Metal Surveys in South African Estuaries IV Keurbooms and Bietou Rivers (Plettenberg Lagoon)

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Abstract

Surveys to study the Keurbooms and Bietou Rivers (Plettenberg Lagoon) were undertaken. Water samples were analysed for nine elements and surface sediments and sediment core samples for sixteen elements using atomic absorption spectroscopy. Inter-element relationships as well as absolute metal concentrations were examined before interpreting the data obtained.

The results indicate that these rivers and their common estuary are not significantly contaminated with respect to metals. The Bietou River has a considerable load which is probably of geochemical origin and metal build-up in the south-western part of the estuary adjacent to the town of Plettenberg Bay is probably attributable to contamination from the urban development.

Introduction

The Keurbooms River has its source in the Kammanasie mountains north of Plettenberg Bay while the Bietou River rises at Kafferskop. Both rivers combine and flow into an estuary approximately 6 km long and 0,5 km wide, east of Plettenberg Bay (Fig. 1). The estuary contains several large islands. The configuration of the mouth is continuously changing and is occasionally totally blocked by a sand bar, leading to dramatic fluctuation of the water level within the estuary.

The area along the river banks is used for residential, agricultural and recreational purposes. Part of the east bank of the Bietou River is controlled by the Department of Environment Affairs and is approachable only by boat. On the west bank of the Keurbooms River, north of the road bridge, the Cape Provincial Administration is developing a recreational resort.

The aim of this survey, which was carried out in July 1978, was to establish current metal levels in this estuary. The data obtained will serve as a baseline for future monitoring surveys, should industrialization or further urban development take place in this region of the South African coast.

Materials and Methods

Surface water samples were collected in 2,5 ℓ high-density polyethylene bottles. Two subsamples were separated from each bulk. These were

a) a 500 mℓ sample acidified with 2 mℓ nitric acid for the determination of mercury, and

b) a 1 000 mℓ sample for the determination of zinc, cadmium, copper, lead, iron, manganese, nickel and cobalt. Ten millilitres of a buffered solution of sodium diethyl-dithiocarbamate were added immediately to this sample which was then shaken for 5 min.

Approximately 500 g of a composite sample of surface sediment was collected using an aluminium scoop. These samples were air-dried between filter paper sheets, disaggregated in a porcelain mortar and sieved through a 210 μm screen. The fraction which passed through the screen was reserved for analysis.

Sediment core samples of up to 600 mm in depth were collected by pushing a length of PVC tubing into the sediment to its full length or until an obstruction was encountered. A polythene-covered cork was inserted into the top to seal it and the corer withdrawn. The other end was sealed and the core frozen to −20°C for storage.

Detailed descriptions of the further preparation of these

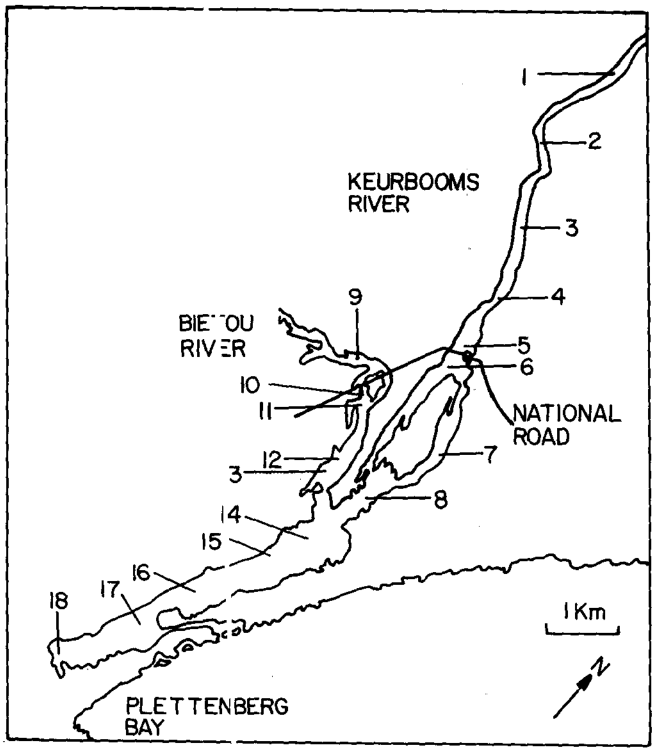

Figure 1
Study area and location of sampling sites

*Present address: Zoology Department, University of Port Elizabeth, PO Box 1600, Port Elizabeth 6000 samples and the determination of their metal contents are explained (Watling and Watling, 1982a).

