Variations in selected water quality variables and metal concentrations in the sediment of the lower Olifants and Selati rivers, South Africa

THARINA SEYMORE, H.H. DU PREEZ, J.H.J. VAN VUREN, A. DEACON and G. STRYDOM

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A survey of the water and sediment quality of the lower Olifants River and lower Selati River was carried out. Metal concentrations (Cr, Cu, Fe, Mn, Ni, Pb, Sr and Zn) in the water and sediment, as well as the physical and chemical characteristics of the water were determined over a two-year period (April 1990 – February 1992). The water quality of the lower Selati River, which flows through the Phalaborwa area, was found to be influenced by the mining and industrial activities in the area. It was also the case with the lower Olifants River after the Selati-Olifants confluence, although the concentrations of most variables did decrease from the western side of the Kruger National Park to the eastern side due to dilution of the water by tributaries of the Olifants River. Variables of special concern were sodium, fluoride, chloride, sulphate, potassium, the total dissolved salts and the metal concentrations (except strontium). The water quality of the Selati River in the study area is a great cause of concern and a further degradation thereof cannot be afforded.

Key words: water quality, sediment, metals.

Tharina Seymore, H.H. du Preez, J.H.J. van Vuren, A. Deacon and G. Strydom, Department of Zoology and Research Unit for Aquatic and Terrestrial Ecosystems, Rand Afrikaans University, P.O. Box 524, Auckland Park, 2006 Republic of South Africa.

Introduction

In South Africa, which is a developing country, large-scale development can be expected to take place. Unfortunately, increasing mining, industrial, agricultural and domestic activities usually lead to water pollution unless certain precautions are taken. These precautions can, however, be very costly and are therefore not always enforced. This may be one of the reasons why the water quality of many South African rivers has been deteriorating over the last few years.

Pollutants can have a direct or indirect effect on aquatic species, for instance a reduction in the survival, growth and reproduction of the species, behavioural changes and an unacceptable percentage of gross deformities or visible tumours in organisms (Stephan 1986). It is, however, difficult to relate specific effects to specific pollutants, as the stage of the organism's development, the physical and chemical quality of the environment (e.g. temperature, pH, water hardness), the chemical species and complexes present, and the interactions between pollutants all play a role in the toxicity of a substance (Hellawell 1986). Furthermore, interactions between pollutants can be either additive (a combined effect), antagonistic (interfering with one another) or synergistic (the overall effect is greater than the sum of the effects of each one acting alone).

Mining and industrial activities in the Phalaborwa area caused this study to be undertaken in order to determine the effect of these activities on the water and sediment quality of the lower Selati River and consequently the lower Olifants River (The Selati River is a tributary of the Olifants River). Metal concentrations (Cr, Cu, Fe, Mn, Ni, Pb, Sr and Zn) in the water and sediment, as well as the physical and chemical characteristics of the water, were thus investigated.

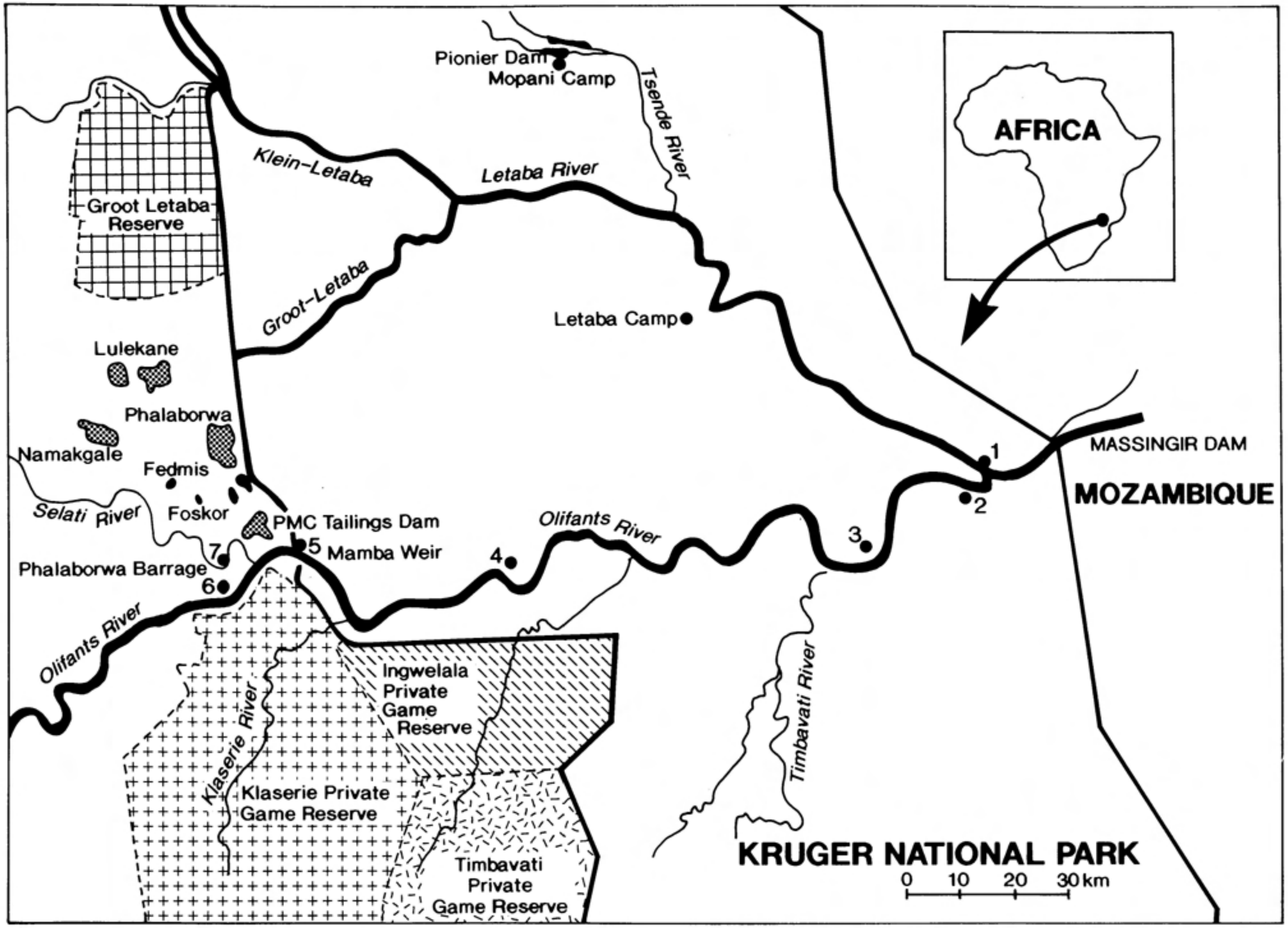

Fig. 1. The lower Olfifants River catchment, indicating the study area and the sampling localities 1 to 7.

Materials and methods

Water and sediment were sampled every alternate month, from April 1990 to February 1992, at six sampling sites (Fig. 1) along the lower Olifants River and one (locality 7) in the Selati River. In February 1992, sampling was also done at Pionier Dam. This dam is situated in the Tsende River (Kruger National Park), receiving no effluents from outside the park, and was therefore used as a natural reference point in the study.

Two surface-water samples were collected at each locality on a bi-monthly basis. One sample was preserved with mercuric chloride ($HgCl_2$). It was refrigerated prior to analysis for sodium (Na), magnesium (Mg), calcium (Ca), fluoride (F^-), chloride (Cl^-), nitrate and nitrite (NO_3+NO_2-N), sulphates (SO_4), phosphates (PO_4-P), total alkalinity (as $CaCO_3$), silicon (Si), potassium (K), ammonia (NH_4-N) and total dissolved salts (TDS). These analyses were carried out at the Institute for Water Quality Studies, Department of Water Affairs and Forestry. The other sample was frozen, until it could be subjected to metal concentration analysis in the laboratory at the Rand Afrikaans University.

During these visits, the following variables of surface water were determined on site at each locality: pH (ORION, Model SA250), water temperature (WTW microprocessor, Model OXT 96), dissolved and percentage saturation oxygen (WTW microprocessor, Model OXT 96), turbidity (Secci-disc) and conductivity (Jenway, Model 4070). During the first year these variables were determined once a day in the afternoon. However, in order to determine whether there would be any difference between readings taken in the morning and readings taken in the afternoon, these variables were determined twice a day at localities 3, 4, 5 and 7 during the second year. Readings were taken between 7:00 and 9:00 and between 11:00 and 17:00. At localities 1,2 and 6, as well as the Pionier Dam, the variables were only determined once a day between 11:00 and 17:00.

Sediment samples were taken with a pole-operated Ekman grab or by hand, using a plastic bottle (when the underlying substratum was rock). The samples were frozen until further analysis in the environmental laboratory at the Rand Afrikaans University. Using standard methods, the thawed water and sediment samples were analysed for metal concentrations (Giesy & Wiener 1977; Franson 1989).

