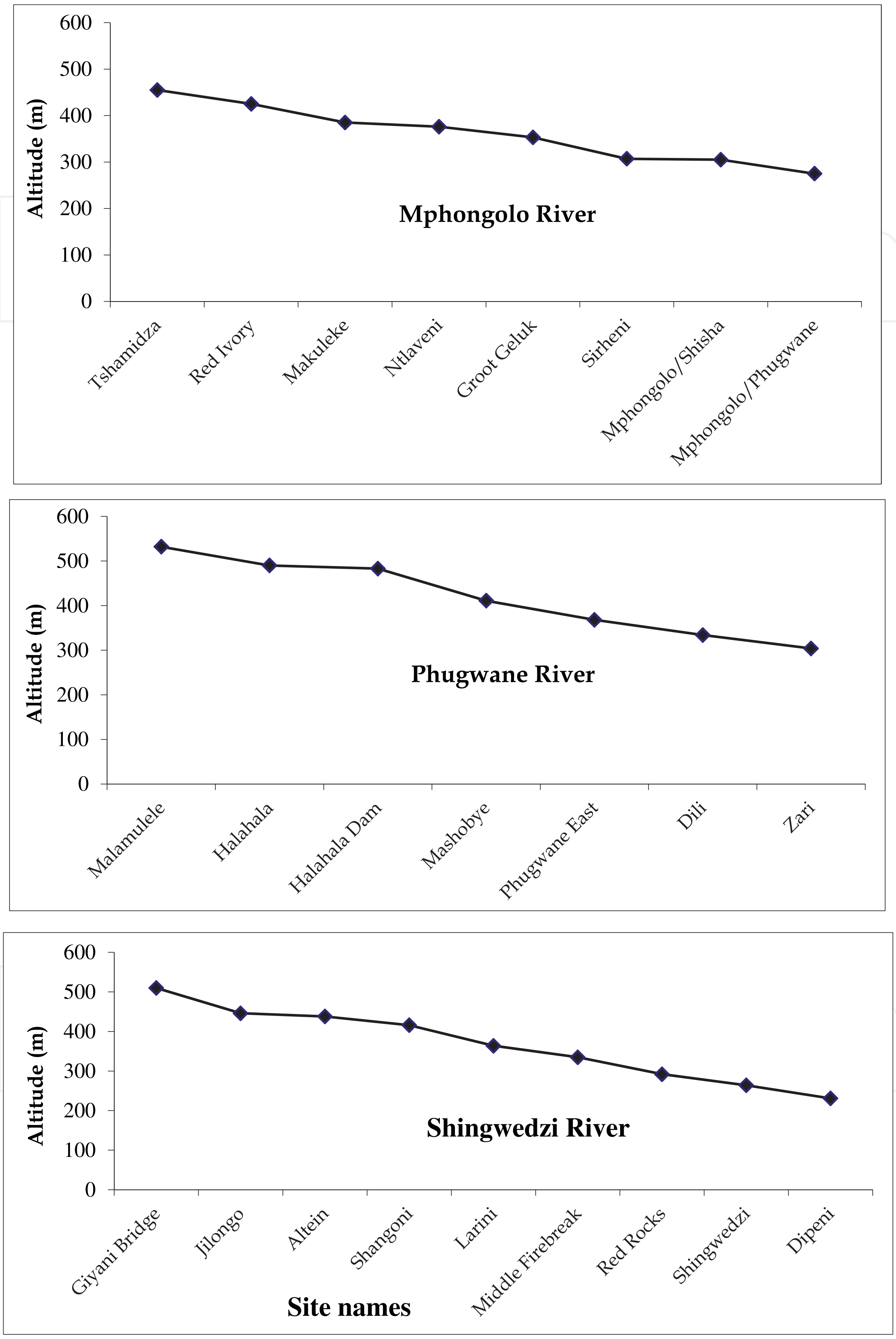

Fig. 4. Long proflies of the Mphongolo, Phugwane and Shingwedzi rivers in the Shingwedzi River sub-catchment, South Africa.

Section	Distance between sites (m)	Calculated gradient	Zone class
Mphongolo River			
Tshamidzi - Red Ivory	6700	0.004478	E
Red Ivory – Makuleke	14100	0.002837	E
Makuleke – Ntlaveni	5500	0.001636	E
Ntlaveni – Groot Geluk	13400	0.001716	E
Groot Geluk – Sirheni	29100	0.001581	E
Sirheni - Mphongolo/Shisha	15400	0.001429	E
Mphongolo/Shisha – Mphongolo/Phugwane	12200	0.002459	E
Phugwane River			
Malamulele – Phugwane confluence (above Mashobye)	25500	0.004745	E
Halahala - Halahala Dam	1000	0.007	D
Halahala Dam – Mashobye	14300	0.005035	D
Mashobye - Phugwane East	22100	0.001946	E
Phugwane East – Dili	14100	0.002411	E
Dili – Zari	13500	0.002222	E
Shingwedzi River			
Giyani Bridge – Jilongo	27700	0.00231	E
Jilongo – Altein	9900	0.000808	F
Altein – Shangoni	10400	0.002115	E
Shangoni – Larini	27800	0.001871	E
Larini - Middle Firebreak	25100	0.001155	E
Middle Firebreak - Red Rocks	11000	0.003909	E
Red Rocks – Shingwedzi	22200	0.001261	E
Shingwedzi – Dipeni	20400	0.001618	E

Table 6. Calculated gradients and zone classes for the sectors in the Shingwedzi River sub-catchment, South Africa.

Longitudinal zone	Macro-reach characteristics		
	Valley form	Gradient class	Zone class
• Source zone	V10	not specified	S
• Mountain headwater stream	V1, V3	> 0.1	A
• Mountain stream	V1, V3	0.04 - 0.99	B
• Transitional	V2, V3, V4, V6	0.02 - 0.039	C
• Upper foothills	V4, V6	0.005 - 0.019	D
• Lower foothills	V8, V10	0.001 - 0.005	E
• Lowland river	V4, V8, V10	0.0001- 0.001	F

Table 7. The geomorphologic zonation of river channels (Rowntree & Wadeson, 1999).

3.3 Impacts

To simplify the discussion of the impacts the rivers were divided into four sections. Section 1 consists of the Mphongolo River up to the confluence with the Phugwane River and sites 1 to 8 are included, Section 2 is the Phugwane River up to its confluence with the Mphongolo River and includes sites 9 to 15, section 3 is the Shingwedzi River upstream of the Mphongolo River confluence and includes sites 17 to 23 while the Shingwedzi River downstream of the Mphongolo confluence to eastern boundary of the KNP, which includes sites 24 to 26 make up section 4. Only the impacts that are regarded as those that will have the most influence in each section are discussed.