Results and Discussion

Samples were collected from eight sites in the Keurbooms River, five sites in the Bietou River and five sites in the estuary below the confluence of the two rivers (Fig. 1).

Metals in Water

Metal concentrations in surface water samples are listed in Table 1.

The concentrations of copper, zinc, iron, manganese, cobalt, nickel and mercury found in these surface water samples are considered to be average for south-eastern Cape rivers (Watling and Emmerson, 1981; Watling and Watling, 1982 a, b, c). Lead and cadmium values are elevated but show no obvious trend which might allow a source to be identified. In fact, cadmium levels are, on average, ten times higher than those determined for any of the south-eastern Cape rivers studied so far with the exception of the polluted Papenkuils River near Port Elizabeth (Watling and Emmerson, 1981). It is probable that the cadmium in the Keurbooms and Bietou Rivers is of geochemical origin as, although there is significant input from the upstream sections of the rivers, no obvious unnatural source of pollution was apparent in this area. The metal chemistry of the water does not appear to have been influenced significantly by the local urban development.

Metals in Surface Sediments

Metal concentrations in surface sediment samples are listed in Table 2.

In general, metal levels in surface sediments are average for rivers of the south-eastern Cape (Watling and Emmerson, 1981; Watling and Watling, 1982 a; b; c), although the sediments in the Bietou River have elevated metal levels when compared with the concentrations found in the sediments collected in the Keurbooms River at an equivalent position in the estuarine sequence (Fig. 1).

Metal levels, particularly those of copper, lead and zinc, decrease along the Keurbooms River as the estuary is approached. Metal concentrations in sample 6 are high, probably because the sample was collected from the area adjacent to a marina; the relatively elevated zinc, cobalt, nickel and iron concentrations could be derived from this source.

Concentrations of copper, lead, zinc, iron, cobalt, nickel and chromium in samples from the Bietou River are elevated relative to their concentrations in samples from the Keurbooms River. This may be due to the presence of mineralization in the Bietou River catchment.

Metal levels again rise sharply at the extreme southwestern end of the estuary, in the area associated with Plettenberg Bay. These elevated levels are most likely the result of urban contamination. Runoff from new development in the area enters this region of the estuary directly and tidal exchange is minimal.

TABLE 1
METAL CONCENTRATIONS (μg/ℓ) IN SURFACE WATER SAMPLES

Site	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Hg
KEURBOOMS RIVER									
1	0,1	1,8	1,5	104	8	<0,1	0,6	5,7	0,009
2	0,1	1,9	1,4	135	9	0,1	0,6	1,2	–
3	0,1	2,0	8,0	102	9	<0,1	0,5	0,5	0,030
4	0,1	3,9	1,3	83	7	0,5	1,6	2,9	–
5	0,2	1,2	2,6	55	7	0,1	0,4	2,2	0,021
6	<0,1	2,4	1,7	45	6	0,3	1,0	1,3	–
7	<0,1	2,6	1,2	25	3	0,2	0,8	3,2	0,042
8	0,2	1,6	5,9	29	4	<0,1	0,4	4,1	0,021
BIETOU RIVER									
9	<0,1	2,3	1,1	88	22	0,1	0,6	5,3	0,027
11	<0,1	3,2	3,5	79	14	0,2	0,9	2,4	–
13	<0,1	2,3	1,5	38	7	0,1	0,7	1,1	0,030
PLETTENBERG LAGOON									
14	0,1	1,7	1,5	40	9	<0,1	0,5	0,9	–
15	0,1	3,2	1,0	20	2	0,3	1,0	1,4	0,045
16	<0,1	1,4	1,2	4	1	<0,1	0,3	0,8	–
17	<0,1	2,6	0,7	15	2	<0,1	0,3	1,5	0,027
18	<0,1	2,0	2,4	61	3	0,1	0,8	2,1	0,039