Results

Water

In general, the readings for the selected physical and chemical variables (Tables 1, 2 and 4) were found to be slightly higher during the afternoon, except for the conductivity, which was slightly lower. The pH of water in localities 1 to 6 ranged from 7,6 to as high as 9,1 over the two-year period, while the pH of the water in Pionier Dam and locality 7 (in the Selati River) was slightly lower, namely 8,1 to 8,8 and 7,8 to 8,0 respectively. Afternoon temperatures recorded during wintertime were on average 19,2 ± 1,4 °C for the first year and 20,4 ± 2,2 °C for the second year, while afternoon average temperatures during spring and summer were 26,7 °C ± 2,3 °C for the first year and 30,6 °C ± 1,5 °C for the second year. The overall temperatures were higher in the second year than in the first (Table 4), as a result of the low river flow during the drought. The Olifants River and Pionier Dam seemed to be very well oxygenated. Locality 7, however, had a low dissolved oxygen concentration of 5,6 ± 1,5 to 5,7 ± 0,3 mg/l. In winter the water was the least turbid, while the highest turbidity occurred in summer, especially in December 1990, when values of 1 to 3 cm were measured (Table 1a). During this month, heavy rainfall occurred and the entire length of the river flowing through the park was flooded. Conductivity shows a different pattern for each year, but in each case locality 7 had the highest conductivity (230 ± 40 mS/m and 230 ± 10 mS/m for years 1 and 2 respectively) and locality 1 the lowest (30 ± 10 mS/m and 40 ± 10 mS/m for years 1 and 2 respectively).

The variables Na, Mg, Ca, F, Cl, SO_4 and K, as well as the total alkalinity and TDS were the highest in concentration at locality 7 (in the Selati River) and the lowest at localities 1 (in the Letaba River) and 6 (located before the Selati-Olifants confluence) for both years (Table 4). Although no values were available for locality 1 in the first year, the general trends seemed to follow the same pattern as

Table 1a

Physical and chemical variables of surface water from the Olifants River (Kruger National Park) and Selati River (April 1990-February 1991)

Locality	Month	pH	Temp °C	Dissolved Oxygen mg/l	Oxygen Saturation %	Turbidity cm	# EC @ 25 °C mS/m	Na mg/l	Mg mg/l	Ca mg/l	F mg/l	Cl mg/l	NO_3 + NO_2-N mg/l	SO_4 mg/l	PO_4 mg/l	Alkalinity as $CaCO_3$ mg/l	Silica mg/l	K mg/l	NH_4-N mg/l	TDS mg/l
1	Apr 1990	8,3	24	N/A	N/A	18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	June 1990	8,4	20	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Aug 1990	8,6	18	11,8	129	32	44	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Oct 1990	8,8	28	10,8	130	N/A	33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Dec 1990	8,3	26	6,8	86	14	35	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Feb 1991	8	30	7,4	113	14	18	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2	Apr 1990	8,9	23	N/A	N/A	15	48	36	22	26	0,59	45	0,03	58	0,009	130	6,9	4,8	0,05	357
	June 1990	8,5	19	N/A	N/A	2	67	53	36	35	0,77	63	0,01	111	0,008	165	4,5	8,8	0,01	512
	Aug 1990	8,5	19	9,9	105	60	91	75	57	43	1,21	88	0,01	171	0,009	215	5,6	15,2	0,02	717
	Oct 1990	8,6	30	9,5	120	N/A	92	61	51	41	1,17	69	0,02	183	0,011	175	7,7	17,0	0,04	644
	Dec 1990	8,1	26	5,3	74	1	44	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	100	N/A	N/A	N/A	N/A
	Feb 1991	8,3	30	7,9	124	16	29	21	13	24	0,33	20	0,19	53	0,006	72	6,2	3,8	0,03	229
3	Apr 1990	9.1	22	N/A	N/A	17	50	36	21	26	0,41	44	0,01	59	0,007	128	6,9	4,6	0,04	354
	June 1990	8,5	19	N/A	N/A	46	80	58	42	39	0,91	67	0,02	148	0,003	166	4,5	11,3	0,03	572
	Aug 1990	8,4	19	10,6	114	60	99	77	60	43	1,23	89	0,01	186	0,009	210	5,7	15,9	0,04	735
	Oct 1990	8,4	27	11,3	148	32	79	59	47	36	0,76	79	0,03	143	0,022	174	7,7	15,9	0,04	601
	Dec 1990	7,8	23	6,4	76	1	230	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	150	N/A	N/A	N/A	N/A
	Feb 1991	8,4	29	7,2	107	11	32	20	10	24	0,40	22	0,21	52	0,017	78	6,7	3,8	0,01	235
4	Apr 1990	9,0	25	N/A	N/A	18	43	32	21	28	0,42	28	0,02	51	0,015	132	7,9	5,5	0,02	335
	June 1990	8,6	19	N/A	N/A	45	65	55	37	34	0,78	66	0,02	103	0,005	172	4,4	8,6	0,05	518
	Aug 1990	8,6	17	9,3	99	80	90	72	52	37	1,03	85	0,01	158	0,013	196	4,8	12,8	0,03	662
	Oct 1990	8,7	25	11,4	134	33	109	73	64	50	1,15	92	0,03	262	0,021	169	9,5	22,9	0,05	781
	Dec 1990	N/A	N/A	N/A	N/A	N/A	45	18	24	41	0,33	24	1,19	14	0,038	182	5,7	3,8	0,12	358
	Feb 1991	8,3	28	N/A	125	11	32	21	11	25	0,44	23	0,26	61	0,016	75	6,6	4,3	0,02	244
5	Apr 1990	8,7	24	N/A	N/A	17	55	37	23	28	0,44	41	0,28	59	0,012	124	7,7	5,0	0,05	354
	June 1990	8,6	18	N/A	N/A	43	63	57	31	33	0,66	77	0,10	134	0,011	174	5,1	10,6	0,05	582
	Aug 1990	8,2	22	13,8	150	70	99	78	59	41	1,12	90	0,12	174	0,016	204	6,3	13,9	0,06	712
	Oct 1990	8,6	24	10,1	121	60	117	95	75	49	1,21	110	0,02	310	0,023	196	9,8	27,1	0,06	914
	Dec 1990	8,1	28	N/A	82	1	51	42	19	29	0,35	45	0,02	45	0,021	132	9,6	4,7	0,03	356
	Feb 1991	8,2	28	N/A	109	11	29	20	11	25	0,44	17	0,05	56	0,014	83	6,6	3,7	0,01	240
6	Apr 1990	8,6	21	N/A	N/A	20	34	31	17	23	0,31	37	0,30	22	0,010	117	8,3	2,1	0,05	285
	June 1990	8,5	17	N/A	N/A	44	48	47	25	29	0,40	53	0,07	40	0,013	178	5,2	2,4	0,04	418
	Aug 1990	8,5	19	10,4	117	35	57	57	33	26	0,32	68	0,09	33	0,015	194	5,9	2,0	0,06	462
	Oct 1990	8,6	22	9,2	103	27	53	49	24	27	0,33	55	0,01	25	0,007	183	9,2	2,5	0,05	414
	Dec 1990	8,2	26	N/A	88	3	N/A	36	16	26	0,30	40	0,46	20	0,008	130	9,2	2,4	0,05	303
	Feb 1991	8,4	27	N/A	129	18	30	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7	Apr 1990	7,9	23	N/A	N/A	48	164	121	107	53	2,82	130	0,38	564	0,014	178	10,6	60,2	0,06	1267
	June 1990	7,8	21	N/A	N/A	23	287	191	177	97	7,70	215	1,02	906	0,012	251	14,4	72,5	0,07	1990
	Aug 1990	7,6	20	5,4	64	43	244	172	193	107	4,28	211	0,49	1006	0,111	204	16,0	87,9	0,06	2046
	Oct 1990	7,9	22	5,9	67	34	225	170	158	82	4,34	197	0,76	789	0,077	233	15,2	71,9	0,09	1775
	Dec 1990	7,9	26	N/A	64	3	190	145	120	71	3,32	176	0,70	615	0,076	215	13,9	62,1	0,19	1472
	Feb 1991	7,9	26	N/A	71	60	239	160	179	107	4,50	198	0,98	903	0,020	200	17,4	82,7	N/A	1528

– Electrical Conductivity N/A – Not available

Table 1b

Physical and chemical variables of surface water from the Olifants River (Kruger National Park) and Selati River (April 1991-February 1992)