In section 1, in the area outside the KNP, the impacts that increased erosion, such as vegetation clearing, grazing and road crossings were rated as "moderate". While the same rating applied to aspects such as sewage and sand mining, the extensive impacts caused by the irrigation scheme downstream of Site 3, where water abstraction for the 20 centre pivots occurred were rated as "high". In addition the effect of return flow containing pesticides and liquid fertilizers from this irrigation scheme should be noted. In section 2 the general impacts and their rating were similar to that in section 1. What should however be noted is the severe impact of the abandoned mining operation situated between sites 9 and 12 where the dysfunctional slimes dams are severely degraded and runoff could be entering the system after rain events. In the same area the water treatment works and sewage treatment works are not well maintained and there is evidence that the return flows from these facilities are polluting the system. The impact of both the mine and the sewage works was rated as "extremely high". Section 3 is probably the most impacted of all sections. The impacts included solid waste dumping and extensive grazing upstream of Site 17, water extraction at Site 17, brickworks that mine sand upstream of Site 18 and an abandoned mine and sewage return flow from the town of Altein, upstream of Site 19. All of these impacts were rated as "high". Within the KNP the impacts were rated as "low" and consisted mostly of road crossings leading to erosion in section 4. Cognisance should be taken of the return flow from Shingwedzi rest camp and associated sewage works which could lead to nutrient enrichment if not properly maintained. Other impacts are the impoundments in the river which leads to a breakdown in river connectivity. These impoundments include the dams upstream of Sirheni (Site 6) and Malamulele (Site 17), the large lake upstream of Makuleke (Site 3) and the Kanniedood Dam between sites 24 and 25. In addittion the low water bridges at sites 24 and 25 increases the impact on the river through erosion and flow modification.

3.4 The water quality parameters

The recorded winter and summer *in situ* water quality results are shown Tables 9 and 10. In order to relate to their possible effects these results should be read in conjunction with the concept of Thresholds of Potential Concern (TPCs) and the values set by the South African National Parks Board (SANparks) for the KNP. Fouché & Vlok (2010) pointed out that "as part of their management strategy the KNP Management realised the importance and applicability of TPCs and acknowledged that monitoring programmes and associated management interventions are interlinked". In order to achieve their short and long term objectives the KNP then set end-points or TPCs (Table 8) which, when clearly articulated, would contribute towards the strong goal-setting or objectives hierarchy approach (KNP, 2009).

Parameter	Set TPC value
***In situ* physico-chemical aspects**	
pH	6,5 – 8,5
Electrical conductivity (µScm-1)	700
Total dissolved substances (mgl-1)	450
Chemical constituents (mgl-1)	
Phosphorous	0,1
Nitrites and nitrates	6
Ammonium	15
Calcium	32
Magnesium	30
Potassium	50
Silicon	18

Table 8. Thresholds of Potential Concern (TPC) values for the Shingwedzi River set by SANParks (KNP, 2009).

During the winter survey the pH values at sites 18, 19, 20 and 22 (Table 9) exceeded the set TPC value (Table 8) with the highest value of 9,09 measured at Site 18. Similar results were recorded during the summer survey (Table 10) with the TPC exceeded at seven sites and the highest value of 9,13 recorded at Site 15. A similar trend where the TPC was exceeded was observed with the electrical conductivity with the highest value of 2590 µScm-1 recorded at Site 14 during winter. In summer, when flow volumes increased, the maximum values were lower than during winter and the highest value recorded was the 1437 µScm-1 recorded at Site 7. Other high values of 1278 and 1029 µScm-1 were recorded at Site 26 and Site 20 respectively.

During the winter survey (Table 9) the TPC value for Total Dissolved Substances (TDS) was exceeded at two sites, with the highest value, 1530 mg l-1, recorded at Site 14. During the summer survey higher values were recorded with the highest value of 1820 mg l-1 recorded at Site 16. In addition the TPC for TDS was exceeded at four sites during the study period.

TPC values for dissolved oxygen was not set by the KNP but international standards for oxygen saturation is set at between 80 and 120% (Dallas & Day 2004) while Kempster *et al.* (1980) suggested a dissolved oxygen concentration range of 4 to 5,8 mgl-1 as acceptable for aquatic life. During the winter survey (Table 9) oxygen saturation varied considerably with the lowest and highest values measured at sites 13 and 14. In addition, with the exception of sites 4, 9, 19, 20, 21 and 22, the values at all the sites were not within the set parameters. Table 10 shows that during the summer surveys matters improved with oxygen values at eleven of the sites within the parameters and no values above the upper parameter of 120%.

With regard to oxygen concentration the results obtained (Tables 9 and 10) show that in both surveys only four sites were within the set parameters. In general, the oxygen concentrations exceeded the upper limit, which could be an indication of excessive algal growth.

When the phosphorous TPC value (Table 8) is converted to a phosphate value, it can be equated to 0.0326 mg l-1. Table 11 shows that with the exception of the sites where no phosphates could be detected, all the values exceeded the set TPC for phosphates in both the winter and summer surveys. The exceedingly high value of 15mgl-1 obtained at Site 26 is noteworthy.

The highest nitrate value recorded for both the winter and summer was 7 mg l^{-1}, which was recorded at sites 3, 22 and 17 (Table 11). In addition, Site 3 was the only site where the set TPC value was exceeded during both the winter and summer surveys.
The set TPC value for ammonium was exceeded at a number of sites, with values varying between 0 and 46 mg l^{-1} in winter, and 0 to 55 mg l^{-1} in summer (Table 11).

Site no.	Site name	pH	Electrical conductivity	Dissolved oxygen	Dissolved oxygen	Total dissolved substances	Total Suspended Solids	Flow
			μScm^{-1}	%	mg l^{-1}	mg l^{-1}	mg l^{-1}	
1	Tshamidzi							NW
2	Red Ivory							NW
3	Makuleke	7.86	631	76.3	5.73	317	0.07	N
4	Ntlhaveni	8.25	285	97.9	7.8	143	0.1435	L
5	Groot Geluk	6.69	287	72.7	6.35	143	0.18	N
9	Malamulele	7.17	832	96	8.2	417	0.054	N
10	Halahala							NW
11	Halahala Dam	7.74	217	165	12.8	109	0.82	N
12	Mashobye	8.06	759	56.9	4.69	378		N
13	Phugwane East	7.45	269	25.1	2.45	308	0.144	N
14	Dili	7.68	2590	178.4	14.62	1530	0.0795	N
15	Zari	7.73	855	52	4.82	429	0.2	N
16	Mphongolo-Phugwane							NW
17	Giyani bridge	7.94	164.5	68	5.6	82.7	0.045	L
18	Jilongo	9.09	247	149.2	11.24	126	0.11	N
19	Altein	8.76	295	115	9.23	147	0.0795	N
20	Shangoni	8.79	1422	95.3	8.72	710	0.013	L
21	Larini	8.2	1027	93	8.8	517		N
22	Middle Firebreak	8.88	503	117.7	10.15	251	0.087	N
23	Red Rocks							NW
24	Dipene							NW
26	Dzombo	7.9	1243	55.2	4.26	623	0.09	L

Table 9. The *in situ* measured and observed water quality and quantity at the sampling sites in the Shingwedzi River sub-catchment, South Africa, during the winter (May and June) surveys. In the table NW = no water, N = no flow, L = low flow, M = moderate flow and H = high flow (Adapted from Fouché & Vlok, 2010).

Table 12 shows that the calculated Water Quality Index (WQI) scores of the sites where diatoms were collected ranged from “poor” to “good” with none of the sites in either the “excellent” and “very poor” classes. It should be noted that with the exception of Site 14, the sites rated as “good” were in lower percentile of the range of that class and closer to being rated as “medium”. The same reasoning could be applied to sites 4, 6 and 20 which lie in the lower percentile of the “medium” class. In totality these results indicate that the water quality within the system is under threat.

At this point the six sites where as many as three TPCs were exceded (Table 11) should be highlighted. Four of the sites (5, 13, 22 and 25) are within the KNP boundaries while two of the sites (9 and 17) are outside. The calculated WQI scores (Table 12) show that the water quality for sites 5, 9, 25 and 17 is "poor" while the score of the Site 13, which lead to a rating of "medium" lies within the lower percentile of that class and could be regarded as "poor".