TABLE 2
METAL CONCENTRATIONS (μg/g) IN SURFACE SEDIMENT SAMPLES

Site	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr
KEURBOOMS RIVER															
1	10,4	12,2	42,8	16 000	50	2,4	9,0	2,0	24 800	4 060	10 000	768	800	22 600	2,8
2	5,8	6,8	28,0	16 000	50	<0,1	7,2	0,6	22 200	2 [illegible]00	18 000	544	1 600	15 200	2,4
3	3,8	5,0	26,2	12 000	60	1,2	6,4	<0,1	7 800	2 [illegible]80	8 000	398	400	14 400	2,0
4	3,4	3,8	27,0	12 000	60	0,8	5,8	<0,1	12 400	2 420	12 000	456	800	12 800	2,0
5	0,8	<0,1	7,6	2 800	70	<0,1	3,0	<0,1	1 800	[illegible]20	10 000	96	400	3 200	0,4
6	1,4	<0,1	17,0	5 000	90	2,4	13,4	<0,1	4 000	1 040	18 000	240	800	5 200	1,0
7	1,2	1,4	10,6	3 800	60	<0,1	1,8	<0,1	2 400	[illegible]60	64 000	256	4 600	2 800	1,2
8	0,2	1,6	4,6	2 000	20	0,8	1,0	0,4	200	150	14 000	102	100	1 800	0,4
BIETOU RIVER															
9	3,2	3,8	39,2	16 000	50	0,2	6,4	<0,1	11 600	3 900	8 000	448	400	17 400	2,6
10	2,2	1,0	22,2	5 200	40	2,0	4,8	<0,1	5 400	2 400	14 000	260	160	10 400	2,2
11	1,6	2,2	20,6	10 000	90	1,0	3,8	<0,1	5 200	1 800	26 000	284	800	8 200	1,4
12	3,0	3,0	29,0	14 000	50	1,2	6,2	0,6	7 200	3 030	16 000	438	1 400	10 800	1,8
13	2,6	1,8	21,8	5 400	40	1,2	5,0	<0,1	6 000	2 130	22 000	356	2 200	8 000	1,2
PLETTENBERG LAGOON															
14	1,2	1,4	8,2	3 400	30	<0,1	2,0	0,6	4 200	500	52 000	276	400	3 000	1,0
15	1,8	2,4	10,5	5 500	40	<0,1	3,0	0,2	4 000	800	20 000	480	2 000	15 000	1,6
16	1,8	<0,1	8,6	3 800	40	<0,1	1,0	<0,1	3 000	720	160 000	466	10 600	20 000	1,8
17	1,8	1,2	10,8	8 000	50	<0,1	2,0	<0,1	4 200	1 400	140 000	530	12 000	3 200	2,4
18	5,6	7,0	33,2	18 000	60	1,2	9,0	<0,1	22 800	6 420	108 000	972	8 800	18 200	3,0

TABLE 3
GEOMETRIC MEANS OF METAL CONCENTRATIONS (μg/g) IN SEDIMENT CORES

Site	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr	Hg
KEURBOOMS RIVER																
6	0,8	2,9	4,6	2 870	16	0,4	1,1	<0,01	1 440	450	8 900	850	81	1 890	2,9	0,001
7	0,9	3,4	5,7	3 970	19	0,7	1,6	<0,01	1 490	600	2 210	890	14	2 690	3,3	0,002
BIETOU RIVER																
10	1,6	2,6	10,6	7 590	16	0,7	3,0	0,09	3 100	1 440	500	1 450	3	4 480	9,1	0,008
12	1,8	2,1	10,2	8 310	22	0,6	2,3	0,14	4 250	1 110	23 300	2 160	136	3 390	8,6	0,020
PLETTENBERG LAGOON																
14	1,2	2,2	3,7	1 490	12	0,2	0,5	0,03	2 480	420	64 000	1 990	480	1 390	5,6	0,005
15	0,9	1,2	2,5	1 300	13	0,1	0,1	0,11	2 340	400	83 000	2 520	770	1 630	3,7	0,002
16	0,8	1,2	2,5	970	14	<0,1	0,1	0,11	2 260	410	94 200	2 570	830	1 650	2,5	0,002
17	0,8	1,0	2,5	1 350	14	<0,1	0,1	0,12	2 070	380	90 000	2 320	810	1 390	5,0	0,002
18	1,2	1,5	3,6	1 830	13	0,1	0,4	0,05	3 070	400	77 600	2 650	640	1 320	4,2	0,015