Locality	Month	pH	Temp °C	Dissolved Oxygen mg/l	Oxygen Saturation %	Turbidity cm	# EC @ 25 °C mS/m	Na mg/l	Mg mg/l	Ca mg/l	F mg/l	Cl mg/l	NO_3 + NO_2-N mg/l	SO_4 mg/l	PO_4 mg/l	Alkalinity as $CaCO_3$ mg/l	Silica mg/l	K mg/l	NH_4-N mg/l	TDS mg/l
1	Apr 1991	-/8,4	-/26	-/7,2	-/89	-/18	-/22	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	June 1991	-/8,4	-/22	-/9,8	-/112	N/A	-/31	22	11	23	0,2	28	0,04	6	0,059	122	9,3	5,5	0,05	243
	Aug 1991	-/8,7	-/23	-/11,8	-/140	N/A	-/33	27	14	22	0,2	32	0,04	4	0,021	129	8,1	6,0	0,04	262
	Oct 1991	-/8,5	-/29	-/5,4	-/73	N/A	-/49	57	20	21	0,4	66	0,04	6	0,014	170	10,8	11,3	0,06	389
	Jan 1992	-/8,8	-/31	-/8,1	-/115	N/A	-/56	47	29	31	0,5	49	0,04	56	0,023	165	9,0	7,3	0,05	421
	Feb 1992	-/8,5	-/31	-/8,3	-/112	N/A	-/33	27	10	21	0,3	27	0,66	4	0,036	115	10,3	7,0	0,07	237
2	Apr 1991	-/8,6	-/24	-/9,0	-/107	-/37	-/38	32	20	26	0,3	34	0,09	48	0,030	122	7,8	3,9	0,03	314
	June 1991	-/8,8	-/20	-/10,7	-/118	-/>49	-/56	41	26	32	0,3	47	0,15	59	0,021	164	7,0	5,0	0,04	409
	Aug 1991	-/8,8	-/24	-/10,0	-/124	N/A	-/80	64	44	36	0,8	71	0,04	133	0,019	198	4,9	12,2	0,04	602
	Oct 1991	-/8,6	-/31	-/8,7	-/121	N/A	-/118	105	64	44	1,3	125	0,04	220	0,015	241	7,2	20,5	0,06	872
	Jan 1992	-/8,7	-/32	-/7,4	-/101	-/22	-/57	65	20	26	0,4	75	0,06	14	0,050	172	9,9	9,9	0,13	420
	Feb 1992	-/8,8	-/32	-/10,7	-/139	N/A	-/90	75	48	38	0,8	84	0,04	121	0,024	224	7,2	16,1	0,06	655
3	Apr 1991	8,6/8,7	21/25	7,6/8,7	87/100	29/33	43/38	33	21	27	0,4	36	0,23	50	0,020	122	8,1	4,2	0,04	320
	June 1991	8,6/8,5	19/20	8,6/8,6	94/94	67/67	55/55	42	26	31	0,3	48	0,22	69	0,030	157	6,8	5,1	0,04	412
	Aug 1991	8,7/8,7	19/22	7,9/9,8	93/119	>76/>76>	83/82	64	45	36	0,8	73	0,04	139	0,014	191	4,1	11,9	0,04	601
	Oct 1991	8,2/8,5	27/33	4,8/8,2	84/130	62/>62	132/132	114	84	49	1,4	135	0,04	298	0,013	254	8,5	24,3	0,62	1016
	Jan 1992	8,5/8,7	29/32	7,1/8,1	93/114	19/23	67/68	55	36	36	0,7	57	0,04	96	0,030	166	9,1	9,7	0,06	493
	Feb 1992	8,1/8,5	28/32	2,4/10,0	32/140	37/37	114/111	92	66	52	1,0	112	0,04	177	0,027	280	10,0	21,0	0,04	862
4	Apr 1991	8,6/8,7	22/26	8,3/8,7	93/108	36/36	44/40	30	20	28	0,3	33	0,24	50	0,020	117	7,8	3,7	0,04	309
	June 1991	8,6/8,6	18/20	8,7/9,6	95/108	63/63	53/54	39	25	32	0,4	45	0,31	60	0,027	156	7,3	5,4	0,04	395
	Aug 1991	9,0/8,9	19/22	7,7/8,8	91/107	>105/>105	96/93	72	54	37	1,1	82	0,04	183	0,010	189	3,4	16,5	0,04	675
	Oct 1991	8,6/8,2	27/33	6,6/9,7	80/141	>62/>62	140/141	122	96	49	1,9	140	0,04	343	0,017	236	8,2	30,9	0,05	1068
	Jan 1992	8,6/8,7	28/31	6,9/8,0	90/112	29/23	66/66	53	35	35	1,0	56	0,04	96	0,030	158	8,9	9,6	0,04	477
	Feb 1992	8,2/8,3	30/32	3,3/6,2	46/86	20/21	111/108	89	64	47	1,1	103	0,04	209	0,028	237	9,4	19,4	0,04	821
5	Apr 1991	8,6/8,6	22/24	7,7/8,1	89/92	41/41	41/39	31	20	25	0,4	36	0,37	53	0,010	113	7,6	3,7	0,04	284
	June 1991	8,6/8,5	15/18	9,3/10,5	94/113	22/26	56/55	41	27	31	0,4	48	0,41	77	0,085	154	7,8	7,0	0,11	420
	Aug 1991	9,1/9,0	18/21	9,7/10,4	115/128	75/>114	99/98	76	57	38	1,2	86	0,06	203	0,027	199	6,4	19,1	0,04	722
	Oct 1991	8,8/8,8	25/29	9,3/10,2	125/126	76/74	145/145	122	101	56	1,9	145	0,04	389	0,044	222	8,0	34,1	0,04	1117
	Jan 1992	8,8/8,9	28/30	7,2/8,2	95/117	27/30	74/76	58	42	35	1,0	60	0,04	145	0,033	147	9,1	14,3	0,07	534
	Feb 1992	8,5/8,6	29/31	5,4/6,9	75/102	17/18	154/153	118	99	62	2,2	132	0,04	467	0,016	222	6,9	39,0	0,04	1187
6	Apr 1991	-/8,5	-/23	-/7,9	-/95	-/47	-/34	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	June 1991	-/8,7	-/16	-/12,3	-/127	-/40	-/40	33	18	26	0,2	37	0,40	19	0,039	151	7,8	1,5	0,05	319
	Aug 1991	-/8,5	-/18	-/10,1	-/114	-/72	-/59	48	31	32	0,5	53	0,06	29	0,011	215	7,7	2,2	0,04	456
	Oct 1991	-/8,5	-/28	-/8,1	-/110	-/42	-/72	71	39	33	0,6	81	0,04	45	0,016	225	10,1	3,6	0,04	547
	Jan 1992	-/8,6	-/29	-/14,3	-/143	-/30	-/42	36	19	27	0,4	37	0,29	22	0,053	146	9,5	2,7	0,06	311
	Feb 1992	-/8,6	-/31	-/7,5	-/103	-/46	-/59	47	30	32	0,6	51	0,04	29	0,015	221	10,1	3,7	0,04	463
7	Apr 1991	7,8/7,8	22/23	5,0/5,8	58/75	38/54	244/230	150	179	97	4,2	201	1,60	888	0,020	204	14,9	85,9	N/A	1638
	June 1991	7,7/7,7	18/19	4,7/4,9	54/54	112/112	224/220	156	165	87	3,4	188	0,39	733	0,439	235	16,0	77,6	0,61	1694
	Aug 1991	8,0/8,0	19/20	3,9/6,3	47/77	50/53	231/215	157	165	97	3,8	204	1,13	795	0,045	220	14,0	79,9	0,09	1766
	Oct 1991	7,8/7,8	26/28	1,8/3,5	23/46	70/72	234/232	191	182	76	4,1	201	0,38	818	0,016	269	15,0	79,2	0,27	1877
	Jan 1992	7,9/8,0	27/30	5,8/8,2	76/112	67/86	240/233	180	179	75	4,6	203	0,60	821	0,287	235	14,8	78,8	0,22	1824
	Feb 1992	7,9/7,9	28/30	3,5/4,8	49/67	57/63	248/252	189	190	98	4,5	219	0,78	969	0,011	246	14,9	81,5	0,15	2048
P Dam	Feb 1992	8,1/8,8	28/32	4,2/9,3	56/133	37/29	84/82	120	26	22	0,8	84	0,04	7	0,033	330	6,4	21,8	0,04	683

– Electrical Conductivity N/A – Not available P Dam – Pionier Dam

for the second year. The concentrations of these variables decreased from localities 7 to 1 (excluding locality 6). However, during the first year, the concentrations of Na, Mg, F, Cl, SO_4 and K slightly increased at locality 3 (near Balule), and Ca, along with the total alkalinity, increased slightly at locality 4. In the second year the total alkalinity also increased slightly at localities 3 and 4. Noticeable was the low sulphate concentration at Pionier Dam (7 mg/l) in comparison with the concentrations at localities 2 to 7 during February 1992, ranging from 30 mg/l to 1000 mg/l (Table 1b). The highest concentrations of NO_3+NO_2-N, phosphate and silicon occurred at locality 7 and the lowest varied between the other localities (Table 4).

Pronounced variations in the metal concentrations precluded unambiguous interpretation of the results. In the first year Cr, Fe and Ni had the highest concentrations at locality 3; Cu, Pb, Sr and Zn at locality 7, and Mn at locality 6. All the metals were the lowest in concentration at locality 1 (Table 2a). The iron concentration seemed to increase tremendously at most localities during December 1990 after the heavy rainfalls. In the second year the highest concentrations of Cr and Cu were recorded at locality 1 and the lowest at localities 5 and 4 (Table 4b). The iron concentrations ranged from 1 740 ± 1 380 µg/l at locality 7 (which is similar to the concentration found in Pionier Dam) to 18 040 ± 35 200 µg/l at locality 3. The concentrations of nickel, lead, strontium and manganese were the highest at locality 7 and the lowest at localities 4, 6, 6 and 2 for each metal respectively (Table 4b). The concentrations of iron, manganese and lead in the Pionier Dam were lower than the concentrations recorded at the other localities during February 1992 (Table 2b). In general, the metal concentrations were lower in the second than in the first year, except for copper at locality 1; iron at localities 1, 4 and 5; manganese at localities 1, 5 and 7; and strontium at localities 1 to 5 and 7. The trends regarding strontium should, however, be treated with caution, as there is insufficient data for this metal.