Site no.	Site name	pH	Electrical conductivity	Dissolved oxygen	Dissolved oxygen	Total dissolved substances	Total Suspended Solids	Flow
			μScm^{-1}	%	mg l^{-1}	mg l^{-1}	mg l^{-1}	
1	Tshamidzi	8.52	762	119.2	9.35	382	0.053	L
2	Red Ivory	8.02	729	32.6	2.89	365	0.0675	L
3	Makuleke	8.01	1003	53.8	4.7	498	0.1775	L
4	Ntlhaveni	8.43	618	84.4	6.24	390	0.1	L
5	Groot Geluk	8.62	395	100.3	7.84	198	0.194	N
6	Sirheni	7.33	230	47.2	4.7	115	0.09	N
7	Vlakteplaas	8.9	1437	58.2	4.73	718	0.1235	N
8	Shisha/Mphongolo	7.08	271	52.5	3.98	271	0.1155	L
9	Malamulele	6.83	750	60.3	5.04	375	0.122	N
10	Halahala							NW
11	Halahala Dam	6.75	194.3	36.9	3.18	96.6	0.082	N
12	Mashobye	8.15	269	90.8	7.09	133	0.1	N
13	Phugwane east	7.48	326	78.6	6.73	160	0.1175	L
14	Dili	8.06	345	108.6	8.07	178	0.0795	L
15	Zari	9.13	445	100.9	7.3	223	0.183	L
16	Mphongolo/Phug-wane	7.91	366	38.5	3.4	1820		L
17	Giyani bridge	8.0	622	33.6	2.37	312		N
18	Jilongo	8.3	333	72.6	6.7	166	0.23	N
19	Altein	8.2	279	75.8	6.77	140	0.029	N
20	Shangoni	8.91	1029	70.7	6.85	515	0.025	N
21	Larini	7.85	169	86.4	6.32	84.7	0.1275	L
22	Middle Firebreak	8.68	176	91.6	7.02	88.4	0.0665	L
23	Red Rocks	8.53	202	88.0	6.95	120.0	0.124	L
24	Shingwedzi	7.55	339	89.1	6.99	170	0.88	M
25	Dipene	7.91	410	86.8	6.31	207	0.062	L
26	Dzombo	7.59	1278	43.9	3.22	642	0.33	N

Table 10. The *in situ* measured and observed water quality and quantity at the sampling sites in the Shingwedzi River sub-catchment, South Africa, during the summer (February and March) surveys. (In the table NW = no water, N = no flow, L = low flow, M = moderate flow and H = high flow (Adapted from Fouché & Vlok, 2010).

Site no.	Site name	PO_4 mg l^{-1}		NO_2 mg l^{-1}		NO_3 mg l^{-1}		NH_4 mg l^{-1}	
		Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
1	Tshamidzi	4		0.6		4		22	
2	Red Ivory	4		0.7		4		20	
3	Makuleke	0		0.7		7	6	0.1	10
4	Ntlhaveni	0.25	0	0.6	0.7	4	3	0	0.1
5	Groot Geluk	0.25	4	0.5	0.6	2	5	20	6
6	Sirheni	3		0.05		2		0	
7	Vlakteplaas	4		0.6		3		0.1	
8	Shisha/ Mphongolo.	4		0.6		2		21	
9	Malamulele	2	4	0.6	0.6	3	3	0.1	25
12	Mashobye	3		0.2		2		22	
13	Phugwane east	3	2	0.7	0.7	2	4	55	21
14	Dili	0	0.25	0.7	0.6	4	2	4	24
15	Zari	0	0	0.7	0.7	2	3	6	22
16	Mphongolo/ Phugwane		0.2		0		1		0
17	Giyani bridge		3		0.6		7		20
18	Jilongo		4		0.6		3	40	0
19	Altein	3	2			2	2	0	0
20	Shangoni	0	0	0	0	0	1	0	38
21	Larini	3		0.6		4		0.3	
22	Middle Firebreak	3	0	0.2	0	7	2	25	23
23	Red Rocks	0.1	3	0.7	0.7	4	4	0.1	0
24	Shingwedzi	3		0.6		3		21	
25	Dipene	3	0.2	0.7	0	2	2	0	46
26	Dzombo	15	0	0.6	0.5	2	2	0.2	44

Table 11. Water quality at the sampling sites in the Shingwedzi River sub-catchment during the February and March (summer) and the May and June (winter) surveys (Adapted from Fouché & Vlok, 2010).

3.5 Biological indices

3.5.1 Diatoms

Table 13 shows the calculated diatom based index scores of the Specific Pollution Sensitivity Index (SPI), the Biological Diatom Index (BDI) and the Trophic Diatom Index (TDI). These results are classified into water quality, ecological status and trophic state classes at the hand of the criteria listed in Table 14.

The allocated water quality classes, based on the SPI and BDI scores, show that with the exception of sites 5 and 14 all the sites were rated as either "unsatisfactory" or "poor" with Site 21 the only site rated as "good". Because of the low SPI and BDI scores the ecological status of all the sites ranged from "poor" to "moderate" quality with no sites rated as "good" quality.

TDI scores are used to determine the trophic status of a water resource and the calculated scores (Table 13) show that a history of high nutrient content, with most sites rated as eutrophic or hypertrophic, was detected in the system. The only sites where low nutrient levels were detected were sites 25 and 21 that were classified as oligotrophic and oligo-/mesosotrophic respectively. The fact that five sites, namely 4, 6, 7, 12 and 24, were rated as hypertrophic should be noted. It is however important to take cognisance of the fact that only Site 4 was outside the KNP and that the trophic status could be ascribed to natural conditions such as a high organic content resulting from animal faeces and organic material of plant origin.

Site numbers	**Site name**	**Water Quality Index scores**	**Water quality classes** (91-100 = excellent, 71 – 90 = good, 51 – 70 = medium, 26 – 50 = poor and 0 – 25 = very poor).
3	Makuleke	76	Good
4	Ntlhaveni	56	Medium
5	Groot Geluk	42	Poor
6	Sirheni	53	Medium
7	Vlakteplaas	60	Medium
9	Malamulele	42	Poor
12	Mashobye	67	Medium
13	Phugwane East	56	Medium
14	Dili	81	Good
17	Giyani bridge	40	Poor
18	Jilongo	76	Good
19	Altein	70	Medium
20	Shangoni	56	Medium
21	Larini	50	Poor
22	Middle Fire Break	74	Good
23	Red Rocks	79	Good
24	Shingwedzi	67	Medium
25	Dipene	48	Poor
26	Dzombo	62	Medium

Table 12. Water Quality Index (WQI) values and the resultant water quality classes (Bate *et al.*, 2004) for sites in the Shingwedzi River sub-catchment, South Africa (Fouche & Vlok, 2009).

3.5.2 Macro-invertebrates

Macro-invertebrates were sampled at 21 sites during summer (Figure 5) and at eleven sites during the winter survey (Figure 8). The results show that not all the required biotopes (Thirion, 2007) were present at all the sites. During the summer survey, ten sites had all the biotopes namely gravel-sand-mud (GSM), stones (S) and marginal vegetation (VEG) present while nine sites had VEG and GSM and two sites only had GSM. Because of the lack of biotopes the calculated SASS results should be viewed with caution.

