The implementation of an aquatic toxicity index as a water quality monitoring tool in the Olifants River (Kruger National Park)

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Large sets of water quality data can leave water quality managers and decision-makers totally overwhelmed. In order to convey the interpretation of the data in a simplified and understandable manner, the water quality results from bi-monthly surveys undertaken at seven different sampling sites in the Letaba, Olifants, and Selati rivers over a two year period (February 1990 to April 1992) were reduced to index values, using a water quality index. The water quality index (Aquatic Toxicity Index or ATI) revealed spatial and temporal trends. The higher index values, recorded for the sampling sites towards the eastern part of the Kruger National Park (KNP), revealed that the water quality was better than the quality measured in the Olifants River on the western boundary. The lowest index values were calculated for the Selati River, with index values consistently below 50. Index values indicate that the water quality in the Selati River was unsuitable for supporting normal physiological processes in fish. The water quality of the Selati River had an immediate impact on the water quality of the Olifants River directly below the confluence. Lower index values recorded at sites further downstream was also attributed to the influence of the Selati River since there are no known point sources of contaminants within the boundaries of the KNP. The index scores also elucidated temporal trends with lower scores evident during winter months. This was due to reduced flow in the Olifants River and a greater contribution of contaminated water from the Selati River. Index values increased following the first seasonal rains due to a dilution effect. Very low index values were recorded at certain sites during flood periods due to increased turbidity, reduced oxygen, and increased metal concentrations.

Key words: water quality index, implementation, Olifants River, Kruger National Park, water quality management.

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Introduction

The Kruger National Park (KNP) receives water from six main rivers of which only four could be regarded as perennial rivers (Walmsley & Davies 1991). The largest, the Olifants River, has received considerable attention due to increased user demands. A significant proportion of the urban, industrial and mining activities were located in the catchment on the escarpment. The Loskop Dam acts as a buffer and, to some extent, ameliorates the effects of poor water quality. The major threat to the Olifants River within the KNP comes from mining activities in the Phalaborwa area (Moore *et al.* 1991) and flushing of silt from the Phalaborwa Barrage (Bauermann *et al.* 1995).

The Olifants River is regarded as the most mineralised river flowing through the KNP (Van Veelen 1991). Some of the major problems affecting water quality in the Olifants River have been identified as high silt loads, high salinity and pollutant levels (caused by farming practices, industrial and mining effluent discharges and possibly mine seepage). Venter & Deacon (1992) mentioned