Sediment

The sediment metal concentrations showed a high variation (Table 3a & b), similar to that found for the water metal concentrations. In the first year chromium and manganese were the highest in concentration at locality 5, while copper, nickel and strontium were the highest in concentration at locality 7. The highest mean concentration of iron, lead and zinc were recorded at localities 6, 3 and 1 respectively. All the metals, except for zinc, were the lowest in concentration at locality 1 (Table 4a). In the second year manganese and zinc were the highest in concentration at locality 3, copper and strontium at locality 7 and chromium and lead at locality 6. In general, the metal concentrations were lower in the second year than in the first, except for chromium at localities 4 and 6; copper at localities 1 and 3 to 6; iron at localities 2 to 4; manganese at localities 2 to 4 and 6 to 7; nickel at localities 4 and 6; and strontium at localities 1 to 4 and 6 to 7.

Discussion

In evaluating the water quality of the study area, three sets of guidelines were used: those summarised by Kempster *et al.* (1982), those proposed by Kühn (1991) specifically for the Olifants River, and the Canadian guidelines (Environment Canada 1987). According to these guidelines, there were chemical constituents in the water of the study area that exceeded the allowable upper limits. Variables of special concern are sodium, fluoride, chloride, sulphate, potassium, the total dissolved salts and the metal concentrations (except strontium). This situation would render the Selati River at locality 7 unfit for aquatic life and might be one of the reasons why *Barbus marequensis* was only occasionally captured there. Furthermore, the Selati River has a negative influence on the water quality of the Olifants River after their confluence. The concentrations of most parameters detected at localities 2 to 5 were higher than the concentrations detected at locality 6 (located before the Selati-Olifants confluence). In most cases (except for the metal concentrations), the concentrations of the variables decreased from the western side of the KNP to the eastern side. This phenomenon can be attributed to the dilution of the water, caused by the tributaries of the Olifants River. At locality 3 (near Balule) an increase in concentration could sometimes be detected, especially during the first year. The explanation for this might lie in the frequent occurrence of reed beds in that part of the river. Reed beds are known for their cumulative capacity of chemical substances like metals. When the reed beds die off or are deposited on the river bed during floods, the decaying process may eventually release the toxicants, like metals, into the water column (De Wet *et al.* 1990). The toxicant concentration in the river water will therefore increase again.

The mean sodium, fluoride, sulphate, chloride, potassium and total dissolved salt concentrations detected at locality 5, from April 1990 to February 1991, were generally lower than the mean concentrations detected from October 1983 to October 1989 (Van Veelen 1990). Concentrations detected from April 1991 to February 1992 were slightly higher than the mean concentrations presented by Van Veelen (1990). The most probable explanation for the decrease and increase of the mean concentrations in the first and second year respectively, is the difference in rainfall pattern of the two years. In the first year the floods contributed to the dilution of the chemical constituent concentrations, but because of the drought in the second year, no dilution could take place and the concentrations have therefore increased (April 1991 - February 1992).

The TDS concentrations detected at locality 7 (1 680 ± 280 mg/l and 1 810 ± 130 mg/l for years 1 and 2 respectively), exceeding the guideline limits of 800 mg/l (Kühn 1991) and 350–550 mg/l TDS (Department of Water Affairs 1986) by far. At Pionier Dam, the fairly high TDS concentration of 680 mg/l is higher than the recommended limit by Department of Water Affairs (1986). One of the reasons might be evaporation, leading to increased concentrations of dissolved mineral salts (Department of Water Affairs 1986). The mean TDS concentrations at localities 2 to 5 ranged from 550 ± 190 mg/l to 710 ± 340 mg/l in the second year (April 1991 – February 1992), which were slightly higher than the TDS concentrations recorded for 1983 to 1989 in the Olifants River (Van Veelen 1990). This increase can be attributed to the fact that April 1991 to February 1992 was a very dry period. During dry periods, which is also the case in water time, the lower flows recorded at the barrage, combined with the almost continuous effluent flow in the Selati River, result in poorer water quality in the lower Olifants River (CSIR 1990). The major sources responsible for the high TDS concentrations are the effluents (1660 mg/l) and seepage (1660 mg/l) from a phosphorous extraction mining company (CSIR 1990). Moderate TDS loads are contributed by the storm water overflow of a copper extraction mining company *via* Loole Creek (1250 mg/l) and seepage from a magnetite tailing dam (1200 mg/l). Upstream inflow also contributes heavily to the daily TDS load in the lower Selati River (1280 mg/l). The effects that TDS concentrations have on aquatic species are, mainly, due to sudden changes in the concentrations, rather than absolute values of the determinants. Some macrophytes sensitive to changes will, for instance, be replaced by less sensitive species at high TDS concentrations of 1500–3000 mg/l (Theron *et al.* 1991). Conductivity and therefore TDS has an influence on the growth rate and life expectancy of fish, depending on the species sensitivity and conductivity level present (Hellawell 1986).

Sulphate is the anionic component mainly responsible for the high TDS concentrations in the Olifants River (Moore *et al.* 1991). The sulphate concentrations recorded at

Table 2a

Concentrationos (µg/l) of selected heavy metals in the water of the Olifants River, (Kruger National Park) and Selati River (April 1990 - February 1991)

Locality	Month	Chromium	Copper	Iron	Manganese	Nickel	Lead	Strontium	Zinc
1	Apr 1990	200	40	1300	20	200	200	N/A	900
	June 1990	300	60	1900	60	200	200	N/A	1000
	Aug 1990	500	70	1300	60	400	400	N/A	200
	Oct 1990	600	60	1300	50	200	300	100	200
	Dec 1990	100	10	1100	5	50	50	80	20
	Feb 1991	20	20	2200	10	100	100	200	20
2	Apr 1990	200	60	3200	60	200	200	N/A	1700
	June 1990	300	40	1900	60	200	400	N/A	1200
	Aug 1990	600	60	2100	30	100	400	N/A	400
	Oct 1990	800	100	1800	300	100	400	400	1000
	Dec 1990	400	60	29800	700	200	60	200	200
	Feb 1991	20	30	2600	40	100	100	300	40
3	Apr 1990	200	70	1500	30	200	200	N/A	1500
	June 1990	500	100	25900	500	300	500	N/A	1200
	Aug 1990	600	30	800	20	200	400	N/A	200
	Oct 1990	800	40	800	200	200	400	500	300
	Dec 1990	1100	200	130000	3500	700	100	400	400
	Feb 1991	100	20	2500	10	80	80	300	20
4	Apr 1990	200	80	9000	200	300	200	N/A	600
	June 1990	600	100	3000	40	400	600	N/A	1400
	Aug 1990	700	20	1100	20	200	400	N/A	300
	Oct 1990	800	40	900	50	200	300	410	400
	Dec 1990	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Feb 1991	300	40	15200	300	200	50	300	90
5	Apr 1990	200	70	1400	200	200	200	N/A	400
	June 1990	700	100	3200	40	400	600	N/A	3800
	Aug 1990	700	30	1000	30	200	400	N/A	300
	Oct 1990	400	40	700	20	200	300	200	300
	Dec 1990	800	20	5700	100	100	70	100	30
	Feb 1991	200	30	4000	80	100	80	300	40
6	Apr 1990	200	50	2400	40	200	200	N/A	2000
	June 1990	800	80	2900	50	400	600	N/A	1100
	Aug 1990	600	10	800	20	100	300	N/A	100
	Oct 1990	500	30	1100	30	200	300	100	300
	Dec 1990	900	100	103900	2400	500	100	500	200
	Feb 1991	200	40	2800	16500	200	90	200	200
7	Apr 1990	200	100	1300	100	300	200	N/A	1500
	June 1990	800	200	14400	200	600	800	N/A	3600
	Aug 1990	1000	60	400	80	200	400	N/A	300
	Oct 1990	600	40	1100	90	200	300	800	400
	Dec 1990	100	100	700	50	50	60	2500	30
	Feb 1991	200	70	2800	200	100	200	3900	40

N/A – Not Available

Table 2b

Concentrationos (µg/l) of selected heavy metals in the water of the Olifants River, (Kruger National Park) and Selati River (April 1991 - February 1992)