Site number	Site name	SPI	BDI	TDI
3	Makuleke	8.8	8.3	70.9
4	Ntlhaveni	7.8	8.1	83.8
5	Groot Geluk	12.7	12.9	66.6
6	Sirheni	10.7	10.5	79.7
7	Vlakteplaas	11	9.9	78.5
12	Mashobye	9.3	8.6	83.4
13	Phugwane East	13.1	10.5	68.6
14	Dili	13.4	12.2	72.5
18	Jilongo	11.5	6.3	73.1
19	Altein	13.5	8.8	66.8
20	Shangoni	11	9.8	76
21	Larini	16.3	13.6	45.9
22	Middle Fire Break	13	10.3	67
23	Red Rocks	11	11.2	68.8
24	Shingwedzi	10.3	8.6	86.5
25	Dipene	12.4	13.4	36.5
26	Dzombo	8.6	9.7	74

Table 13. Calculated scores for the Specific Pollution Sensitivity Index (SPI), the Biological Diatom Index (BDI) and the Trophic Diatom Index (TDI) for sites the Shingwedzi River sub-catchment, South Africa (Adapted from Fouché & Vlok, 2009).

SPI and BDI			TDI	
Index scores	**Water quality**	**Ecological status**	**Index scores**	**Trophic status**
> 17	Very good	High quality	< 35	Oligotrophic
15 - 17	Good	Good quality	35 – 50	Oligo-mesotrophy
12 - 15	Satisfactory	Moderate quality	50 - 60	Mesotrophy
9 - 12	Unsatisfactory	Poor quality	60 - 75	Eutrophic
< 9	Poor		> 75	Hypertrophy

Table 14. Index scores for the calculated diatom indices and the related classification (Adapted from Kelly & Whitton, 1995; Lenoir & Coste, 1996).

During the summer survey, the highest SASS score of 81 was recorded at Mashobye where although only VEG and GSM biotopes were present specimens belonging to fifteen families were identified. Of the fifteen families only four were regarded as sensitive, scoring above 8 on the sensitivity scale. In addition seven families were air breathers, indicating that they could survive a poor water quality environment. Five other sites, namely Red Ivory, Phugwane East, Jilongo, Altein and Shangoni, had a score ranging between 65 and 75, with the number of families recorded varying between twelve and fifteen. These sites all had the full range of biotopes but low numbers of sensitive families and high numbers of air breathing families were observed indicating that the water quality was poor, probably due to organic pollution. When the SASS results for the sites where all the biotopes were present for the summer survey (Figure 5) are considered a decreasing downstream trend in water quality in the Mphongolo, Phugwane and Shingwedzi rivers, is observed. Similar results were observed during the winter survey (Figure 6) when the biotope diversity was lower with most of the sites having only stones (S) as a biotope. The lowest score of 14 was recorded at Zari where GSM was the only available biotope compared to the highest score of 72 recorded at Larini, again with stones (S) as the only available biotope. No sensitive families were present at Zari, whilst two of the four families present were air breathers. At Larini four sensitive families were recorded, with five air breathing families present.

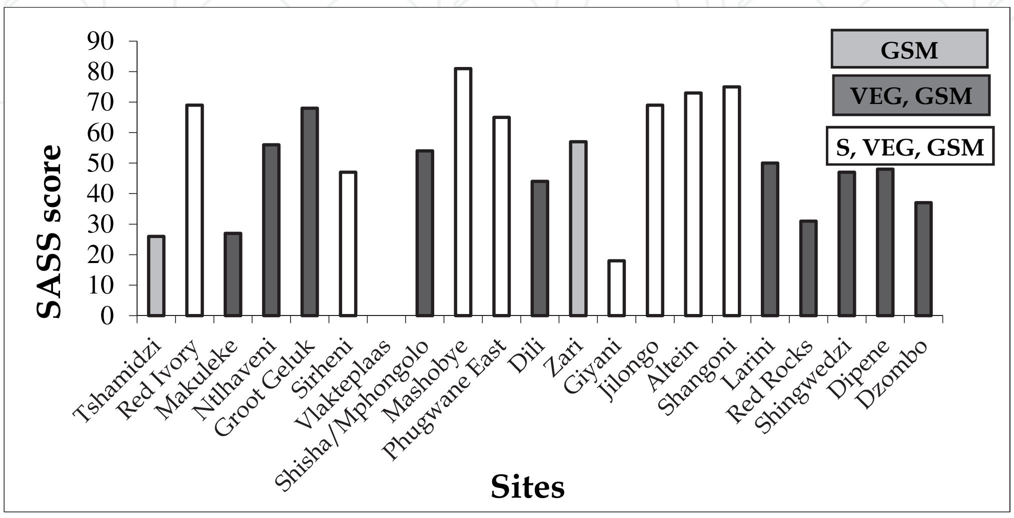

Fig. 5. SASS scores for the summer survey in the Shingwedzi River sub-catchment, South Africa. (Biotopes: GSM = ground, sand and mud; VEG = vegetation; S= sand).

According to Dallas & Day (2004) the two factors that have the most profound impact on macro-invertebrate populations are flow and the amount of total dissolved substances. Low SASS scores are generally regarded as an indication of poor quality (Thirion, 2007). Based on the scores obtained, and supported by the low numbers of sensitive families and the high number of air breathers, it is clear that the water quality in the Shingwedzi River system is poor. It can be ascribed to organic pollution which result from the lack of infrastructure in the catchment, with no or dysfunctional sewage treatment works and cattle faeces the main contributors. The Shingwedzi River System can be classified as an intermittent seasonal river (Rossouw *et al.*, 2005). These authors describe this type of river as "a river that exhibit seasonally predictable intermittent flow where surface flow may disappear for a period each year reducing the channels to isolated pools or drying up completely during the dry season and flow that commence during the rainy season and may be sustained or be intermittent over the wet season". In addition these intermittent rivers can have variable flow and one to two year dry cycles in a five-year period are normally present (Rossouw *et al.*, 2005). The low SASS scores could therefore be a result of a lack of flow, which is exacerbated by the weirs that obstruct flow, and an increase in water extraction.

3.5.3 Vegetation

Table 15 shows that with regard to the calculated Vegetation Response Assessment Index (VEGRAI) scores and the resultant Ecological Categories the sites ranged fom a low category D, which reflects a "largely modified" ecosystem (Table 16) to a category A, which reflects an "unmodified or natural" system (Table 16). Although there is clear indication that impacts are negatively affecting the riparian zone more than 50% of the sites were in a better state than a category C. This indicates a system that is moderately modified to largely natural.

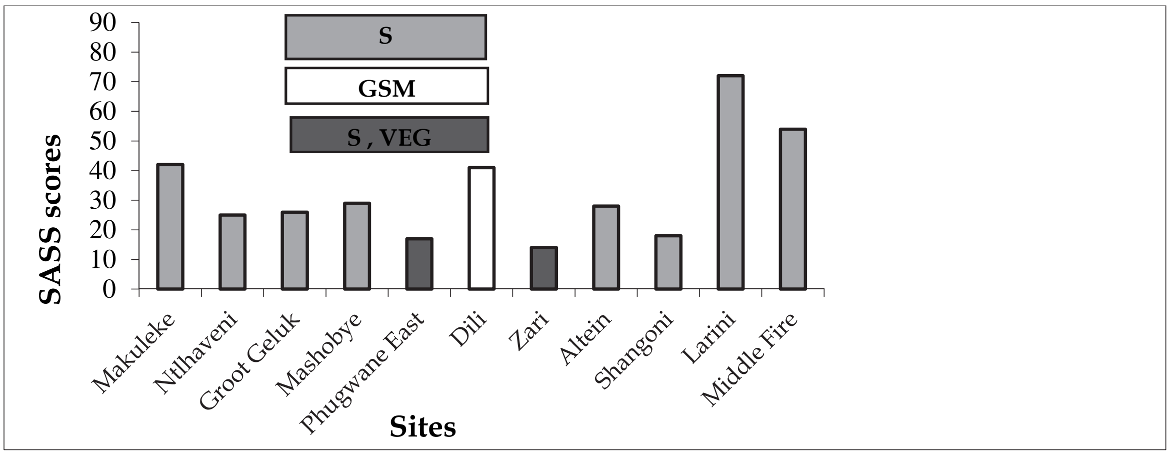

Fig. 6. SASS scores for the winter survey in the Shingwedzi River sub-catchment, South Africa. (Biotopes: GSM = ground, sand and mud; VEG = vegetation; S= sand).