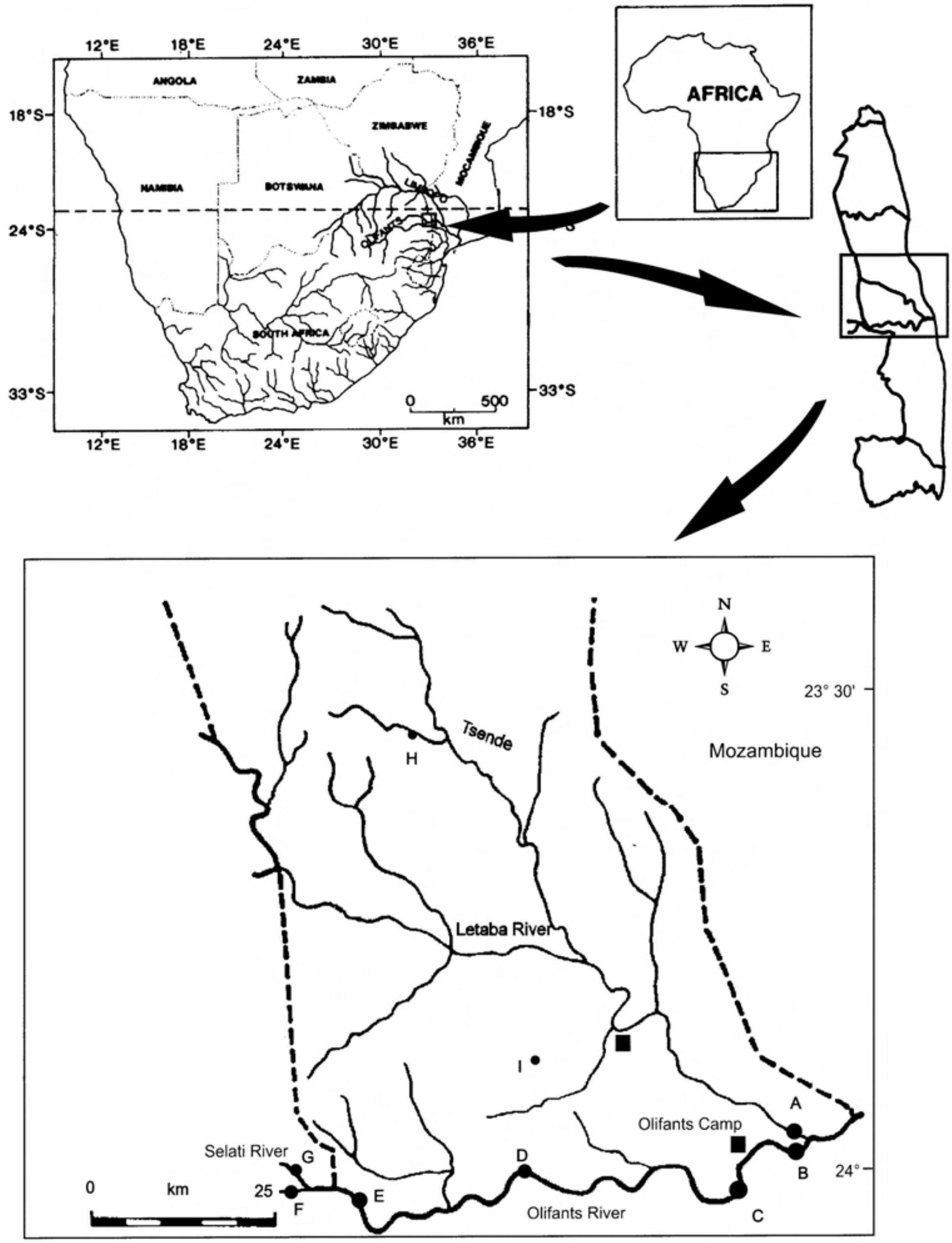

Fig. 1. Map indicating sampling sites situated on the Letaba River (A), Olifants River (B-Hiking trail camp, C-Balule, D-Nhlaralumi confluence, E-Mamba Weir and F-Phalaborwa Barrage), Selati River (G), Nhlanganini Dam (H) and Pioneer Dam (I).

contaminated dust, for example copper, as a possible source of pollution of the river. The dust is generated by mining activities.

A water quality monitoring programme was initiated towards the end of 1983 by the Department of Water Affairs and Forestry (DWAF), South African National Parks and other interested parties (Bruwer & De Wet 1983). Twenty-four sampling sites were selected for the six main rivers flowing through the KNP. The assessment of the water quality status and trends of the rivers was limited to certain chemical water quality variables (Van Veelen 1991). The lack of data on metal concentrations led to the initiation of a research project to determine the extent of metal contamination in the biotic and abiotic component of the Olifants River (Van Vuren *et al.* 1991).

During the sampling survey from 1990 to 1992, a large amount of water quality data was collected (Wepener 1997). In an attempt to simplify the interpretation of the data, a water quality indexing system for aquatic biota (i.e. aquatic toxicity index or ATI) was developed (Wepener *et al.* 1992a). The ATI was able to condense large amounts of water quality data by reducing it into two index values (viz. an index score and the lowest rating score). The index value produced gives an indication of the rivers' suitability for a specific beneficial use (i.e. maintenance of the aquatic ecosystem). The lowest rating score was also selected since the aggregation technique used to derive the final score will mask the most valuable information, namely the identity of the determinant which limits the water's "suitability-for-use" and the degree to which it occurs.

The principle objective of this paper was to assess the water quality status and the trends of the Olifants River and the Selati River during the course of the metal monitoring project, for the period February 1990 to June 1992 (Wepener 1997), by employing the ATI. The water quality of the different sites was compared to water quality of two reference sites within the KNP. Results obtained were also compared to the historical water quality status of the Olifants River for the period September 1983 to September 1989 as reported by Van Veelen (1991).

Material and Methods

Sampling sites.

Bi-monthly sampling was conducted for the period February 1990 to June 1992. Five sampling sites were situated within the borders of the KNP (four sites in the Olifants River and one in the Letaba River), whereas two sites were located outside the park on the western boundary (Fig. 1). Site A was situated in the Letaba River, close to the confluence with the Olifants River (a few kilometres downstream from DWAF site B8M30 at Mingerhout Dam). Site B was situated in the Olifants River close to the confluence with the Letaba River (± 2 km downstream of DWAF site B7M18 at the Olifants hiking trail base camp). The locations of sites C and D correspond to DWAF sites B7M17 (Balule rest camp) and B7M16 (Nhlaralumi confluence) whereas site E was situated close to Mamba Weir (DWAF site B7M15). Site F was below Phalaborwa barrage (DWAF site B7M15) and site G was situated in the Selati River at the low water bridge (both situated outside the park boundaries). The sites chosen for this study and those of the DWAF were not necessarily in the same locations, but in close enough proximity to compare the water quality results obtained.