Locality	Month	Chromium	Copper	Iron	Manganese	Nickel	Lead	Strontium	Zinc
1	Apr 1991	200	90	8600	100	100	100	200	100
	June 1991	200	40	3200	70	100	50	200	40
	Aug 1991	200	10	1700	30	100	100	N/A	4
	Oct 1991	< 6†	60	300	40	<10	200	100	500
	Jan 1992	< 6	40	500	30	<10	200	600	90
	Feb 1992	400	60	7800	90	30	100	N/A	300
2	Apr 1991	200	30	3100	20	90	100	400	80
	June 1991	100	30	1100	20	50	40	200	100
	Aug 1991	30	10	1500	20	100	100	N/A	5
	Oct 1991	10	20	1100	50	<10†	90	500	30
	Jan 1992	60	90	700	100	<10	100	300	800
	Feb 1992	40	40	3100	60	20	200	N/A	50
3	Apr 1991	200	40	4800	60	90	200	300	100
	June 1991	200	60	2000	30	100	80	300	200
	Aug 1991	100	20	2700	80	80	40	N/A	300
	Oct 1991	<6	40	400	60	<10	200	900	80
	Jan 1992	70	30	1700	80	<10	100	400	200
	Feb 1992	60	50	96600	700	40	200	N/A	40
4	Apr 1991	200	30	2100	50	80	200	200	200
	June 1991	30	30	400	<2†	20	10	30	200
	Aug 1991	30	10	1300	<2	100	200	N/A	20
	Oct 1991	<6	20	200	40	<10	200	800	70
	Jan 1992	10	20	100	20	<10	200	900	80
	Feb 1992	200	40	44000	300	20	200	N/A	70
5	Apr 1991	100	30	1200	30	50	100	200	30
	June 1991	200	40	1200	20	100	90	300	90
	Aug 1991	40	20	2300	20	100	100	N/A	30
	Oct 1991	20	20	200	70	40	200	500	40
	Jan 1992	20	10	20	10	<10	80	600	50
	Feb 1992	50	50	88800	600	40	200	N/A	40
6	Apr 1991	200	30	3100	80	100	100	200	100
	June 1991	200	40	1900	30	80	100	200	20
	Aug 1991	100	10	1300	50	100	70	N/A	10
	Oct 1991	<6	30	200	5	<10	200	80	50
	Jan 1992	20	10	200	20	<10	70	100	10
	Feb 1992	50	50	65400	400	30	100	N/A	80
7	Apr 1991	200	40	1400	100	70	100	3000	40
	June 1991	100	50	1900	700	90	80	3700	30
	Aug 1991	50	30	1500	100	100	200	N/A	30
	Oct 1991	<6	20	300	300	<10	200	2000	50
	Jan 1992	<6	30	700	200	<10	200	2200	80
	Feb 1992	100	40	4600	200	50	200	N/A	40
P Dam		50	50	1700	40	30	70	N/A	60

† Detection limit of AAS   N/A – Not Available   P Dam – Pionier Dam

locality 7 exceeded one of the proposed guideline values (Kühn 1991), namely 250 mg/l. As the concentrations were above 600 mg/l, the water should be considered unfit for household purposes. Sulphates may give rise to gastro-intestinal irritation (Department of Water Affairs 1986). The mean sulphate concentrations at localities 1 to 5 were fortunately well below 600 mg/l, for the main use of the Lower Olifants River after entering the KNP is for game watering, aquatic ecosystem maintenance and the supply of domestic water to the Olifants, Satara and Balule rest camps. Further downstream, the Massingir Dam inside Mozambique also supplies some water for domestic use and game watering (CSIR 1990). Since high sulphate concentrations have a definite effect on fish (Burnham & Peterka 1975), it might be one of the reasons why only a few fish species were detected in the Lower Selati River.

The mean fluoride concentrations at locality 7 (4,5 ± 1,6 mg/l and 4,1 ± 0,4 mg/l for years 1 and 2 respectively) were much higher than the concentrations recorded at the other localities and exceeded the limit of 1,5 mg/l (Table 4). Studies on the ecological significance of exposure of aquatic animals to fluoride are limited (Rose & Marier 1977). However, when fry of *Catla catla* were exposed to different fluoride concentrations for 96 hours, protein synthesis was inhibited from 1,2 mg/l fluoride upwards, glycogen and iron decreased from 4,3 mg/l fluoride upwards and the lipid metabolism was altered from 7,2 mg/l fluoride upwards (Pillai & Mane 1984). Fluoride toxicity is influenced, however, by water hardness. High calcium concentrations suppress fluoride concentrations by precipitating insoluble calcium fluoride (Smith *et al.* 1985). LC50 values (96-hour) for fluoride toxicity do exist, ranging from 51 to 460 mg/l — depending on the species and conditions (Smith *et al* 1985). However, the available data suggests that a consensus about the maximum safe level of fluoride concentration for fish in natural waters of varying hardness has not yet been achieved.

Although the sodium and potassium concentrations at locality 7 were higher than the guideline values and were also fairly high at Pionier Dam, the lack of sufficient research data on the effects of elevated sodium and potassium concentrations on aquatic life precludes discussion thereof. However, fish mortalities in the Olifants River have previously been associated with high levels of K, Cl, SO_4, Mg and Na. Elevated potassium levels are thought to have been the actual cause of death (Moore 1990).

Ammonia is produced as a metabolite from the natural degradation of nitrogenous organic material present in all surface waters (Ellis 1989). However, high levels reach waters as fertiliser components and through effluents from industries and sewage works. The less toxic ammonium ion (NH_4^+) exists at lower pH values, while the more toxic ammonia (NH_3) is present in more alkaline conditions. Therefore as the temperature and pH increase, the percentage toxic free ammonia increases. In the study area, the pH tended to be more alkaline and the temperatures were high, the ammonia concentrations should therefore be carefully monitored. An indication of sublethal concentrations for fish might be 0,006–0,34 mg/l NH_3, for Smith & Piper (1975) detected histological effects at these concentrations. The calculated concentration of 0,1782 mg/l NH_3 at locality 7 in the second year might have been sublethal to the fish.

However, in addition to pH and temperature, there are other factors affecting the toxicity of ammonia. A decrease in dissolved oxygen will increase the toxicity of ammonia, but an increase in [CO_2] in water up to a level of approximately 30 mg/l appears to decrease the toxicity (Ellis 1989). Copper salts apparently combine additively with ammonia in their toxic effects (Herbert & Van Dyke 1964), while calcium reduces the toxicity of ammonia. In addition to its toxicity, ammonia may also impose an additional oxygen demand on the receiving stream as a result of its potential to be oxidised by autotrophic bacteria to nitrite and then to nitrate (Ellis 1989).

Phosphorus in surface water will mostly be present either as orthophosphates or as polyphosphates. All polyphosphates in water will, however, revert in time to orthophosphates (Ellis 1989). The phosphate levels in the Lower Olifants River were generally around 0,02 mg/l. Only at locality 7 (in the Selati River) higher levels of 0,136 mg/l on average were detected in the second year. Although phosphates are non-toxic, they are indicative of pollution from detergents, fertilisers, sewage (Kempster *et al.* 1982). According to a survey done by the CSIR (1990), orthophosphate (PO_4-P) concentrations in the seepage and effluent discharged into the Selati River by a phosphorus extraction mining company were sufficiently high as to cause moderate eutrophication problems. This statement can be confirmed by personal observations, for during the course of the study the aquatic plants and algae seemed to increase, especially at localities 5 (Mamba weir) and 4.

Calcium is an integral part of bone and is non-toxic (Kempster *et al.* 1982). It is relevant to this study because of the influence it has on metal toxicity. Calcium reduces the toxicity of metals to fish by hindering their adsorption. According to Mason (1991), calcium is antagonistic to lead, zinc and aluminium. The calcium ion competes with other metal cations for binding sites on the gill surface, thereby decreasing the direct uptake of cationic metals by fish. In contradiction to this, Giesy & Alberts (1984) pointed out that although Ca^{2+} may occupy sites on the organic ligand, the binding strengths are low compared to transition metals. Therefore, Ca^{2+} is not capable of blocking sites in the presence of other metal ions and will be exchanged for by the other metals on the organic ligands. The buffering capacity of the study area seemed to be fairly good, as the alkalinity ranged between 140 ± 20 and 235 ± 20 mg/l $CaCO_3$. The alkalinity of natural water is rarely more than 500 mg/l as $CaCO_3$ (Kempster *et al.* 1982). The water of the lower Olifants River would be considered hard and most metals are less toxic in hard water than in soft water (Hellawell 1986).

Temperature changes can have a major impact on fish life. One example is the low temperature discharges from impoundments that may trigger spawning (Theron *et al.* 1991). According to the guidelines proposed by Kühn (1991), the temperature of the water being discharged into the Olifants River at Phalaborwa Barrage, for instance, should be within 5 °C of the background water temperature. Another example of fish being affected by temperature changes, happened on the 25 October 1989, when a hailstorm caused a sudden decline in temperature. This incident was thought to have been the actual reason for fish mortalities in the Olifants River (Deacon *pers. comm.*). It is therefore not the temperature itself that causes concern, but the rate of change of water temperature. Although a sudden temperature change was detected in the study area from August to October, it is of no value, since information like this should be recorded on a daily basis.