Site no	Site Name	River	VEGRAI score	EC class
1	Tshamidzi	Mphongolo	72.4	C
2	Red Ivory	Mphongolo	73.3	C
3	Makuleke	Mphongolo	68.9	C
4	Ntlhaveni	Mphongolo	80	C/B
5	Groot Geluk	Mphongolo	81.5	B
6	Sirheni	Mphongolo	76.7	C/B
7	Vlakteplaas	Shisha	94.1	A
8	Shisha-Mphongolo confluence	Mphongolo	78.6	C/B
9	Malamulele	Phugwane	49.0	D
10	Halahala	Phugwane	52.4	D
12	Mashobye	Phugwane	79.4	C/B
13	Phugwane-east	Phugwane	82.8	B
14	Dili	Phugwane	76.8	C
15	Zari	Phugwane	78.5	C/B
17	Giyani bridge	Shingwedzi	63.4	C
18	Jilongo	Shingwedzi	77.4	C/B
19	Altein	Shingwedzi	61.7	C/D
20	Shangoni	Shingwedzi	80.1	B/C
21	Larini	Shingwedzi	72.4	C
22	Middle Firebreak	Shingwedzi	60.5	C/D
23	Red Rocks	Shingwedzi	81.2	B/C
24	Shingwedzi camp	Shingwedzi	75.4	C
25	Dipene causeway	Shingwedzi	80.6	B/C
26	Dzombo	Dzombo	90.7	A/B

Table 15. The calculated Vegetaton Response Assessment Index (VEGRAI) scores and Ecological Category (EC) classes of the sites surveyed in the Shingwedzi River and tributaries, South Africa (Adapted from Fouché & Vlok, 2009).

Index scores (% of total)	Category/class description	Ecological category / Ecological class
90 - 100	Unmodified, natural.	A
80 - 89	Largely natural with few modifications. A small change in natural habitats and biota may have taken place but the ecosystem functions are essentially unchanged.	B
60 - 79	Moderately modified. Loss and change of natural habitat and biota have occurred, but the basic ecosystem functions are still predominantly unchanged	C
40 - 59	Largely modified. A large loss of natural habitat, biota and basic ecosystem functions has occurred.	D
20 - 39	Seriously modified. The loss of natural habitat, biota and basic ecosystem functions is extensive.	E
0 - 19	Critically/Extremely modified. Modifications have reached a critical level and the system has been modified completely with an almost complete loss of natural habitat and biota. In the worst instances the basic ecosystem functions have been destroyed and the changes are irreversible.	F

Table 16. The generic Ecological Categories, or classes, and their descriptions related to VEGRAI and FRAI scores (Adapted from Kleynhans & Louw, 2007).

The vegetation at seven sites in the Mphongolo River was surveyed in this study. The VEGRAI results (Figure 7) show that the three sites outside the KNP boundaries, Tshamidzi, Red Ivory and Makuleke, were in the worst condition (Ecological Category C). At Nthlaveni limited improvement was observed with the Ecological Category improving towards a B category (EC = C/B). This was followed by a further improvement to a B category at Groot Geluk. The presence of the Sirheni Dam however had a negative influence on the vegetation at the Sirheni site, which is downstream of the impoundment, resulting to a change to a category C. Some improvement was again observed downstream of this site, which could be partly ascribed to the influence of the Shisha River and the vegetation at the Mphongolo-Shisha confluence site was classified as a category C/B. The fitted trend line in figure 9 indicates a downstream improvement in the state of the riparian vegetation along the Mphongolo River.

The Tshamidzi site is in the upper catchment of the Mphongolo River and lies on the watershed between the Luvuvhu and Shingwedzi catchments. Eighteen woody species were recorded of which only ten were classified as “riparian”. There is therefore a degree of terrestrial invasion in the form of the *Dichrostachys cinerea* recorded and this “invasion” is typical of an area with low flow and variable seasonal differences. The population structure of the riparian woody plants seems to be in good condition as there are sufficient numbers of juveniles, e.g. *Breonadia salicina*, present. This species is regarded as a TPC species indicative of healthy riparian vegetation. The Red Ivory site is characterized by a deep V-shaped valley in which the river flows and this has the effect that the riparian zones on both sides are narrow. One of the implications is that very few shrubs can establish and this could also be the reason for the low diversity with only nine species of woody plants recorded. The actual site is an unused river crossing with resultant erosion. This is exacerbated by the fact that the surrounding area is used for cultivated lands and grazing. The Makuleke site is influenced by the imoundment immediate upstream of the survey site. As a result of the effect of flood control by the dam wall a number of woody terrestrials have established and these species contribute up to 30% of the recorded plants at the site. On the other hand seepage, resulting from return flow, has led to the establishment of a well defined marginal zone. As is the case with rivers that flow through inhabited areas, signs of pollution are evident in the form of excessive algal growth and the presence of solid waste such as plastic bags and other household refuse.

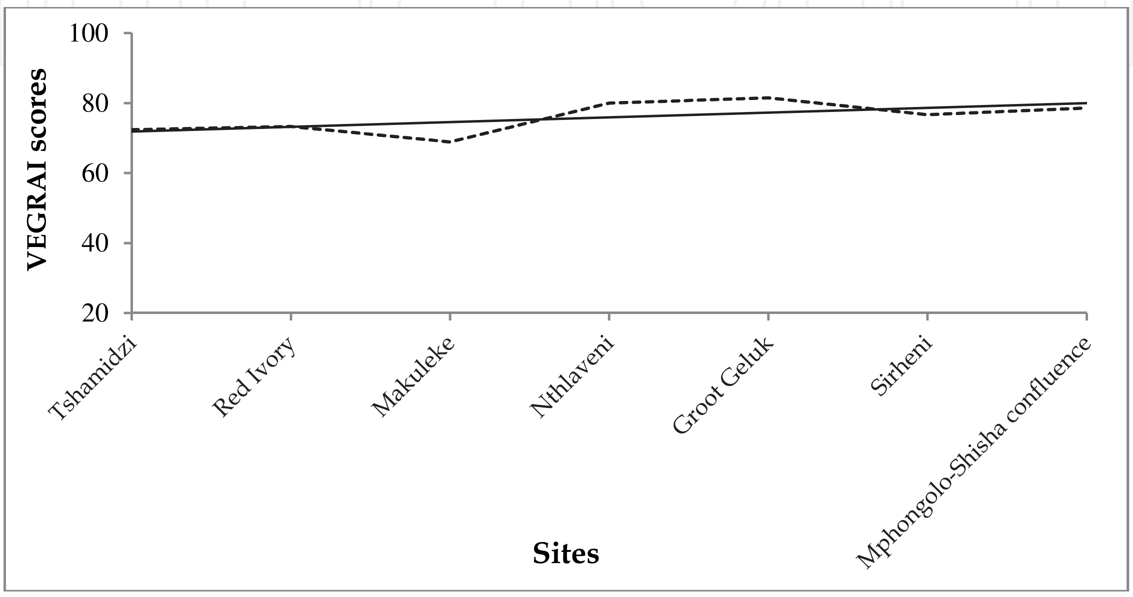

Fig. 7. Calculated VEGRAI scores for sites 1, 2, 3, 4, 5, 6 and 8 in the Mphongolo River, South Africa. (The solid line represents a fitted trend line). (Adapted from Fouché and Vlok, 2009)

The Shisha River is unique because it originates within the KNP and therefore does not have as many of the anthropogenic impacts as the other rivers in the system. With the exception of the Langtoon Dam in its upper catchment the impacts observed are all natural. The Vlakteplaas site, which is typical of this reach of the Shisha River, consists of a deep stagnant pool that gives permanency to the site resulting in a well established marginal zone or wetted perimeter. It is possibly the most undisturbed site of all the sites surveyed during this study and was classified as the only category "A" site of the survey.