Two reference sites were selected inside the KNP in order to compare the results obtained from the above-mentioned sampling sites with results from theoretically unpolluted sites. These reference sites (Hlanganini Dam - Site H and Pionier Dam - Site I) only receive water from catchment areas within the borders of the KNP. Water samples from sites H and I were collected during February 1992 and April 1992 respectively. Historical data for DWAF sites B7M18 and B7M15 were obtained from the National Water Quality Monitoring Programme database in Pretoria. No trace metal concentrations were available for the historical data and therefore index scores were only calculated using macro element data. Average daily flow and monthly flow data for the period 1990 to 1992 for site B7H015A01 (Mamba Weir) were obtained from the DWAF database. The flow data was included since Seymore *et al.* (1994) concluded that rainfall played a major role in .the water quality of the lower Olifants River.

Table 1
Individual ATI scores and corresponding lowest rating scores at Letaba River (Site A) and Hiking trail Camp (Site B) sampling sites. N.S. refers to no sample collected

	Letaba River (A)		Hiking trail (B)	
	Index score	Lowest rating	Index score	Lowest rating
February 1990	54.12	Zn (43.23)	60.87	Zn (3.69)
April 1990	49.56	Zn (18.81)	55.18	Zn (4.07)
June 1990	43.38	Zn (16)	55.83	Zn (11.99)
August 1990	40.53	Cr (40.64)	55.78	Cr (36.25)
October 1990	49.94	Cr (36.77)	50.33	Zn (17.13)
December 1990	83.18	Cr (78)	46.23	Cr (38.99)
February 1991	84.75	Pb (80.91)	85.92	Pb (78.71)
April 1991	62.54	Cu (58.27)	77.15	Cr (65.56)
June 1991	82.29	Cr (71.47)	79.29	Zn (71.57)
August 1991	82.68	Cr (70.69)	79.40	TDS (70.69)
October 1991	67.77	Zn (34.21)	79.14	TDS (57.67)
December 1991	77.36	Pb (68.50)	64.62	Zn (20.42)
February 1992	65.24	Zn (41.07)	73.93	NTU (60.57)
April 1992	N.S.	N.S.	N.S.	N.S.
June 1992	N.S.	N.S.	N.S.	N.S.

Water samples

It was not possible to collect the water samples from all the sites on the same day. However, in order to make temporal comparisons the samples were always collected in the same sequence (i.e. day 1 – sites F and G; day 2 – site E; day 3 – site D; day 4 – sites C, B and A). Water samples were collected bi-monthly at sites C, E, F and G from February 1990 to June 1992, whereas bi-monthly samples were collected at site A, B and D for the period February 1990 to February 1992.

Two sets of unfiltered water samples were collected (±10 cm below the surface) at the different sampling sites. All water samples and physical measurements were obtained between 14:00 and 16:00. The following physical variables were measured: dissolved oxygen (WTW Microprocessor, Model OXT 96), pH (Orion, Model SA 250) and turbidity (Novasina Analite 152 nephelometer). A set of water samples was preserved with mercuric chloride and stored at 4 °C until further analyses. These samples were analysed by the Institute for Water Quality Studies of the DWAF for ammonium (NH_4^+), fluoride (F), orthophosphate (PO_4), potassium (K), and total dissolved salts (TDS).

A second set of water samples was acidified (pH 2) with 55 % HNO_3 (AR) and evaporated on a hot plate to 5 ml. Each sample was made up to 50 ml with doubly distilled water.

Analytical procedures

All metal analyses were completed with a "Varian Spectra AA" atomic absorption spectrophotometer with an impact bead to increase sensitivity. The metals analysed and corresponding detection limits were chromium (0.006 mg/l), copper (0.003 mg/l), lead (0.01 mg/l), manganese (0.002 mg/l), nickel (0.1 mg/l) and zinc (0.001 mg/l). Standard curves were constructed for the different metals using commercially available certified stock solutions (Saarchem-Chemicals). An inter-laboratory check with the Chamber of Mines Research Organisation (COMRO) revealed no systematic difference in metal analyses.

Calculations and statistics

Aquatic toxicity index (ATI) scores for bi-monthly samples were calculated for each site. The water quality variables used to derive an index score were: dissolved oxygen (DO), pH, NH_4^+, TDS, K, PO_4, turbidity (NTU), fluoride (F), manganese (Mn), nickel (Ni), copper (Cu), chromium (Cr), lead (Pb) and zinc (Zn).