Dissolved oxygen (DO) is essential to all aquatic life. For warm water species the target guideline value is 5 mg/l (Kempster *et al.* 1982). At locality 7 the mean DO concentration was just above 5 mg/l, namely 5,7 ± 0,3 mg/l and 5,6 ± 1,5 mg/l for years 1 and 2 respectively. However, as temperature increases, the DO decreases. This effect could clearly be seen at locality 7 in August 1991 and October 1991 when the DO decreased from 3,9 mg/l to 1,8 mg/l in the morning, with an increase in temperature from 19,0 °C to 25,5 °C (Table 1b). Although 3,9 and 1,8 mg/l DO concentrations are very low, time is the deciding factor in the survival of fish species. Warm water species would survive 3–5 mg/l DO if they are not exposed to it for more than eight hours out of any 24-hour period, and some species would survive 1–3 mg/l DO if they are not exposed to it for more than a few hours (Train 1979). Species not able to withstand low DO concentrations would therefore not occur in the Selati River at locality 7, which might be another reason why only a

Table 3a

Concentrationos (µg/g) of selected heavy metals in the sediment of the Olifants River, (Kruger National Park) and Selati River (April 1990 - February 1991)

Locality	Month	Chromium	Copper	Iron	Manganese	Nickel	Lead	Strontium	Zinc
1	Apr 1990	60	10	18000	200	40	30	N/A	20
	June 1990	50	10	10200	100	40	10	N/A	20
	Aug 1990	40	10	N/A	60	20	20	10	80
	Oct 1990	50	10	N/A	70	30	20	20	30
	Dec 1990	40	10	2500	40	20	50	10	1200
	Feb 1991	30	10	9400	90	20	10	20	100
2	Apr 1990	70	20	32200	200	40	40	N/A	50
	June 1990	70	10	18100	200	60	20	N/A	40
	Aug 1990	60	20	N/A	100	40	20	30	30
	Oct 1990	60	20	N/A	100	40	20	40	30
	Dec 1990	40	10	8700	100	30	10	20	20
	Feb 1991	20	10	3500	70	30	50	10	10
3	Apr 1990	400	40	49200	600	200	40	N/A	70
	June 1990	200	30	19000	300	90	30	N/A	90
	Aug 1990	90	40	N/A	300	70	30	90	50
	Oct 1990	60	10	N/A	100	30	20	30	30
	Dec 1990	30	20	2500	100	50	50	10	20
	Feb 1991	50	30	15100	200	60	30	10	30
4	Apr 1990	40	10	14800	200	40	40	N/A	30
	June 1990	90	10	18200	200	50	30	N/A	40
	Aug 1990	100	20	N/A	200	60	30	60	50
	Oct 1990	100	20	N/A	200	50	30	30	60
	Dec 1990	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Feb 1991	30	10	13900	30	20	10	5	10
5	Apr 1990	100	30	30000	400	80	50	N/A	30
	June 1990	900	20	19800	400	100	30	N/A	100
	Aug 1990	200	40	N/A	400	100	30	100	50
	Oct 1990	80	10	N/A	100	40	20	70	30
	Dec 1990	80	20	8800	200	50	10	40	20
	Feb 1991	90	20	49400	300	50	10	40	30
6	Apr 1990	40	10	50900	200	50	40	N/A	80
	June 1990	800	20	19000	400	90	20	N/A	70
	Aug 1990	90	20	N/A	200	40	30	40	40
	Oct 1990	90	10	N/A	200	40	20	40	40
	Dec 1990	70	10	3500	300	40	10	30	20
	Feb 1991	80	10	22600	300	50	10	40	20
7	Apr 1990	200	400	39700	400	100	60	N/A	100
	June 1990	200	200	12000	100	80	40	N/A	40
	Aug 1990	200	500	N/A	400	200	30	300	60
	Oct 1990	200	40	N/A	200	60	20	50	30
	Dec 1990	80	40	6100	90	40	10	80	10
	Feb 1991	40	40	8600	70	30	20	60	10

N/A – Not Available

Table 3b

Concentrationos (µg/g) of selected heavy metals in the sediment of the Olifants River, (Kruger National Park) and Selati River (April 1991 - February 1992)

Locality	Month	Chromium	Copper	Iron	Manganese	Nickel	Lead	Strontium	Zinc
1	Apr 1991	20	10	5700	40	10	10	10	10
	June 1991	30	10	9700	80	30	10	10	10
	Aug 1991	30	10	6000	40	20	10	10	5
	Oct 1991	10	10	6000	70	5	5	10	10
	Jan 1992	40	20	14900	100	20	5	20	20
	Feb 1992	20	20	10700	200	20	10	N/A	50
2	Apr 1991	30	10	11600	100	20	10	20	10
	June 1991	40	10	17300	100	30	10	30	10
	Aug 1991	100	10	33300	200	50	20	30	20
	Oct 1991	30	10	20700	200	20	5	30	20
	Jan 1992	20	20	14900	200	20	5	20	20
	Feb 1992	30	10	20500	200	30	10	N/A	30
3	Apr 1991	500	40	65300	500	80	30	80	50
	June 1991	30	70	2000	1000	80	10	60	60
	Aug 1991	60	20	35700	200	60	10	40	40
	Oct 1991	30	10	18500	200	20	5	20	20
	Jan 1992	60	30	19300	50	40	5	60	30
	Feb 1992	10	10	9400	100	20	10	N/A	40
4	Apr 1991	50	10	17900	300	50	10	40	10
	June 1991	50	10	37600	200	40	10	30	20
	Aug 1991	1100	20	41000	400	80	20	50	40
	Oct 1991	30	10	20400	200	20	5	30	20
	Jan 1992	100	40	25400	100	80	10	60	70
	Feb 1992	70	20	24000	200	50	20	N/A	50
5	Apr 1991	20	10	8200	100	20	10	30	10
	June 1991	60	10	19700	300	60	20	50	10
	Aug 1991	90	20	21100	300	70	10	50	20
	Oct 1991	50	30	14600	300	40	5	60	30
	Jan 1992	60	20	16700	60	40	5	60	30
	Feb 1992	200	50	9500	500	100	20	N/A	10
6	Apr 1991	80	10	14200	100	40	10	40	10
	June 1991	1500	10	44900	400	50	20	60	40
	Aug 1991	50	10	200	300	40	10	30	20
	Oct 1991	80	20	18100	500	30	5	50	30
	Jan 1992	80	5	21500	60	50	5	30	20
	Feb 1992	200	70	17700	300	100	50	N/A	100
7	Apr 1991	50	300	15100	300	50	10	200	20
	June 1991	50	50	8700	600	30	10	70	10
	Aug 1991	50	80	9300	100	40	10	80	20
	Oct 1991	80	20	19800	300	40	5	50	20
	Jan 1992	60	700	26000	100	60	10	600	40
	Feb 1992	100	100	14400	100	40	10	N/A	40
P Dam	Feb 1992	20	10	19800	50	20	10	N/A	40

N/A – Not Available P Dam – Pionier Dam

Table 4a

Mean values (± SE) of selected variables from the Olifants River (Kruger National Park) and Selati River (Apr 1990 – Feb 1991) compared to guideline values by Kempster et al. *(1982), Kühn (1991) and Canada (1987)*