In the Phugwane River the vegetation was surveyed at six sites and the VEGRAI results (Figure 8) indicate that two of the sites, namely Malamulele and Halahala which are both outside the KNP boundaries, are the only two sites in the entire system that were classified as a category D, which reflects that they are "largely modified" (Table 16). In the case of the Malamulele site it can be attributed to human interference in the form of farming activities and pollution. Downstream of this site some improvement was observed at the Mashobye site. As was the case with the Mphongolo River the downstream trend is an upwards one in the riparian vegetation scores. The observed trend throughout the river is depicted by the trend line fitted in Figure 8.

The Malamulele site is definitely the most impacted site of all the sites surveyed in the study. It is situated at origin of the stream flowing out of the wetland. This site in the headwaters of the river is in an area that is poorly managed with crop fields extending into the riparian zone. The Halahala site is a typical example of the effect of no or very little water flow and water quantity and seasonality can be regarded as the factor with the most influence on the classification of the vegetation. Although thirteen woody species were recorded in the riparian zone only five were classified as riparian. This indicates an invasion of terrestrial species into the riparian zone which is typical of ephemeral streams and in particular those that flow through low rainfall areas. In general the population structure of the woody riparian species seems in order but very few juveniles were observed. In addition no non-woody riparian species were observed in the marginal zone.

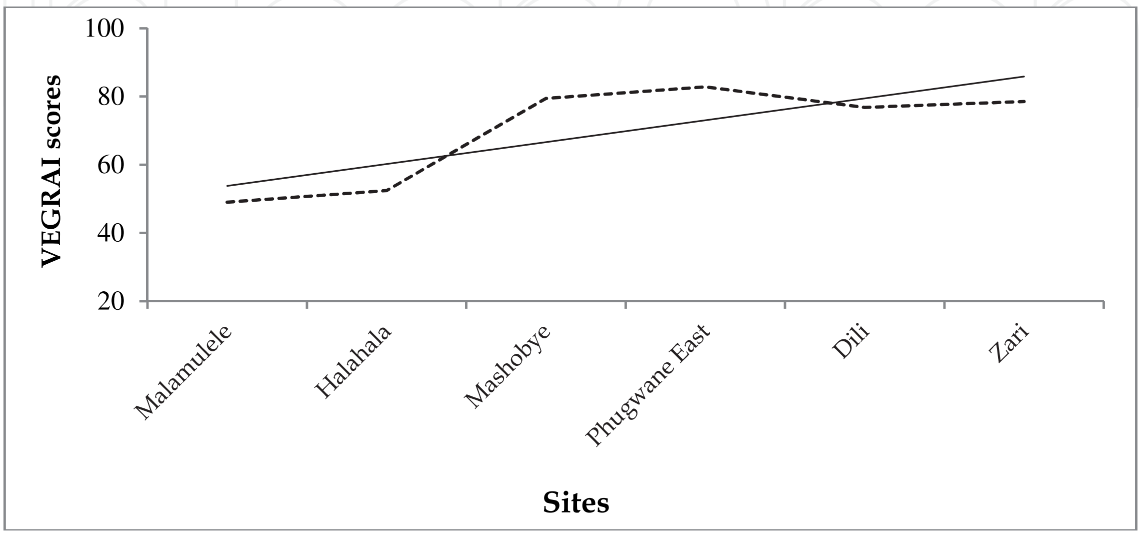

Fig. 8. Calculated VEGRAI scores for sites 9, 10, 12, 13, 14 and 15 in the Phugwane River, South Africa (The solid line represents a fitted trend line). (Adapted from Fouché & Vlok, 2009).

The vegetation at nine sites in the Shingwedzi River was surveyed during this study. As was the case with both other rivers a downstream increase in the status of the riparian vegetation was observed as depicted by the fitted trend line in Figure 9. The severe fluctuation between sites should be noted. In this river no unmodified or natural sites were observed.

The Altein site shows distinctive signs of a high degree of impact in the form of wood cutting and grazing by cattle and goats. As a result the grass cover consisted of pioneer species. The broken road bridge acts as a hydraulic control forming a deep pool immediately upstream. Further upstream of the site an extraction weir regulates the flow in the river. Although 16 woody species were recorded five species, or more than 30%, are terrestrial species. In addition the woody species is dominated by shrubs (e.g. *Gymnosporia senegalensis*) and creepers (e.g. *Acacia ataxacantha*). Very few large tree specimens were present which can be the result of wood harvesting. It is however important that some juveniles of *Philenoptera violacea* and sub-adult *Ficus sycomorus* were observed. Both these species are regarded as preferential riparian woody species

The vegetation at the Shangoni site, which is downstream from the abandoned mines with resulting bad water quality, is still reasonably intact. In part this can be attributed to the remoteness of the site and the resultant low human impact. Fields that were historically ploughed and grazing areas were observed near the site but the effects are not evident at the site. In addition there are also few humans living upstream of the site. On the other hand the low impact on the vegetation can be ascribed to the fact that the adverse effect of the water quality resulting from drainage of the mines are "more recent" and the riparian zones, other than the marginal zone have not yet been affected. The adverse effects in the marginal zone are evident from the fact that despite of the semi-permanent pool only a few scattered sedges are present at the site.

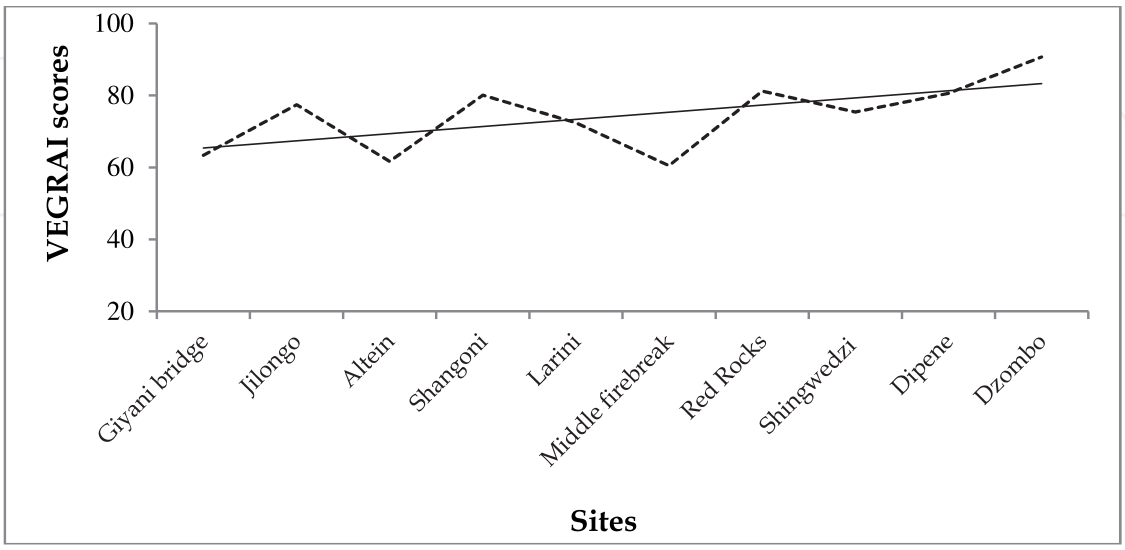

Fig. 9. Calculated VEGRAI scores for the sites in the Shingwedzi River, South Africa (The solid line represents a fitted trend line). (Adapted from Fouché & Vlok, 2009).