A final index score was produced for all the above-mentioned variables by employing a computer based software programme, WATER2 (for a detailed explanation of the aquatic toxicity index and software programme, refer to Wepener *et al.* 1992a). The final index score was presented as a "suitability for use" value between 0 and 100. A score of 10 and less

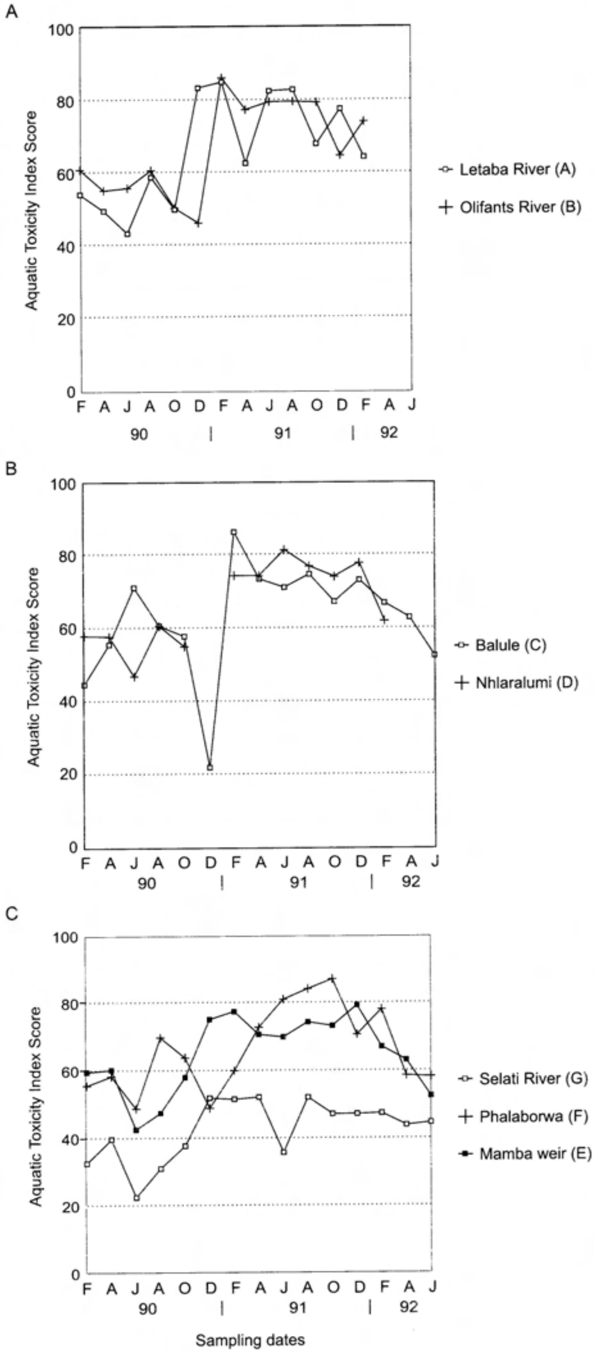

Fig. 2. Aquatic toxicity index rating scores of water quality at seven different sampling sites for the period February 1990 to June 1992.

reflecting water quality totally unsuitable for sustaining fish life and that of 100 representing pristine water conditions. The detailed water quality results used in the discussion are provided by Seymore *et al.* (1994).

Results

The water quality at the different sampling sites in the Olifants River, Selati River, and Letaba River was represented as ATI scores ranging between 0 and 100. The results obtained are presented graphically in Figure 2. The individual scores at each sampling site and corresponding lowest rating scores are presented in Tables 1, 2, and 3. The monthly flow recorded during the sampling period is presented in Figure 3.

It was evident from Fig. 2 that the water quality indicated certain temporal and spatial trends. From the ATI scores in Table 3 and Fig. 2C it was clear that the water quality of the Selati River was the lowest of all the sites monitored with an average score of 42.48. The water quality was influenced mainly by high TDS concentrations (mean of 1765 mg/l and maximum concentration measured 2064 mg/l). The high TDS concentrations in the Selati River were caused by elevated levels of anions and cations in the surface water. The major cationic and anionic constituents were found to be Na (mean concentration for the sampling period = 166 mg/l) and sulphate (SO_4 - mean concentration for the sampling period = 823 mg/l).

The general water quality trends at sites E and F showed a similar pattern, with the quality decreasing during June 1990 followed by an increase from August to October

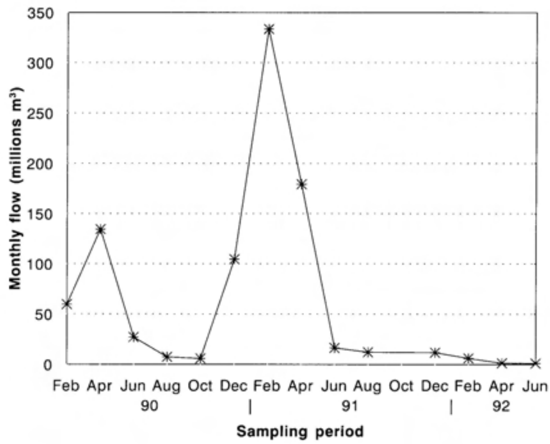

Fig. 3 Flow measurements (million m³) at Mamba Weir for the period February 1990 to June 1992.