Variable	Locality 1	2	3	4	5	6	7	Guideline values: Kempster *et al.* (min-max)	Kempster *et al.* median	Kühn	Canada
WATER											
ΘpH	8,3 ± 0,3	8,4 ± 0,3	8,3 ± 0,4	8,6 ± 0,3	8,3 ± 0,03	8,4 ± 0,2	7,8 ± 0,1	6,0 – 9,0	6,5 – 9,0		6,5 – 9,0
Temperature (°C)	24,3 ± 4,1	24,5 ± 4,3	23,1 ± 3,7	23,1 ± 4,2	24,1 ± 3,4	22,3 ± 3,7	23,3 ± 2,5		a	b	
Dissolved O_2 (mg/l)	9,2 ± 2,1	8,2 ± 1,8	8,9 ± 2,1	10,4 ± 1,1	12,0 ± 1,9	9,8 ± 0,6	5,7 ± 0,3	>4 – >5,8	>5		>5
O_2 saturation (%)	114,5 ± 17,8	105,8 ± 19,7	111,3 ± 25,6	119,3 ± 14,8	115,5 ± 24,4	109,3 ± 15,3	66,5 ± 2,9				
Turbidity (cm)	19,4 ± 7,4	18,6 ± 21,6	27,8 ± 20,4	37,4 ± 24,4	33,6 ± 25,7	24,2 ± 13,0	34,8 ± 18,4				
Conductivity (mS/m)	32,5 ± 9,3	61,8 ± 23,7	95,0 ± 64,2	64,0 ± 27,5	69,0 ± 29,9	44,4 ± 10,6	224,8 ± 39,5		a		
Na (mg/l)	N/A	48,8 ± 18,8	49,8 ± 19,9	45,2 ± 22,7	54,8 ± 25,2	44,0 ± 9,2	160,0 ± 22,1		500	100	
Mg (mg/l)	N/A	35,6 ± 16,8	35,8 ± 17,9	34,8 ± 18,4	36,2 ± 22,9	22,6 ± 6,1	155,6 ± 31,9		1500		
Ca (mg/l)	N/A	33,8 ± 7,8	33,6 ± 7,5	35,7 ± 8,5	33,9 ± 8,4	26,2 ± 1,8	86,0 ± 19,8		1000		
F (mg/l)	N/A	0,81 ± 0,34	0,74 ± 0,31	0,69 ± 0,32	0,70 ± 0,34	0,33 ± 0,04	4,49 ± 1,56	1,5 – 1,5	1,5	1,5	
Cl (mg/l)	N/A	57,1 ± 22,9	60,4 ± 24,5	53,0 ± 29,1	63,2 ± 31,7	50,7 ± 11,1	187,7 ± 28,7	50 – 400		100	
NO_3+NO_2-N (mg/l)	N/A	0,05 ± 0,07	0,06 ± 0,08	0,25 ± 0,43	0,10 ± 0,09	0,19 ± 0,17	0,72 ± 0,23			[c] 6	[f] 0,06
SO_4 (mg/l)	N/A	115,0 ± 54,4	117,7 ± 52,9	108,2 ± 82,3	129,6 ± 92,9	28,2 ± 7,3	797,0 ± 160,2		1400	250	
PO_4-P (mg/l)	N/A	0,009 ± 0,002	0,012 ± 0,007	0,018 ± 0,010	0,016 ± 0,004	0,01 ± 0,003	0,052 ± 0,038		0,1		
Alkalinity ($CaCO_3$) (mg/l)	N/A	142,7 ± 48,0	151,1 ± 41,1	154,3 ± 40,4	152,0 ± 43,0	160 ± 30,8	213,5 ± 23,3	>20 – >20	>20		
Silica (mg/l)	N/A	6,18 ± 1,10	6,29 ± 1,09	6,46 ± 1,78	7,53 ± 1,72	7,57 ± 1,67	14,56 ± 2,13		50		
K (mg/l)	N/A	9,90 ± 5,36	10,31 ± 5,26	9,66 ± 16,68	10,83 ± 8,15	2,26 ± 0,20	72,87 ± 9,99		50	50	
NH_4-N (mg/l)	N/A	0,03 ± 0,01	0,03 ± 0,01	0,05 ± 0,03	0,04 ± 0,02	0,05 ± 0,01	0,09 ± 0,05	0,016 – 124	0,016	[d] 0,01^{+}	[d/g] 1,37 – 2,2
TDS (mg/l)	N/A	491,8 ± 179,7	499,4 ± 180,1	483,0 ± 190,1	526,3 ± 234,0	376,4 ± 69,6	1679,7 ± 281,7			800	
Chromium (µg/l)	300 ± 210	390 ± 260	570 ± 340	510 ± 230	400 ± 220	520 ± 240	480 ± 340	10 – 100	50		2
Copper (µg/l)	40 ± 20	60 ± 30	70 ± 50	60 ± 30	50 ± 30	60 ± 40	100 ± 40	5 – 200	5	50	[h] 2 – 4
Iron (µg/l)	1500 ± 400	6900 ± 10200	26800 ± 46700	6000 ± 5500	2700 ± 1800	19000 ± 38000	3400 ± 5000	200 – 1000	200	300	300
Manganese (µg/l)	30 ± 20	210 ± 260	700 ± 1300	110 ± 90	90 ± 70	3200 ± 6000	120 ± 60	100 – 1000		50	
Nickel (µg/l)	150 ± 50	180 ± 60	280 ± 200	230 ± 80	210 ± 100	260 ± 140	230 ± 170	25 – 50	50	50	[h] 25 – 150
Lead (µg/l)	200 ± 120	260 ± 140	270 ± 150	290 ± 170	260 ± 190	280 ± 180	340 ± 250	20 – 100	30	2	[h] 1 – 7
Strontium (µg/l)	120 ± 30	330 ± 70	380 ± 70	340 ± 70	200 ± 60	260 ± 160	2400 ± 1300		200000	[e] 10000	
Zinc (µg/l)	410 ± 400	750 ± 610	610 ± 570	560 ± 460	810 ± 1360	660 ± 690	980 ± 1300	30 – 100	100	50	30
SEDIMENT											
Chromium (µg/g)	40 ± 10	50 ± 20	130 ± 120	80 ± 40	240 ± 300	200 ± 290	130 ± 60				
Copper (µg/g)	10 ± 2	10 ± 3	30 ± 10	10 ± 6	21 ± 10	10 ± 5	210 ± 190				
Iron (µg/g)	10000 ± 5600	15600 ± 10900	21500 ± 17100	15700 ± 1900	22000 ± 8600	24100 ± 17100	16600 ± 13500				
Manganese (µg/g)	90 ± 40	130 ± 40	260 ± 150	160 ± 70	300 ± 110	250 ± 70	210 ± 150				
Nickel (µg/g)	30 ± 10	40 ± 10	80 ± 40	40 ± 10	70 ± 20	50 ± 20	80 ± 40				
Lead (µg/g)	20 ± 10	30 ± 10	30 ± 10	30 ± 10	20 ± 10	20 ± 10	30 ± 20				
Strontium (µg/g)	10 ± 5	30 ± 10	40 ± 30	30 ± 20	60 ± 30	40 ± 3	110 ± 90				
Zinc (µg/g)	250 ± 450	30 ± 10	50 ± 30	40 ± 10	40 ± 30	50 ± 20	40 ± 30				

Θ – log [H^{+}] N/A – Not available [a] Depend on local conditions and life species present [b] Within 5 °C of background temperature (99,9% of the time) [c] Nitrate [d] Depend on pH, [Ca^{2+}] and DO

[e] ^{90}Sr [f] Nitrite [g] Ammonia [h] Dependent on hardness

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Table 4b

Mean values (± SE) of selected variables from the Olifants River (Kruger National Park) and Selati River (Apr 1991 – Feb 1992) compared to guideline values by Kempster et al. *(1982), Kühn (1991) and Canada (1987)*