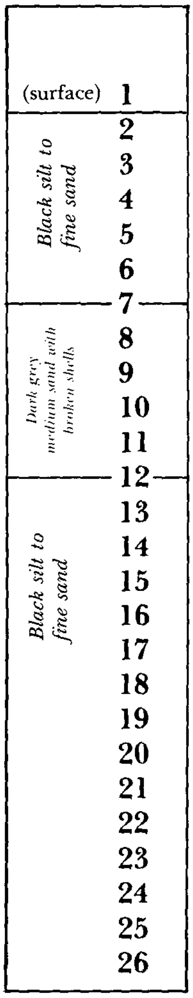

TABLE 4
METAL CONCENTRATIONS (μg/g) IN BIETOU RIVER SEDIMENT CORE, SITE 12

Sample	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr
1	2,4	6,5	11,1	8 100	20	0,6	2,4	0,162	7 640	1 230	40 100	2 690	280	4 050	9,1
2	1,3	3,4	7,6	4 610	14	0,4	1,3	0,110	5 900	810	42 300	2 120	300	3 080	5,7
3	1,4	1,8	8,5	5 740	15	0,5	1,6	0,114	6 720	890	46 200	2 310	330	3 660	6,7
4	2,1	2,4	10,9	8 000	20	0,6	2,4	0,126	7 790	1 200	40 200	2 760	300	3 710	8,7
5	2,0	2,1	9,1	6 050	16	0,5	1,8	0,120	6 250	970	43 300	2 320	300	3 450	7,3
6	2,4	2,4	13,5	9 510	23	0,8	3,0	0,176	6 880	1 420	39 800	2 970	290	4 910	11,1
7	1,8	1,2	8,5	6 020	14	0,4	1,6	0,124	5 150	640	52 100	2 140	370	2 280	6,0
8	1,4	1,2	6,7	5 090	13	0,3	1,3	0,142	4 810	670	56 600	2 000	410	2 930	5,6
9	1,1	1,1	5,9	3 860	12	0,3	1,1	0,122	3 420	530	45 800	1 720	330	2 650	4,8
10	0,8	0,8	4,4	2 680	11	0,3	0,8	0,110	320	520	43 600	1 530	320	2 430	3,3
11	1,0	1,0	4,6	2 660	11	0,3	0,8	0,106	2 960	460	44 600	1 430	340	2 710	3,1
12	2,0	2,0	3,2	15 000	25	0,8	3,2	0,211	6 000	1 500	35 000	4 000	200	4 100	12,2
13	3,9	3,0	2,9	19 100	39	1,5	6,0	0,387	8 470	2 200	16 500	4 360	85	5 300	17,5
14	1,6	1,9	12,9	9 750	24	0,7	2,7	0,090	4 190	1 100	9 750	2 110	41	3 560	9,3
15	1,5	2,0	12,0	8 980	22	0,7	2,7	0,061	3 760	1 100	9 590	1 920	43	3 510	8,6
16	1,6	3,3	12,4	8 970	21	0,7	2,4	0,076	3 590	1 130	20 600	1 850	116	3 610	8,9
17	0,5	0,7	3,8	2 810	7	0,2	0,8	0,017	1 100	380	4 510	600	23	1 360	3,0
18	1,7	1,9	12,6	9 350	23	0,7	2,5	0,101	3 940	1 140	25 400	1 910	150	3 370	8,9
19	2,1	1,9	15,4	12 900	30	0,8	3,4	0,193	4 560	1 390	10 400	2 370	48	3 340	12,2
20	2,1	2,1	14,6	11 600	29	0,8	3,1	0,214	4 430	1 460	18 200	2 210	103	3 060	12,0
21	2,3	2,0	15,8	13 300	38	0,8	3,5	0,214	4 660	1 870	14 600	2 400	69	3 970	13,5
22	2,3	3,0	15,1	12 800	41	0,9	3,4	0,179	4 450	1 790	13 600	2 330	69	3 530	12,8
23	3,0	3,5	17,9	15 100	44	1,0	4,0	0,285	4 810	1 920	17 900	2 520	96	3 610	14,4
24	2,8	2,5	20,0	15 900	47	1,0	4,2	0,251	4 840	1 860	12 600	2 670	58	3 800	14,9
25	3,6	3,2	22,3	19 400	54	1,5	5,4	0,355	5 240	2 230	17 500	3 170	87	5 110	18,7
26	4,4	6,7	22,7	25 100	53	1,2	5,7	0,542	5 970	2 310	19 300	3 220	95	4 980	19,4