1990 (Fig. 2C). The water quality (as reflected in the ATI scores) continued to increase at site E from December 1990 to February 1991. The water quality remained fairly constant (ATI scores between 69 and 78) from February 1991 to December 1991 (Fig. 2C). From December 1991 to June 1991 there was a steady decline in the ATI at site E. The ATI score at site F decreased from October 1990 to December 1990 (Fig. 2C) but the following surveys revealed a similar pattern in ATI scores to those observed at Mamba Weir. This is shown by the increase in water quality from February 1991 to October 1991 followed by a subsequent decrease in ATI scores from December 1991 to June 1992).

Table 2
Individual ATI scores and corresponding lowest rating scores at Balule (Site C) and Nhlaralumi confluence (Site D) sampling sites. N.S. refers to no sample collected

	Balule (C)		Nhlaralumi confluence (D)	
	Index score	Lowest rating	Index score	Lowest rating
February 1990	44.58	Zn (12.83)	57.92	Zn (14.93)
April 1990	55.61	Zn (16.79)	57.69	Zn (27.98)
June 1990	71.11	Zn (49.31)	46.81	Zn (8.6)
August 1990	60.65	Cr (35.73)	60.57	Cr (32.77)
October 1990	57.84	Cr (27.43)	55.01	Cr (27.84)
December 1990	21.78	Cr (16.23)	N.S.	N.S.
February 1991	86.31	NTU (61)	74.35	Cr (60.49)
April 1991	73.47	Cr (66.66)	74.29	Zn (59.25)
June 1991	71.11	Zn (49.31)	81.33	Zn (50.33)
August 1991	74.71	Zn (44.64)	76.88	TDS (66.93)
October 1991	67.18	NH_4^+ (28.91)	74.02	TDS (49.59)
December 1991	73.15	Zn (58.94)	77.73	Pb (67.94)
February 1992	66.84	Mn (47.02)	61.69	TDS (59.95)
April 1992	62.89	TDS (40.07)	N.S.	N.S.
June 1992	52.43	TDS (22.36)	N.S.	N.S.

It was evident from the results that the ATI scores at site E were closely related to changes in the water quality of the Selati River (site G). This resulted in the water quality of the Olifants River generally being poorer directly below the confluence with the Selati River when compared to the quality at site F above the confluence. It was, however interesting to note that during periods of high rainfall (Fig. 3) the water from the Selati River actually increased the water quality of the Olifants River at site E (i.e. increased index scores during December 1990 to April 1991). Low ATI scores recorded at the Selati River from June 1991 to June 1992 are reflected by concomitant lower scores at Mamba Weir when compared to site F above the confluence.

Metals were the major driving force water quality variables affecting the water quality and suitability-for- use at site F during most of the study period (Table 3). It was only to the end of the sampling period that variables such as NH_4^+, TDS and NTU were major water quality factors. High TDS and F concentrations accounted for the lowest individual rating scores in the Selati River. It was evident that the water quality at site E was initially (February 1990 to April 1991) determined by water quality conditions in the upper Olifants River. This is reflected in the lowest rating scores, i.e. metals and suspended solids (NTU). However, during the low flow period from June 1991 to June 1992 the water quality at site E was affected by TDS and F originating from the Selati River.

These changes in water quality were clearly related to changes in water flow measured at Mamba Weir during the study period (Fig. 3). The flow could be regarded as a direct measure of rainfall and subsequent runoff from the catchment during this period. The increase in flow during April 1990 is reflected by increased ATI scores at all three sites. Decreased flow experienced from June 1990 to October 1990 resulted in decreased water quality at sites E and G, but only during June 1990 at site F. The substantial increases in flow measured during December 1990 and April 1991 (Fig. 3) were accompanied by concomitant increases in water quality at sites E and G. This was in contrast to the decreased ATI scores recorded Phalaborwa Barrage during December 1990 to February 1991. As the flow decreased from June 1991 to June 1992, so did the ATI scores at sites E and G. However, the ATI scores at site F remained high (i.e. 70–86) during the corresponding period, and only decreased below 60 in June 1992 (Table 3).