It is important to note that the Shingwedzi site, downstream of the Rest camp, is impacted by subsurface water extraction, polllution and a low-water bridge. This bridge forms a weir and a large semi-permanent pool is present at the site. The river has a wide sand bed, in excess of 80m, with the pool and deeper channel against the left hand bank. The low diversity of woody riparian species is of concern but on the other hand no invasion by terrestrial or exotic species was recorded. A further concern is the low juvenile count of the riparian species present.

The Dzombo site is the second least impacted site and is in the least impacted river in the current survey. It is however important to note that it is a small ephemeral stream which is subjected to extended periods of drought. This is reflected by the high number terrestrial species present in the riparian zone.

3.6 Fish

3.6.1 Historic fish distribution and biodiversity of the Shingwedzi River

Fish distribution data were primarily obtained from the data bases of the Limpopo Department of Environment and Tourism (LEDET), the South African Institute of Aquatic Biodiversity (SAIAB), the KNP, the now defunct Transvaal Provincial Administration (TPA) as well as from the work of Gaigher (1969), Pienaar (1978), Russell (1997) and Olivier (2003). In addition data was obtained from experts (Angliss, pers com.[1]; Deacon, pers com.[2]; Kleynhans, pers com.[3]; Engelbrecht, pers com. [4]) and added on to the data. This data were then used to construct the historic data and eventually deduct the reference state (RS).

[1] Angliss, M.K., Anglo Platinum, Polokwane, South Africa.
[2] Deacon, A.R., Scientific Services, Kruger National Park, South Africa
[3] Kleynhans, C.J. Resource Quality Services, Department of Water Affairs, Pretoria, South Africa.

When the historic data was compared with the fish data provided by Kleynhans *et al.* (2007a) for the two reference fish distribution sites (2LF2 and 2LF3) in the Shingwedzi River system some differences are observed namely:

a. That although Kleynhans *et al.* (2007a) lists the eel *Anguilla marmorata* no reference to its presence was found in the other literature surveyed.
b. That the Southern Mouth Brooder, *Pseudocrenilabrus philander,* is listed by Kleynhans *et al.* (2007a) as "a species derived to be present" at site 2LF3 in the Mphongolo River, the only record in the surveyed literature is that of Pienaar (1978) who collected the species in the vicinity of Red Rocks..
c. That the tigerfish, *Hydrocynus vittatus* and the Purple Labeo, *Labeo congoro*, are not listed at both 2LF2 and 2LF3. This despite the fact that the presence of *H. vittatus* is reported by Pienaar (1978) at sites in the proximity of the current sites 6, 15, 24 and 25 and by Deacon (pers com.[2]) at Site 6.

Family	Historic biodiversity	Recorded during the survey
Characidae	*Hydrocynus vittatus*	
	Brycinus imberi	*Brycinus imberi*
	Micralestes acutidens	
Cyprinidae	*Labeobarbus marequensis*	
	Barbus afrohamiltoni	*Barbus afrohamiltoni*
	Barbus matozzi	
	B. trimaculatus	*B. trimaculatus*
	B. paludinosus	
	B. unitaeniatus	*B. unitaeniatus*
	B. viviparus	*B. viviparus*
	B. annectens	*B. annectens*
	B. toppini	*B. toppini*
	B. radiatus	*B. radiatus*
	Labeo congoro	
	L. cylindricus	*L. cylindricus*
	L. rosae	*L. rosae*
	L. ruddi	*L. ruddi*
	L. molybdinus	*L. molybdinus*
	Opsaridium peringueyi	
	Mesobola brevianalis	*Mesobola brevianalis*
Schilbeidae	*Schilbe intermedius*	*Schilbe intermedius*
Clariidae	*Clarias gariepinus*	*Clarias gariepinus*
Mochokidae	*Synodontis zambezensis*	
	Chiloglanis paratus	
Cichlidae	*Oreochromis mossambicus*	*Oreochromis mossambicus*
	Tilapia rendalli	*Tilapia rendalli*
	Pseudocrenilabrus philander	
Gobiidae	*Glossogobius giuris*	*Glossogobius giuris*
Anguillidae	*Anguilla mossambica*	

Table 17. The historic fish diversity and fish recorded during this survey in the Shingwedzi River sub-catchment, South Africa.

[4] Engelbrecht, J. Private Limnology Consultant, Lydenburg, South Africa.

New frequency of occurrence (FROC) data was constructed by combining the findings of the Kleynhans *et al*. (2007) with the historic data gathered in this project. As part of this exercise certain sites were grouped together with the existing reference sites or were grouped on their own.

3.6.2 Results of the survey

Table 17 shows that during the surveys a total of 18 fish species, belonging to six families, were collected throughout the river system. Although specimens from of eleven species were not collected the absence of the *Labeobarbus marequensis*, *Hydrocynus vittatus* and the two eel species (*Anguilla marmorata* and *A. mossambica*) is of concern since both *H. vittatus* and *L. marequensis* is dependent on flow for breeding and the eels are the only true migrators that are negatively affected by barriers that prevent migration. The absence of *Barbus matozzi* agrees with the observations of Engelbrecht (pers com.[4]) who found the species absent in areas of historic distribution in other rivers in adjoining WMAs. The absence of Purple Labeo (*Labeo congoro*) and the Brown Squeaker (*Synodontis zambezensis*) specimens in the samples could be ascribed to the lack of deep pools. The fact that no *Barbus paludinosus* specimens were collected is ascribed to a lack of habitat, which includes shallow water adjacent to the wetted perimeter. When flow is diminished this is the type of habitat primarily affected. The absence of *Micralestes acutidens* is of real concern as this is one of the more common species, as is the case with *L. marequensis* . The specimens of the River Sardine (*Mesobola brevianalis*) and the Redeye Labeo (*Labeo cylindricus*), collected at sites 3 and 17 respectively, are the first records of the two species at the specific sites.
Two approaches were followed in the calculation of the FRAI scores. In the first approach each site was treated as an individual data point in order to establish the extent of anthropogenic impacts between sites. The second approach was to combine the survey results of the sites within the same ecoregion of each tributary. This resulted in groupings (Table 5) which each was then regarded as a reach within the river system (Kleynhans, 2007). For each of these reaches a FRAI score was then calculated.