Metals in Sediment Cores

Sediment cores were collected near sites 6 and 7 in the Keurbooms River and sites 10 and 12 in the Bietou River (Fig. 1). It was impossible to collect sediment cores from sites in either the Keurbooms or Bietou Rivers above the national road bridge as the rivers were too fast to allow a diver to remain stationary long enough to collect the sample. Below the confluence of the two rivers cores were collected at sites 14—18. Core descriptions, metal concentrations in individual samples and inter-element correlation matrices have been reported in detail (Watling and Watling, 1980).

The geometric means for the concentrations of each element in these cores have been calculated and are listed in Table 3. While this is not the ideal way to display core data, it does serve as an easy method for identifying anomalous areas.

From the surface sediment data (Table 2) and from the metal concentrations in the two Bietou River cores (Table 3) it is evident that this river has a mineralized catchment. The metal distribution in core 12 is detailed in Table 4. The clay content hardly varies throughout the sequence although the amount of shell debris in the sediment increases markedly at the top of the core. The concentrations of copper, lead, zinc, iron, manganese, cobalt, nickel, cadmium and chromium increase in the lower part of the core. Although this is not a systematic trend all the above metals show significant inter-element relationships which indicate their similar provenance. Catchment leaching has increased the metal contents of the sediments, probably as far as the confluence of the two rivers. The interrelationships of the sediment geochemistry with iron and manganese in the correlation matrix web (Watling, 1977) derived from the matrix (Table 5) indicates that the catchment rocks are rich in iron. Dissolved iron in the river water precipitates when conditions of higher salinity are encountered, carrying other metals with it. The collection and analysis of core samples higher up the Bietou River should confirm the presence of this postulated mineralization.

The concentrations of metals in the cores collected from the Keurbooms River and estuary (Table 3) are much lower than those found in the Bietou River. In addition, fewer significant inter-element correlations exist (Table 6). The carbonate facies and clay facies are well developed but the cobalt, nickel and zinc matrix web is not related to the clay facies. Consequently adsorption of elements onto the clay minerals is not the main distributing factor for metals in this section of the estuary. There is slight evidence of urban contamination at the southwestern end of the estuary but this is not significant when the estuary is considered as a whole.

Conclusion

This initial survey of the Keurbooms and Bietou Rivers has in-

TABLE 5
INTERELEMENT CORRELATION MATRIX FOR BIETOU RIVER

	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr
Cu	–	0,237	0,706	0,941	0,868	0,834	0,874	0,842	0,622	0,796	0,006	0,828	–0,067	0,497	0,928
Pb		–	0,151	0,157	0,210	0,151	0,205	0,159	0,186	0,199	–0,166	0,085	–0,176	0,322	0,222
Zn			–	0,806	0,778	0,682	0,714	0,561	0,272	0,727	–0,193	0,457	–0,262	0,435	0,807
Fe				–	0,893	0,868	0,915	0,818	0,470	0,841	–0,150	0,736	–0,232	0,497	0,962
Mn					–	0,730	0,761	0,759	0,473	0,691	0,011	0,744	–0,084	0,277	0,878
Co						–	0,950	0,673	0,323	0,897	–0,404	0,564	–0,462	0,699	0,915
Ni							–	0,688	0,344	0,942	–0,425	0,586	–0,485	0,728	0,962
Cd								–	0,467	0,608	0,092	0,691	0,027	0,265	0,769
Na									–	0,207	0,520	0,871	0,476	0,162	0,453
K										–	–0,468	0,475	–0,516	0,802	0,919
Ca											–	0,435	0,993	–0,512	–0,260
Mg												–	0,364	0,227	0,697
Sr													–	–0,508	–0,336
Al														–	0,629
Cr															–