The water quality at sites A, B, C and D demonstrated similar trends to sites E, F and G. There were however a few site specific anomalies which were not reflected in the ATI scores of sites further up or downstream (i.e. increased ATI score at site C during June 1990). The ATI score at site C decreased sharply (i.e. 57.8–21.7) from October 1990 to December 1990. This is attributed to sediment release (and an increase in associated sediment-bound metals, i.e. Cr) from Phalaborwa Barrage on the day of sampling (Fig. 2B). It was not possible to collect any samples from site D due to inaccessible roads. It could, however, be inferred that the ATI score would be similar to the score for Balule sampling site. It is important to note that the drastic decrease in the ATI score at site C during December 1990 is not reflected in the water quality of sites E, F and G due to the fact that the latter sites were sampled a day before the sediment release from the Barrage. The ATI scores at sites C and D increased to above 70 during February 1991 (Table 2). The scores remained above 60 for the period April 1991 to April 1992. It is important to note that the ATI scores at these sites were generally higher at these sites when compared to the site upstream at Mamba Weir. A decrease in index scores was recorded from February 1992 to June 1992 at site C. This pattern was similar to that observed at sites E and F, and it would also appear to be related to a steady decrease in flow during the corresponding period.

The influence of the water quality from the Selati River during the latter half of the sampling period was also visible at site D, and to

Table 3

Individual ATI scores and corresponding lowest rating scores at Mamba Weir (Site E), Phalaborwa Barrage (Site F) and Selati River (Site G) sampling sites. N.S. refers to no sample collected

	Mamba Weir (E)		Phalaborwa Barrage (F)		Selati River (G)	
	Index score	Lowest rating	Index score	Lowest rating	Index score	Lowest rating
February 1990	59.46	Zn (38.48)	55.50	Zn (8.57)	21.66	Zn (10.92)
April 1990	60.06	Zn (37.29)	58.19	Zn (11.31)	39.74	Zn (8.13)
June 1990	42.55	Zn (9.85)	48.74	Zn (12.73)	22.63	Zn (20.6)
August 1990	47.41	Cr (33.25)	69.55	Cr (37.30)	31.09	Cr (20.91)
October 1990	57.87	Zn (46.49)	63.64	Zn (12.74)	37.77	TDS (27.99)
December 1990	74.89	NTU (50.54)	48.85	Cr (44.91)	52.86	TDS (36.01)
February 1991	77.18	NTU (49.87)	59.81	Mn (10.02)	51.47	F (27.29)
April 1991	70.43	NTU (66.89)	72.54	Mn (15.23)	52.09	F (30.41)
June 1991	69.68	Cr (67.74)	80.66	Zn (64.56)	35.78	NH_4^+ (28.96)
August 1991	74.06	TDS (64.61)	83.79	Cr (71.37)	52.03	TDS (28.21)
October 1991	72.94	TDS (47.74)	81.18	TDS (78.81)	47.11	TDS (25.65)
December 1991	78.98	F (76.54)	86.67	Pb (68.93)	47.12T	DS (26.28)
February 1992	66.84	TDS (45.23)	70.38	NH_4^+ (80.03)	47.38	TDS (22.06)
April 1992	62.91	TDS (30.11)	77.82	NTU (58.39)	43.84	TDS (23.96)
June 1992	52.43	TDS (28.32)	58.42	NH_4^+ (55.32)	44.62	TDS (23.46)

a lesser degree at site C. This is reflected in TDS, which accounted for the lowest rating score during August and October 1991 and February 1992 at site D. During the initial sampling period (February 1990 to August 1991) the water quality at sites C and D was influenced by conditions in the upper reaches of the Olifants River (i.e. metals contributing to the lowest rating scores).

The water quality at sites A and B displayed similar trends. However, in most instances the ATI scores of the Letaba River were lower than the scores in the Olifants River at site B (Fig. 2A). This could most probably be related to different activities in the upper catchments of the specific rivers. The different conditions in the respective catchments are clearly demonstrated by the ATI scores recorded during December 1990. The score in the Olifants River decreased due to water release from the Barrage, whereas the score at site A increased substantially to 83.2 (Table 1). For nine out of the 13 surveys the ATI scores indicated that the water quality at site B was in a better condition than the water quality of the sites on the western boundary of the park (i.e. sites E and F).

The ATI scores of Hlanganini Dam and Pionier Dam were 74.6 and 73.3 respectively. The average ATI score for Site B for the period 1990-1992 was 66.81 compared to the average ATI score, based on historical data, of 71.45 for the period 1983-1989. The average ATI score at Site E based on historical data was slightly lower (62.67) during 1983-1989 period than the period from 1990-1992 (65.91). It is important to bear in mind that the historical index scores do not include information on metal concentrations.

Discussion

Water quality indices have been implemented successfully in interpreting trends in water quality in rivers in the United Kingdom (Tyson & House 1989), India (Bhargava 1983) and Nigeria (Egborge & Benka-Cocker 1986). Seymore *et al.* (1994) concluded that "rainfall" played a major role in the water quality of the lower Olifants River. The implementation of an aquatic toxicity index on the water quality data from the Olifants River, Letaba River and Selati River indicated that definite spatial and temporal trends could be observed.