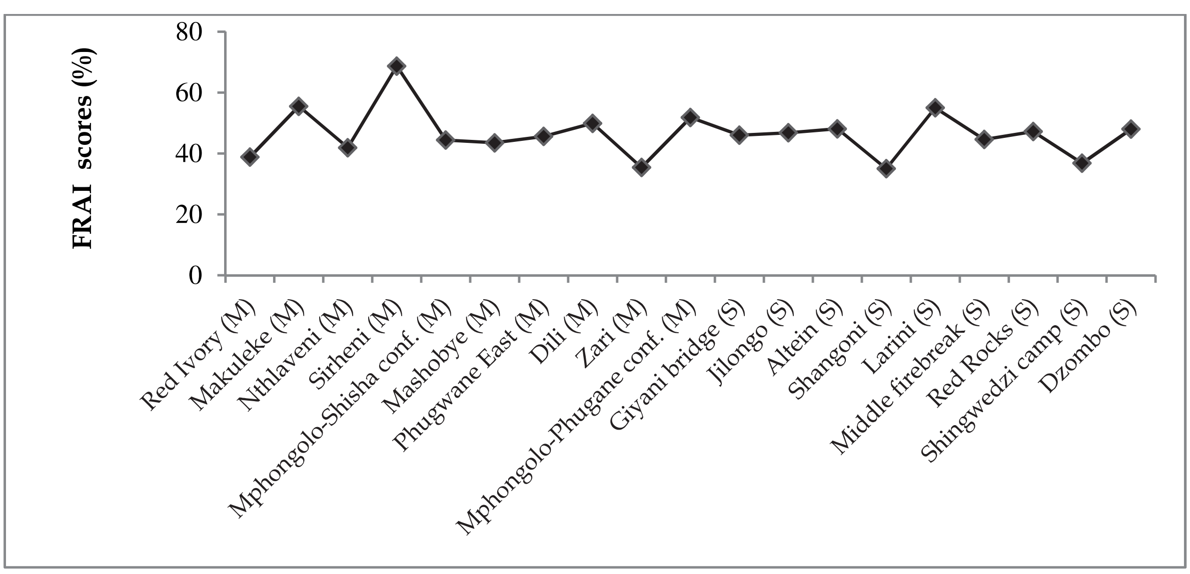

Fig. 10. The calculated Fish Response Assessment Index (FRAI) scores for the sites in the Shingwedzi River sub-catchment, South Africa (Adapted from Fouché & Vlok, 2010).

The FRAI results obtained for individual sites in the main stem of the river are shown in Figure 10. In the tributaries a trend of downstream improvement of the FRAI scores were observed. The exception was the low score obtained at Zari, in the Phugwane River, which indicates that a negative impact had occurred upstream of the site. Initially an upward trend was observed in the main stem Shingwedzi River, but a distinct decrease in the FRAI score occurred at Shangoni, below which a downward trend was observed.
Table 18 shows the FRAI scores for four of the reaches formed by the grouping of sites in the sub-level 2 ecoregions. Because Site 1 (Tshamidzi) had received water only one day prior to the March 2008 survey and Site 2 (Red Ivory) only had a stagnant pool Reach I was not included. The FRAI scores show that the reaches were in a reasonably good ecological state, with the Mphongolo River being the best. The Phugwane River, with a score of 60,8 was in the worst state and this could be ascribed to the fact that this tributary had the lowest and most erratic flow. Notably, the sites within reaches II, III and IV comprised a combination of sites lying outside and inside the boundaries of the KNP.

Reach	River/Tributary	Calculated FRAI score	Ecological category (EC)
II	Mphongolo and Shisha	78.7	B/C
III	Phugwane	60.8	C/D
IV	Shingwedzi	70.5	C
V	Shingwedzi	62.2	C

Table 18. The FRAI scores calculated for the ecological reaches in the Shingwedzi River and tributaries, South Africa. (Fouché & Vlok, 2010).

4. Conclusion

A review of the literature, as cited in this report, has shown that the perception exists that phosphate is the only water quality parameter adversely affected by activities within the sub-catchment and creates the idea that this river has low levels of pollution. This study has however shown that it was not only phosphate but that it also applied to the nitrogenous compounds, ammonium and nitrate. All three the compounds exceeded the TPC values set by the KNP at a number of sites. In addition the TPC values for pH, electrical conductivity and Total Dissolved Substances were also exceeded in a number of instances. Based on the above the calculated Water Quality Index scores shows that on average the water quality of the rivers could only be rated as of "medium" quality. These findings are supported by the low SASS and diatom index scores and are proof that the level of pollution is higher than originally thought. The fact that this is underpinned by the diatom based indices indicates that the pollution is a continuous and ongoing process.
It is of concern that the high nutrient content in the water and the resultant trophic status of the rivers, as is indicated by the high Trophic Diatom Index scores, is most certainly the result of anthropogenic impacts such as incorrect or lack of waste management practices and return flow from commercial agricultural. With an increase in the population, as is expected in the sub-catchment, these activities, and consequently pollution, will increase.
Research for this project has shown that historically the mean annual run-off (MAR) in the sub-catchment is low and consequently the flow in the Shingwedzi River and tributaries is not only low and episodic but also extremely variable. The current study however points to

even lower flows. The evidence for this is observed in the riparian vegetation where there is a visible encroachment by terrestrial woody species. Lower water levels during floods as well as a decrease in the base flow create a suitable environment that allows these woody terrestrial species to flourish and even become dominant in some instances. The second indication that flow has diminished lies in the absence of fish species that are dependent on flow for breeding such as the tigerfish, *H. vittatus,* and the Lowveld largescale yellowfish, *L. marequensis* (Fouché, 2009). In addition the fragmentation of the rivers caused by the building of weirs has destroyed the connectivity and consequently the loss of the only true migratory species within the system namely the eel *A. mossambica.*

Higher demands for water resulting from an ever increasing population will ultimately lead to the construction of more weirs to create water storage reservoirs. This will not only diminish the flow and lead to further fragmentation of the river but incorrect management of releases could negatively impact on the seasonality and flow regime of the river. This in turn will not only affect the reproductive strategies of instream biota such as fish but also the recruitment of the obligate riparian plant species. These weirs can act as migratory barriers and could prevent local migratory fish species to migrate for breeding and dispersion purposes.

Based on the above it can be concluded that the Shingwedzi River and its tributaries is not only vulnerable but increasingly under threat. The vulnerability is related to the fact that these rivers are in a water scarce area. To conserve these rivers, and in particular the role that they play within the landscape, is of utmost importance and can only be achieved through a well designed management plan that is properly implemented and maintained.

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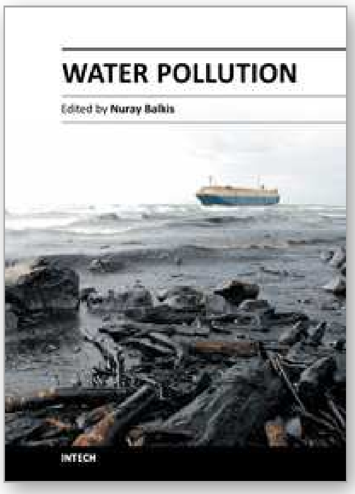

Water Pollution
Edited by Prof. Nuray Balkis

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Water pollution is a major global problem that requires ongoing evaluation and revision of water resource policy at all levels (from international down to individual aquifers and wells). It has been suggested that it is the leading worldwide cause of deaths and diseases, and that it accounts for the deaths of more than 14,000 people daily. In addition to the acute problems of water pollution in developing countries, industrialized countries continue to struggle with pollution problems as well. Water is typically referred to as polluted when it is impaired by anthropogenic contaminants and either does not support a human use, such as drinking water, and/or undergoes a marked shift in its ability to support its constituent biotic communities, such as fish. Natural phenomena such as volcanoes, algae blooms, storms, and earthquakes also cause major changes in water quality and the ecological status of water. Most water pollutants are eventually carried by rivers into the oceans.