TABLE 6
INTERELEMENT CORRELATION MATRIX FOR KEURBOOMS RIVER AND LAGOON

	Cu	Pb	Zn	Fe	Mn	Co	Ni	Cd	Na	K	Ca	Mg	Sr	Al	Cr
Cu		0,275	0,335	0,228	0,064	0,039	0,178	–0,144	0,449	0,314	0,011	0,174	–0,037	0,185	0,479
Pb			0,741	0,680	0,426	0,722	0,744	–0,583	–0,258	0,558	–0,696	–0,607	–0,710	0,577	0,057
Zn				0,914	0,484	0,847	0,941	–0,654	–0,088	0,764	–0,783	–0,607	–0,798	0,777	0,134
Fe					0,539	0,837	0,920	–0,547	–0,063	0,799	–0,745	–0,554	–0,732	0,852	0,193
Mn						0,598	0,511	–0,223	–0,333	0,419	–0,433	–0,381	–0,402	0,509	–0,104
Co						–	0,937	–0,692	–0,436	0,618	–0,917	–0,829	–0,902	0,709	–0,181
Ni							–	–0,738	–0,210	0,731	–0,899	–0,751	–0,902	0,778	–0,050
Cd								–	0,276	–0,248	0,826	0,756	0,874	–0,232	0,173
Na									–	0,218	0,487	0,686	0,454	0,056	0,466
K										–	–0,455	–0,251	–0,453	0,934	0,233
Ca											–	0,938	0,983	–0,532	0,233
Mg												–	0,932	–0,347	0,326
Sr													–	–0,502	0,202
Al														–	0,128
Cr															–

dicated that neither are significantly contaminated with respect to metals. The Bietou River has a considerable metal bed-load which is probably of geochemical origin. Metal build-up in the south-western part of the Keurbooms estuary adjacent to the town of Plettenberg Bay is probably attributable to contamination from urban development. Changes in the water chemistry of this area as the result of, for example, dredging or seasonal flooding, could remobilize considerable amounts of metals.

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3. SCRIPT REQUIREMENTS

3.1 An original typed script in double spacing and two copies should be submitted. The title should be concise and followed by the authors' names and complete addresses. One set of original line drawings on good quality drawing paper or glossy photoprints should be submitted. Photographs should be on glossy and not matt paper, enlarged sufficiently to permit clear reproduction in halftone. Three sets of copies should accompany each submission. All illustrations (line-drawings and photographs) must be fully identified on the back and should be provided with descriptive legends typed on a separate sheet. Illustrations should be packed carefully, with cardboard backing, to avoid damage in the post. The appropriate positions of illustrations should be indicated in the text.

3.2 Tables are numbered in arabic numbers (Table 1) and should bear a short yet adequate descriptive caption. Their appropriate positions in the text should be indicated.

3.3 The SI system (International System of units) should be used.

3.4 References to published literature should be quoted in the text as follows: Smith (1978) the date of publication, in parentheses, following the author's name. All references should also be listed together at the end of each paper and not given as footnotes. They should be arranged in alphabetical order (first author's surname) with the name of the periodical abbreviated in the style of the *World List of Scientific Periodicals* (4th edn, Butterworths, London, 1963–1965, with supplements) and appear as follows:

MATSON J.V. and CHARACKLIS W.G. (1976) Diffusion into microbial aggregates. *Water Research* **10** (10) 877–885.

THRING M.W. (1975) *Air Pollution* p 132 Butterworths, London.