Although there were site-specific changes in the water quality, the general trend at all the sites investigated, was similar. There was an initial decrease of water quality during periods of low flow from June 1990 to October 1990, followed by an improvement of water quality during the rainy season (December 1990 to April 1991). The water quality remained fairly constant from April 1991 to December 1991. However, the prolonged period of low flow from June 1991 to June 1992 resulted in ATI scores beginning to decline from December 1991 to June 1992.

It was evident that the water quality of the Selati River had a direct influence on the water quality of the Olifants River directly below the confluence. Furthermore, the Selati River also had an effect on the sampling sites further downstream during periods of low flow (April 1991 to June 1992). However this effect dissipated further downstream towards the eastern boundary. The water quality of the Olifants River increased towards the eastern boundary.

Although the regional geology of the catchment area does contribute to the natural mineralisation of the surface and ground water (Theron *et al.* 1991), it was unlikely that the high TDS concentrations could be attributed to the regional geology alone. Although the lower-catchment of the Olifants River falls within the same granitic geological region as the Selati River, the mean TDS concentration at site F (360 mg/l) in the Olifants River (approximately two kilometres upstream from the confluence with the Selati River) were much lower when compared to the mean TDS levels in the Selati River (1765 mg/l). It could, therefore, be inferred that the geogenic effects were of lesser importance than the anthropogenic effects.

The point and non-point sources of Na, K, SO_4, Mg, and Cl are derived from mining activities in the vicinity of Phalaborwa. These mining operations are dependent on water abstraction from the Olifants River, and contaminated water then returns to the Selati River due to seepage from settling ponds and storm water overflow (CSIR 1990). The combined effects of anions and cations, as reflected in the low ATI scores, was the most probable cause of the low fish species diversity found in the Selati River during this survey (Seymore *et al.* 1994; Wepener 1997).

The high mean TDS (1765 mg/l) and F (4 mg/l) concentrations, measured in the Selati River, gives rise to concern as these determinants seem to be the main factors lowering the water quality and affecting aquatic biota at this sampling site (Table 3 – lowest rating scores). Research by Burnham & Peterka (1975) and Smith *et al.* (1985) showed that increased SO_4 and F concentrations could result in mortalities to larval fathead minnows (*Pimephales promelas*). From biological surveys conducted in the Selati River (Wepener 1997) it was evident that these constituents have had an effect on the aquatic fauna.

The results indicated that the Selati River has a major influence on the TDS levels in the Olifants River within the KNP boundaries. This was particularly relevant during the latter half of the sampling period. The TDS levels increase in the Olifants River after the confluence with the Selati River and show a slight improvement at the eastern most sampling site (Wepener 1997). This resulted in TDS concentrations being the major factor affecting the ATI score, and therefore the suitability-for-use, at Mamba Weir. To a lesser extent this was also observed at the other sampling sites in the Olifants River. It must be borne in mind that although the water quality is discussed in terms of ATI and the lowest index rating scores, the other water quality variables also contribute to the suitability-for-use of the water. Therefore, TDS would not be the only variable affecting the water quality, but rather a combination of all the variables together. The lowest index rating score only highlights the variable which produces the lowest index score.

It was noted that during this sampling survey the water quality of the Selati River was mainly influenced by TDS and trace metal concentrations and not by high turbidity levels. The water quality of the Olifants River was, however, influenced by both TDS and turbidity. Erosion of land surfaces in catchment areas by rain and wind is a continuous and historically natural process. In the case of the Olifants River land use practices such as overgrazing, non-contour ploughing and the removal of riparian vegetation have accelerated the process of erosion and resulted in increased suspended solids in the river. Most suspended solids originating from the upper-catchment of the Olifants River have been deposited in Phalaborwa Barrage. This has resulted in a 46 % reduction in the capacity of the Barrage (Theron *et al.* 1991). During periods of high flow the Barrage has been flushed, and high concentrations of suspended solids were released into the park. Suspended solids concentrations of 24 000 mg/l to 77 000 mg/l and consequent decreased oxygen concentrations have resulted in massive fish kills in the Olifants River (Venter & Deacon 1992; Bauermann *et al.* 1995). The high concentrations of suspended solids measured in the Olifants River during December 1990 and February 1991 were partly responsible for the low ATI scores at sampling sites B, C and F during these surveys. It must be borne in mind that that the samples from sites B and C were collected after the release of water with high suspended solid concentrations from the Phalaborwa Barrage. The sample from site F was taken before water release from the Barrage. The increased turbidity recorded at site F during December 1990 could be attributed to the overflow of turbid water over the Barrage wall. This resulted in fairly localised increases in turbidity. Low turbidities were recorded at Mamba Weir during the corresponding period. It was likely that the increased volume of non-turbid water from the Selati River contributed in diluting the turbid water from the Barrage, thereby reducing the turbidity at this site.