Variable	Locality 1	2	3	4	5	6	7	*Pionier Dam	Guideline values: Kempster *et al.* (min-max)	Kempster *et al.* median	Kühn	Canada
WATER												
ΘpH	8,5 ± 0,2	8,7 ± 0,1	8,6 ± 0,1	8,5 ± 0,3	8,7 ± 0,2	8,6 ± 0,1	7,9 ± 0,1	8,1	6,0 – 9,0	6,5 – 9,0		6,5 – 9,0
Temperature (°C)	26,8 ± 3,7	27,3 ± 4,5	27,4 ± 5,3	27,3 ± 4,8	25,5 ± 5,0	24,1 ± 5,5	24,9 ± 4,4	32,3		a	b	
Dissolved O_2 (mg/l)	8,4 ± 2,0	9,4 ± 1,2	8,9 ± 0,7	8,5 ± 1,2	9,1 ± 1,4	10,0 ± 2,5	5,6 ± 1,5	9,3	>4 – >5,8	>5		>5
O_2 saturation (%)	106,8 ± 21,2	118,3 ± 12,2	116 ± 15,9	110,3 ± 16,1	113,0 ± 12,7	115,3 ± 15,8	71,8 ± 21,1	133				
Turbidity (cm)	18 ± 0	36,0 ± 11,1	49,7 ± 19,6	51,7 ± 29,1	50,5 ± 33,5	46,2 ± 12,8	73,3 ± 20,6	29				
Conductivity (mS/m)	38,3 ± 11,5	73,2 ± 26,3	81,0 ± 32,1	83,7 ± 34,3	94,3 ± 42,8	51,0 ± 13,3	230,3 ± 11,7	82		a		
Na (mg/l)	36,0 ± 13,6	63,7 ± 23,7	66,7 ± 28,2	67,5 ± 31,3	74,3 ± 35,2	47,0 ± 13,4	170,5 ± 16,7	120		500	100	
Mg (mg/l)	18,8 ± 7,0	37,0 ± 16,3	46,3 ± 22,3	49,0 ± 26,1	57,7 ± 32,1	27,4 ± 7,9	176,7 ± 9,0	26		1500		
Ca (mg/l)	23,6 ± 3,8	33,7 ± 6,5	38,5 ± 9,1	38,0 ± 7,6	41,2 ± 13,3	30,0 ± 2,9	88,3 ± 9,8	22		1000		
F (mg/l)	0,32 ± 0,12	0,65 ± 0,36	0,77 ± 0,37	0,97 ± 0,53	1,18 ± 0,68	0,46 ± 0,15	4,10 ± 0,41	0,8	1,5 – 1,5	1,5	1,5	
Cl (mg/l)	40,4 ± 15,1	72,7 ± 29,0	76,8 ± 35,4	76,5 ± 36,7	84,5 ± 41,2	51,8 ± 16,1	202,7 ± 9,0	84	50 – 400		100	
NO_3+NO_2-N (mg/l)	0,16 ± 0,25	0,07 ± 0,04	0,10 ± 0,09	0,12 ± 0,11	0,16 ± 0,16	0,17 ± 0,15	0,81 ± 0,43	0,04			[c] 6	[f] 0,06
SO_4 (mg/l)	15,2 ± 20,4	99,2 ± 68,0	138,2 ± 83,1	156,8 ± 102,1	222,3 ± 154,8	28,8 ± 9,0	837,3 ± 74,4	7		1400	250	
PO_4-P (mg/l)	0,031 ± 0,016	0,026 ± 0,011	0,022 ± 0,007	0,022 ± 0,007	0,036 ± 0,025	0,027 ± 0,016	0,136 ± 0,1'67	0,033		0,1		
Alkalinity ($CaCO_3$) (mg/l)	140,2 ± 22,8	186,8 ± 39,6	195,0 ± 55,3	182,2 ± 43,7	176,2 ± 40,9	189,6 ± 38,1	234,8 ± 20,3	330	>20 – >20	>20		
Silica (mg/l)	9,50 ± 0,96	7,33 ± 1,46	7,77 ± 1,91	7,50 ± 9,31	7,63 ± 0,85	9,04 ± 1,08	14,93 ± 0,58	6,4		50		
K (mg/l)	7,42 ± 2,05	11,27 ± 5,84	12,70 ± 7,56	14,25 ± 9,31	19,53 ± 13,08	2,74 ± 0,84	80,48 ± 2,69	21,8		50	50	
NH_4-N (mg/l)	0,05 ± 0,01	0,06 ± 0,03	0,14 ± 0,21	0,04 ± 0	0,06 ± 0,03	0,05 ± 0,01	0,27 ± 0,18	0,04	0,016 – 124	0,016	[d] 0,01+	[d/g] 1,37 – 2,2
TDS (mg/l)	310,4 ± 78,3	545,3 ± 187,0	617,3 ± 246,7	624,2 ± 262,0	710,7 ± 339,1	419,2 ± 90,9	1807,8 ± 133,1	680			800	
Chromium (µg/l)	150 ± 120	80 ± 70	110 ±80	80 ± 90	70 ± 60	100 ± 80	80 ± 60	50	10 – 100	50		2
Copper (µg/l)	50 ± 20	40 ± 20	40 ± 10	30 ± 10	30 ± 10	30 ± 10	40 ± 10	50	5 – 200	5	50	[h] 2 – 4
Iron (µg/l)	3700 ± 3300	1800 ± 940	18100 ± 35200	8000 ± 16100	15600 ± 32700	12000 ± 23900	1740 ± 1400	1700	200 – 1000	200	300	300
Manganese (µg/l)	60 ± 30	50 ± 30	170 ± 250	80 ± 120	120 ± 210	100 ± 140	290 ± 210	40	100 – 1000		50	
Nickel (µg/l)	60 ± 50	50 ± 50	60 ± 40	50 ± 50	60 ± 40	60 ± 40	60 ± 50	30	25 – 50	50	50	[h] 25 – 150
Lead (µg/l)	130 ± 40	110 ± 40	130 ± 60	130 ± 60	120 ± 40	100 ± 30	160 ± 40	70	20 – 100	30	2	[h] 1 – 7
Strontium (µg/l)	280 ± 200	350 ± 90	470 ± 230	500 ± 390	380 ± 150	140 ± 50	2700 ± 700	N/A		200000	[c] 10000	
Zinc (µg/l)	170 ± 170	180 ± 300	160 ± 90	100 ± 70	50 ± 20	50 ± 40	40 ± 20	57	30 – 100	100	50	30
SEDIMENT												
Chromium (µg/g)	20 ± 10	40 ± 30	120 ± 180	230 ± 370	80 ± 60	320 ± 510	70 ± 30	20				
Copper (µg/g)	10 ± 4	10 ± 3	30 ± 20	20 ± 10	20 ± 20	20 ± 20	200 ± 240	15				
Iron (µg/g)	8900 ± 3300	19700 ± 6900	25000 ± 20800	27700 ± 8600	15000 ± 4800	19400 ± 13300	15500 ± 6000	19800				
Manganese (µg/g)	90 ± 50	170 ± 50	350 ± 360	220 ± 90	150 ± 150	270 ± 140	270 ± 170	50				
Nickel (µg/g)	20 ± 10	30 ± 10	50 ± 30	50 ± 20	60 ± 30	50 ± 30	40 ± 10	20				
Lead (µg/g)	7 ± 4	9 ± 5	10 ± 10	12 ± 7	10 ± 8	20 ± 20	10 ± 4	10				
Strontium (µg/g)	10 ± 6	30 ± 5	50 ± 20	40 ± 10	50 ± 10	40 ± 10	210 ± 210	N/A				
Zinc (µg/g)	20 ± 10	20 ± 8	40 ± 10	40 ± 20	20 ± 10	40 ± 30	30 ± 10	40				

* – Only a single value   Θ – log [H^+]   N/A – Not available   [a] Depend on local conditions and life species present   [b] Within 5 °C of background temperature (99,9% of the time)   [c] Nitrate

[d] Depend on pH, [Ca^{2+}] and DO   [e] ^{90}Sr [f] Nitrite   [g] Ammonia   [h] Dependent on hardness

few fish species were detected there (personal observation). The mean DO concentrations of the other localities ranged from 8–12 mg/l. According to Ellis (1989) it is rare to find more than 8–10 mg/l of dissolved oxygen, even under optimum conditions, since the amount of oxygen dissolved from the air into water is small. Higher oxygen concentrations can, however, occur, due to photosynthetic oxygen produced under the influence of sunlight by algae and other aquatic plants, as was observed for the locality at Mamba.

If the factors influencing metal toxicity are excluded for the moment, it is clear from Table 4 that the metal concentrations of the selected metals in the water of the study area are mostly higher than the recommended guideline values (except for strontium). In this study, much higher concentrations were detected in the sediment (μg/g x 1000) than in the water (μg/l), due to the adsorption of metals on sediment particles. There is, however, a continuous interaction between the water and the sediment columns, depending on factors such as the water pH. The iron concentrations in the water increased considerably in December 1990, but increasing solubility was not the only reason for this phenomenon. Weathering of underlying rock formations, especially basalt, will produce iron (Dury 1981). As locality 3 (near Balule) is underlain by basalt, the highest iron concentrations were detected there. Iron is also a highly abundant element and therefore, of all the metals investigated, iron was found to occur in the highest concentrations. The copper and strontium concentrations in the Selati River, especially in the sediment, were much higher than the concentrations in the Olifants River. This indicates that these two metals originate from a local source which is not connected to the Kruger National Park.

A factor playing a major role in metal distribution is rainfall. A noticeable difference could be seen between the wetter first year and the dryer second year. In the first year peaks of the metal concentrations in the water occurred at localities 7 and 3. Peaks at locality 7 can mainly be attributed to mining and industrial effluents, while peaks at locality 3 might be attributed to the frequent occurrence of reed beds, accumulating the metals and releasing them again when decaying. In the second year, peaks also occurred at localities 7 and 3, but with the addition of locality 1 (in the Letaba River). It might be that because of the drought, the river flow in the Olifants River was very low and therefore the carrying capacity of the water volume for metals decreased. By contrast, the Letaba River might have had a stronger flow, thus rendering higher solubility and concentrations of metals.

Conclusions

The mining and industrial activities in the Phalaborwa complex definitely have an influence on the water quality of the lower Selati River. The sodium, fluoride, chloride, sulphate, potassium, TDS and metal concentrations (except for strontium) were higher than the guideline values of Kempster *et al.* (1982), Kühn (1991) and Canada (Environment Canada 1987). The water quality of the lower Olifants River after the Selati-Olifants confluence was also influenced by activities upstream of the Selati River, especially localities 5 (Mamba weir) and 3 (near Balule). At Mamba the mean TDS, potassium, chloride, sulphate, fluoride and sodium concentrations reported for 1991/1992 were very similar or slightly higher than the mean concentrations reported for 1983 to 1989 by Van Veelen (1990). However, dilution caused by smaller tributaries decreased the toxicant concentrations to levels that, with the exception of the metal concentrations, comply with the recommended guideline values. The mean metal concentrations (excluding strontium) were higher than the guideline values at all the localities. The large variance detected in the metal concentrations of the water and sediment points to the need for more frequent monitoring of this area.

It is recommended that a more intensive study should be undertaken specifically on the water and sediment quality of the study area. The metal levels in particular should be studied, as well as the effect thereof on aquatic life. It will be necessary to combine the field study with experimental work, in order to determine the effects of the physical and chemical environment on the metal toxicity. This is very important, for the water in the lower Olifants River is hard and alkaline, and will therefore reduce the toxicity of the metals by forming inorganic complexes. Monitoring can be limited to localities 2, 3, 5, 6 and 7. Special attention should be given to locality 3, in order to determine the role of the reed beds. The interaction between water and sediment with regard to metal distribution should be investigated, as well as seasonal effects on toxicity and metal distribution.

For future management it is recommended that drastic measures be taken in order to reduce the impact of mining activities on the water quality of the Selati River, because it is not only the water quality of the Selati River that is being influenced, but also the water quality of the lower Olifants River (especially during low flow periods). If, for some or other reason, the water quality of the Selati River cannot be improved, it should at least be maintained at its present status. A further degradation in water quality cannot be afforded.

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