Moore *et al.* (1991) speculated that the increased turbidities recorded in the Olifants River potentially have a number of effects on aquatic organisms in the river. These include effects on predator-prey interactions and physiological impairments such as gill function, reduced foraging efficiency, growth and destruction of spawning habitats. Moore *et al.* 1991 ascribed the decreased distribution of endangered and scarce species such as Pel's Fishing Owl (*Scotopeli peli*) and tigerfish (*Hydrocynus vittatus*) to high turbidity. Increased suspended solids concentrations, together with metallic elements have been cited as reasons for the decreased distribution of four fish species and the disappearance of six fish species from the Olifants River (Russell & Rogers 1991).

Concentrations of metals increased at most sites during periods of low flow (June 1990 to October 1990 and December 1991 to June 1992). This was attributed to the loss of the dilution factor associated with increased runoff (Seymore *et al.* 1994). Although the flow during December 1990 increased to 104.5 million m^3 compared to 4.1 million m^3 in September 1990 (Figure 3), the total metal concentrations increased, instead of decreasing as would be expected from the dilution effect of increased water volume. This could be attributed to increases in suspended solids, resulting in increased metal adsorption to silt particles, as well as liberation of deposited metals from the sediments. With the subsequent increased flow experienced from January 1991 to April 1991, the total metal concentrations and TDS concentrations decreased in the water column due the dilution effect of increased volume. During this period the suspended solids concentrations were much lower than the corresponding period in 1990.

In most natural water systems trace metal concentrations are low, and any increase could lead to contamination of the ecosystem, resulting in potential adverse effects. From Tables 1 to 3 it was clear that metals (specifically Cr, Mn, Pb and Zn) were important factors in decreasing the suitability-for-use of the water at all the sampling sites. The mean metal concentrations at all the sites monitored (Wepener 1997) clearly showed that the Selati River was the main source of Cu and Mn contamination, whereas the main sources of the other metals were in the upper catchment of the Olifants River.

High NH_4^+ concentrations at Sites F and G (Table 3) and high orthophosphate concentrations at Site G (Seymore *et al.* 1994) could be attributed to industrial pollution and possibly sewage effluent from the towns in close proximity to the Olifants and Selati Rivers. High levels of these nutrients may lead to eutrophication problems at these sites. The high concentrations of NH_4^+ at Site C during the low flow period in October 1991 could be attributed to the excretory products of hippopotami in densely populated pools.

Experimental research showed that the measured levels of total metal concentrations in the Olifants and Selati rivers (zinc–1.5 mg/l; chromium–850 μg/l; and manganese–2.3 mg/l) may have negative effects on the physiology of fish (Wepener *et al.* 1992b, Wepener *et al.* 1992c, Wepener *et al.* 1992d). Increased metal concentrations, together with high TDS and turbidity levels could have resulted in altered physiological effects of fish in these regions. The average ATI score of below 50 for the Selati River may explain the virtual absence of "pollution sensitive" fish species in the Selati River, i.e. Cyprinid species (Seymore *et al.* 1994; Wepener 1997).

The ATI scores at the reference sites (Sites H and I) clearly indicated that the water quality of the Olifants River was influenced by anthropogenic activities in the upper-catchment rather than geogenic factors. The water quality in the Olifants River did not change much from 1983 to 1992 at Site E but there was a slight decrease in water quality at Site B over the same period. Although the ATI scores of the Olifants River were indicative of contamination and/or sedimentation effects, the average ATI values were above 60 for most of the time. It could therefore be surmised that the Olifants River would sustain normal fish life. However, periodic pollution events and increased siltation have resulted in a number of fish kills and could possibly have had an effect on the biotic diversity of the lower Olifants River.

Conclusions

The application of the ATI to data sets from Hlanganini Dam, Pionier Dam, the Olifants, Letaba and Selati rivers demonstrated that the indexing system complies with the requirements identified by Wepener *et al.* (1992a). The ATI was able to demonstrate seasonal cycles and trends in water quality and highlighted river reaches which showed a change in quality. The advantage of using a computerised ATI is vested in the fact that a number of variables can be interpreted immediately and the resultant index value will enable managers to pinpoint deteriorating water quality and even the possible source of the decreased water quality. The ATI, therefore, produces valuable management information in a timely and efficient manner. The ATI scores highlighted the same water quality trends observed by Seymore *et al.* (1994). It is proposed that the relationship between results generated by the ATI and information produced by a biotic index such as SASS4 is investigated. This is of particular relevance since the use of water quality indices, in combination with biotic, habitat, hydrological and riparian vegetation indices have been proposed as tools in the National River Health Programme (Uys *et al.* 1996). The use of the ATI could lead to greater certainty when making management decisions concerned with water quality management in the Kruger National Park.

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